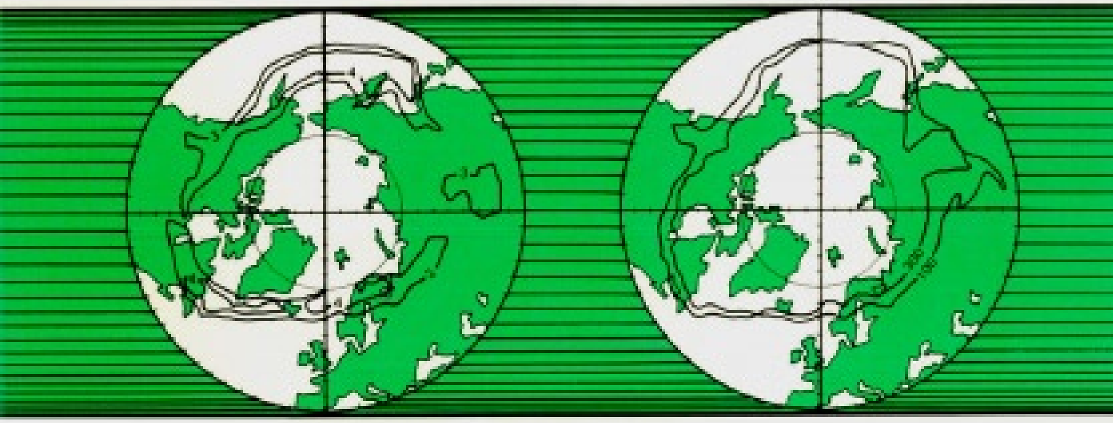
THE GLOBAL FOREST SECTOR

An Analytical Perspective



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Preface

This book is the final report of the Forest Sector Project at The International Institute for Applied Systems Analysis (IIASA). The primary goal of the Project was to study long-term developments in the production, consumption, and world trade of forest products. The aim was to aid in the formulations of investment strategy in forest industrial companies and of forestry and forest industrial policies in different world regions by governmental agencies and international authorities.

For this purpose, a global model of the forest sector was built and, employing this model, a number of scenarios were developed. Based on conservative assumptions, the base scenario served as a reference for making judgments about the relative impacts of alternative assumptions. The scenario variations were chosen to study the impact of alternative rates of economic growth, changes in currency exchange rates, impact of trade liberalization, impact of environmental changes, etc. The scenarios should not be regarded as unbiased forecasts, but rather as conditional forecasts aiming to answer what-if questions. For the practitioner to fully use the Project results, it is necessary to develop additional scenarios that are particularly relevant to the policy issues concerned.

In many respects, IIASA has been an ideal base for the Project. The forest sector has a well defined yet complicated structure, in which the slow rotation period of both forest resources and industrial capacity accentuates the need for a long-term evaluation via dynamic analysis. Therefore, it provides an ideal case for the application of systems analysis techniques to study the adaptation of industry to changing technology, demand patterns, and new sources of raw material. The study serves as an example of how to analyze structural change in part of the global economy. The forest sector is of major importance to all mankind and, in particular, to a number of member countries of IIASA. Such a long-term, global study of a topic so far largely neglected by researchers may be of central importance for strategic decision-making in the forest sector. It was an interdisciplinary effort in which the expertise found in several IIASA research programs was synthesized. Furthermore, IIASA is a natural center for the collaborating network that is necessary to conduct such a major, international research task.

The project evolved through a number of phases. Though IIASA has been engaged in research related to the forest sector since the early days of its existence, the first proposal for this particular global study appeared at the end of 1978. The initiative came from Peter de Janosi, who was then leader of the System and Decision Sciences Area at IIASA. A memorandum, which he helped me prepare, explored possible topics for IIASA in forest sector research. Åke Andersson, from IIASA's regional economics group, soon joined the discussion and so did Andrzej Wierzbicki (Dr. de Janosi's successor), Rolfe Tomlinson (Leader of the Management and Technology Area), and Paavo Uronen, who was engaged in research on forest industrial control problems.

After a series of more formal preparatory meetings, a one-year pilot study was started at IIASA by Risto Seppälä of Finland in the fall of 1980. A year later, the Forest Sector Project began under his leadership, the immediate tasks being to establish an international network of scientific collaborators and to explore methodological alternatives and data sources. The initial Project team included Wolf-Dieter Grossmann of FRG and Lars Lönnstedt of Sweden, working on regional forest sector modeling, and Ann Francescon of the UK, analyzing international trade data in forest products. Anne Morgan of the US served as the network coordinator and as editor of the Project newsletter, *Modules*. She left the core team in 1983, but her support to the Project continued.

In the fall of 1982 Professor Seppälä returned to the Finnish Forest Research Institute, but remained an active collaborator throughout the rest of the Project. I became Leader and, within a year, the composition of the core team also changed.

Of the new core team, I would like to thank first and foremost Dennis Dykstra of the US. Professor Dykstra joined the project in August 1983, showed an intense dedication, and made invaluable contributions to forest resource modeling and to global forest sector modeling in general. He was also the network coordinator and editor of *Modules*.

Åke Andersson of Sweden was with the team from September 1983 until January 1985. His primary area of research was demand analysis for forest products, but he was also Deputy Leader of the Project. In spite of his other work commitments, he produced many important scientific and other contributions to the Project.

Valery Fedorov of the USSR joined in March 1983. He worked on statistical problems as well as on the Soviet component of the global model. The latter was completed with the cooperation of Soviet scientists from other projects at IIASA; in particular with Vladimir Iakimets, Leonardas Kairiukstis, and Anatoli Smyshlayev.

From September 1983 Gábor Kornai of Hungary took on overall responsibility for computer software and data base system development in the Project. He also continued the work started by Dr. Francescon on the analysis of international trade data. In May 1984, Miloslav Lenko, an outstanding computer professional from Czechoslovakia, joined the software team. For a shorter period he was assisted by Carol Weeks of the US.

The core team was finally strengthened considerably by Clark Binkley of the US, who came for the last half year of the Project to work on forest resource modeling, to participate in the scenario development, and to help edit this volume, particularly Parts I–IV.

Many scientists made extremely valuable contributions to the Project during shorter visits to IIASA, much of which is reported herein. First, Darius Adams (US) played a central role in drafting the Project plan during the summer of 1982. Sten Nilsson (Sweden) participated in this effort as well. Professor Adams contributed several articles during the course of the Project and made valuable suggestions for the proposed outline of this volume. Daniel Chappelle (US) made an important contribution by reviewing much of the material herein.

Seppo Salo (Finland) worked on the first proposal of an equilibrium model of the global forest sector in 1982, the final results of which are included in this volume. Joseph Buongiorno (US) and Keith Gilless (US), based on earlier work in the US, set up the first operational model at IIASA to demonstrate an equilibrium approach for trade analysis. Their work had a profound impact when the decision concerning basic methodology was taken by the Project collaborators in the Network Meeting of August 1983. Also, Matti Kirjasniemi's (Finland) efforts during the summer of 1983 had a major impact on this methodology. Employing the data bases of Jaakko Pöyry Oy, he put together most of the data for pulp and paper industries that are used in the global model.

Kenneth Lyon and Roger Sedjo (US) contributed to the global forest resource analysis, Matti Palo (Finland) to the deforestation issue, and Pekka Kauppi (Finland) to defining our analysis of the impact of air pollution on forests.

Many visitors contributed to the analysis of demand in forest products, including David Batten (Australia), Anders Baudin (Sweden), Runar Brännlund (Sweden), Börje Johansson (Sweden), William McKillop (US), Esko Uutela (Finland), and Sören Wibe (Sweden). The transportation cost data for our analysis were derived by Harold Wisdom (US). Also, Jack Weeks (UNIDO) and Cynthia Griffin (US) contributed to the transportation issue. Trade barriers were also investigated by Dr. Weeks. With regard to tariff and nontariff barriers, I wish to acknowledge the valuable contributions of Samuel Laird (UNCTAD) and A. Olechowski (World Bank). Permission to reproduce parts of the UNIDO paper entitled *Tariff and Non-Tariff Measures in the World Trade of Wood and Wood Products* is gratefully acknowledged.

A major effort to better understand trade practices was carried out by András Nagy (Hungary). This work, which includes contributions from a number of scientists, will appear in a separate IIASA volume edited by Professor Nagy, ***International Trade in Forest Products.***

Several of the Project visitors devoted their effort to the analysis of a particular country or region. Peter Schwarzbauer (Austria), besides working on the Austrian part, put together some data for other Western European countries. Alfredo Iusem (Argentina) contributed the entire Brazilian component model, as well as most of the requirements for the rest of Latin America. Erkki Viitanen (Finland), in collaboration with FAO and the Economic Commission for Africa, produced the African component for the analysis. Additionally, the following scientists worked on their respective countries: Canada: Karel Jegr; US: David Brooks; Chile: Ramiro Morales; Norway: Birger Solberg; Sweden: Lars Hultkrantz and Uno Zackrisson; Finland: Jari Kuuluvainen, Heikki Seppälä and Risto Seppälä; the Netherlands: Ton Gerritse and Abbo de Wit; FRG: Heiner Ollmann and Joachim Kreysa; Italy: Massimo Florio and Enor Signorotto; Hungary: Tibor Bencze, Csaba Forgács, Aladár Halász, and István Vályi; GDR: Hans-Ulrich Brautzsch; Poland: Władysław Strykowski; USSR: Alexei Reteium; Bulgaria: Rumen Dobrinsky and Georgi Raffailov; Japan: Isamu Nomura; Australia: David Batten and Cheryl Larsen; New Zealand: Bruce Manley.

Moreover, a number of scientists from many disciplines, including forestry, economics, and mathematics, made valuable suggestions and other contributions to the effort. Methodological discussions with Michel Balinski, George Dantzig, Alan Manne, and Thomas Naylor of the US were of great importance. The late Leonid Kantorovich of the USSR provided his enthusiastic support to the Project and thereby strengthened the Soviet collaboration remarkably. I am also grateful to Michael Saunders of the Stanford University, whose MINOS code proved to be the essential tool for solving our global model. Richard Haynes, William Lange, Clark Row, and David Darr played an important role in coordinating the US collaboration, as did David Boulter and Peter Pearse in Canada.

Invaluable suggestions and criticism were provided by many practitioners of the forest sector representing industrial and governmental organizations. I should particularly mention Richard Herring, Les Reed, Keith Thompson, and David Wilson of Canada; Lamar Beasley, Robert Buckman, Dale Kalbfleisch, Irene Meister, and Richard Pearson of the US; Ron Aurell, Karl Kempe, and Lennart Schotte of Sweden; Mylle Jouhki, Olavi Lehtikoski, Veikko Vainio, and Niilo Ryti of Finland; Walter Kauman of France; Maco Dakov of Bulgaria; Alexander Iakunin, Boris Milner, and Gennady Shaitanov of the USSR; John Brotchie of Australia; Hideo Takehara of Japan; as well as the following representatives of the United

Nations: Bengt-Olof Karlsson (UNIDO), Tim Peck (ECE), Christopher Prins (ECE), and Philip Wardle (FAO).

A series of meetings to concentrate on the European forest sector in particular was organized. The chairman of this activity, the European Task Force, was Peter Glück of Austria.

I wish to express my gratitude also to the IIASA Council for making the Project possible and to the Board of Directors, Thomas Lee, Vitali Kaftanov, and Boris Segerståhl. In particular, I wish to thank C.S. Holling, former director of IIASA, whose consistent support was essential for completing the Project.

The Project was primarily financed through IIASA's budget. Supplementary financial support, which is gratefully acknowledged, was received from the following organizations: Canadian Forestry Service, Central Association of the Finnish Forest Industries, Commonwealth Scientific and Industrial Research Organization (Australia), the Forest Service of the US Department of Agriculture, the Food and Agriculture Organization of the United Nations (FAO), National Forest Products Association (US), Radiata Pine Association of Australia, the Swedish University of Agricultural Sciences, United Nations Industrial Development Organization (UNIDO), and the Weyerhaeuser Company Foundation.

A central contribution was made by Miyoko Yamada of Japan, who joined the Project in September 1982. As Project assistant she took excellent care of a large variety of tasks, such as secretarial, visitor and conference services, and the general administration, such as budget control. Her computer skills became particularly famous. Her transformation of this manuscript into a camera-ready volume is an excellent example. Ms. Yamada was assisted by Mary McGechaen of Canada and Lucy Tomsits of Hong Kong.

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Introduction

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The world's forests — separated by great distances, controlled by disparate political systems, and distinguished by different ecological characteristics — are increasingly linked through international trade and global effects of environmental degradation. Only recently have the data and analytical techniques become available to permit a comprehensive analysis of these linkages. These data are summarized and the techniques are reviewed in this book, and, for the first time, a consistent, detailed analysis of the world's forest sector is presented.

For the purposes of this book we define the forest sector as the set of activities related to the use of wood: forest growth and harvest; the manufacture of pulp, paper, and solid-wood products; and international trade and intermediate and final consumption of these products; in short, the forest-products industry broadly defined. We omit from this definition the valuable nontimber outputs of the forests — clear water, pleasant landscapes for recreation, the animals of the forest, and so on. Our treatment of fuelwood is not as complete as the magnitude of its consumption would warrant. Rather, our focus is on the sector's critical global linkages. Both nontimber outputs and fuelwood, while remaining essential features of forestry, influence such linkages only indirectly.

In addition to serving as a state-of-the-art review of forest sector analysis, this book is the final report of the Forest Sector Project carried out at IIASA (International Institute for Applied Systems Analysis) during 1981–1985. The Project participants studied long-term structural changes that might occur in the forest sector on a global basis. The emphasis was on issues of major relevance to the industrial and governmental policymakers in different regions of the world who are responsible for forest policy, forest industrial strategy, and related trade policies. These include investment strategy related to production facilities, forestry plantation programs, and forestry infrastructure, such as roads needed to access timber in remote locations.

The key elements of structural change in the forest industry are related to a variety of issues concerning demand, supply, and international trade in wood products. Such issues include the growth of population and the global economy, the development of new wood products and substitutes for wood products, the future supply of roundwood and alternative fiber sources, the development of new technologies for forestry and industry, pollution regulations, cost competitiveness, tariffs and nontariff trade barriers, and even political stability.

Understanding the changes that originate within the forest sector is not sufficient. Forestry, the forest products industry, and forest products consumers are inevitably affected by many decisions made outside the sector. Examples include currency exchange rates, taxation, subsidies, and monetary policy. Forest sector analysis provides insight into how changes within the sector and forces originating outside the sector affect the key concerns of forest-products prices, production, consumption, trade, profits, employment, and the state of the world's forests.

The research program of the IIASA Forest Sector Project centered on an aggregated analysis of the long-term development of international trade in forest products. This necessitated an analysis of forest resources, industrial production, and forest-products demand throughout the world. The forest sector is sufficiently complex that one concern cannot be analyzed in isolation from others. For example, increased rates of forest plantation establishment in one part of the world affect the profitability of logging more distant stands of virgin timber in another. To account for these linkages requires formal analytical models of the forest sector.

An integrated forest sector model contains four major components:

(1) A model of timber supply, including methods for linking forest growth to timber costs and for projecting future forest growth while accounting for timber removals and changes in the forest land base.
(2) A model of the processing industries that describes how timber is converted into intermediate and final forest products and how key characteristics of the processing industry, such as capacity, processing costs, and technical efficiency, change over time.
(3) A model of product demand that relates the needs for forest products to factors within the forest sector, such as prices, and to factors outside the sector, such as levels of housing construction, population, and income per capita.
(4) An implicit or explicit model of trade among regions to link the locationally fixed supplies of raw materials and forest products to the regions of final consumption.

This book is organized along the following lines. In Parts I–IV we review the current state of forest sector analysis. In the four sections we examine, respectively, forest resources and timber supply, forest industries, the demand for forest products, and international trade in forest products. In these parts of the book we also attempt to present what is known about quantitative approaches to each component of an integrated forest sector model.

During the past decade, many countries have built national forest sector models to assist central economic planning, policy analysis, or economic forecasting. In this book we make no attempt to catalog, summarize, or review these models. Instead, we examine the key components of such models and, by reference, include them in our discussion.

In Parts V and VI of the book we summarize the global forest sector analysis that has been done at IIASA. The model employed for this analysis, discussed in Part V, recognizes 18 regions, which cover the globe, and 16 intermediate and final forest products (although the modeling system has intentionally been designed to permit redefinition of both regions and products). Each region is described by a regional component model, which includes a demand model for all final products, a model of forest industrial production, and a model of timber supply. The regional components are connected by bilateral trade linkages that recognize transportation costs, the tariff and nontariff barriers to trade, and trade inertia due to logistical, marketing, or trade policy considerations.

This is the first systematic analysis of world trade in forest products. The global perspective requires that trade flows balance, a constraint that has not entered national forest sector models used in many countries today. The IIASA model also imposes two other important kinds of consistency requirements: material flows must balance and prices must stay in line with costs. The structure of the IIASA model is very simple. It gains its power by covering the world's forest sector in its entirety while balancing material flows and maintaining price–cost consistency.

The *global forest sector model*, which, because of its focus, has often been referred to as the *global trade model* (GTM), is designed as a policy analysis tool, not as a forecasting model. The objective of forecasting is to predict accurately the development of key factors for decisions, such as prices or production levels. In contrast, a policy analysis model attempts to show how these variables are likely to change in response to alternative decisions made by governments (such as changes in tariff levels, taxes, subsidies, or exchange rates) or by industry (such as investments in productive capacity, forest plantations, and forestry infrastructure). To emphasize this distinction, all of our results in Part VI (Scenario Analysis) are presented as changes from a *base scenario*. This scenario itself is not a forecast, but rather the outcome of a moderate set of assumptions about future developments within and outside of the forest sector. Other demonstration scenarios that are included in Part VI are:

(1) Alternative levels of economic growth.
(2) Variations in currency exchange rates.
(3) Liberalization of trade.
(4) Increased timber harvests in the USSR.
(5) Effects of European air pollution ("acid rain").
(6) CO_2-induced climatic warming (the "greenhouse effect").

The main emphasis of the IIASA Forest Sector Project has been the development of the global forest sector model as a policy analysis tool for the use of analysts in many countries. In demonstrating the utility of the model for this purpose, some interesting results have emerged from our analysis of these scenarios. For example, when regions are linked by trade, the impacts of changes in one (or a few) regions are dampened by adjustments in other regions and by changes in trade flows. Therefore, national forest sector models that ignore import and export demand will tend to overstate the sensitivity of economic responses to policy interventions.

The outcomes of our simulations, which are discussed in detail in Part VI of this book, seem fairly sensitive to several factors, including the assumed levels of growth in population and income, currency exchange rates, technological developments in the forest industry and in industries that produce substitutes for forest products, the assumed level of timber harvests in the USSR, and the growth of forest products consumption in China (where one quarter of the world's population resides).

Finally, the potential of plantation forests in developing countries to contribute to trade in forest products is largely conditional upon growth in domestic demand. In Brazil, for example, we assume rates of growth in population and income that are modest by historical standards. Even so, the growth of domestic demand for forest products over the next 30–50 years apparently outstrips the capacity of their aggressive plantation program. Thus, the capacity of such *emerging regions* to contribute a net surplus to global trade depends very strongly on the growth in their own domestic consumption.

Part I

Forest Resources and Timber Supply

CHAPTER 1

Forest Resources of the World: Forests in Transition

R.A. Sedjo

Much of the history of humankind's relation with forests has involved their destruction. Forests have been regarded either as a timber resource to be exploited and utilized or as an impediment to other land uses, typically agricultural. This process, which in some cases began thousands of years ago, is documented by Thirgood (1981) for the Mediterranean region, by Clark (1984) for the US South, by Menzies (1985) for China, and by Gill (1985) for Bangladesh. In general terms, the process consists of increasing pressures upon the forests, as rising populations demand industrial wood and fuelwood, and pressures to clear forests to expand the agricultural land base. The initial result is often deforestation, environmental degradation, and, in the longer term, a scarcity of industrial wood and/or fuelwood.

However, this process does not inevitably lead to a complete breakdown of the forest system. Often the excesses of the early conversion periods lead to societal adjustments which halt or reverse these trends. For example, the *Guanzi*, a fourth-century BC Chinese manual on the art of government, contains instructions on how a ruler should ensure a continuous supply of timber, including rules for timber planting, management, and protection of the forests. Also, forest management has been practiced in Europe since at least the thirteenth century. Forest cover in China has experienced both expansions and contractions, being most likely to contract during periods of great political instability when neither governmental power nor private incentives provided an environment in which the long-term advantages of forest management prevailed over the expediency of short-term harvest and liquidation (Menzies, 1985). Over the past two decades, the experiences of China [1] and South Korea show the ability of even nonwealthy countries to resist and reverse the pressures toward deforestation.

Over the past 100 years in the West, the experiences of New England, the US South, and Central Europe demonstrate the ability of heavily denuded areas to renew their forest cover. This has generally been the case in the temperate regions of the world, where the data suggest that the amount of land in forests has remained essentially constant since World War II.

The growing technological ability of society to plant, grow, and harvest trees as a crop has furthered the trend toward managed and, indeed, artificially generated forests. Favorable real prices for industrial wood and, especially, sawlogs (Manthy, 1978) have added economic incentives to those of environmental protection. In many parts of the world the private sector has been actively involved in tree planting as a commercial activity, even in the absence of substantial governmental incentives.

In this chapter we describe in a broad-brush fashion the forests of the world — with a focus on forests with high commercial value. Many forests are in a state of transition. The virgin, old growth forests of the world are diminishing in importance as a part of the wood resource. Gradually, the economics of timber growing are replacing the economics of timber extraction. Intensively managed plantations are replacing the natural forest stands as the major source of industrial wood. Fuelwood plantations are also being viewed as an important solution to the growing scarcity of fuelwood in Third World countries. This transition is mid-way through its progress. Some regions have been devoid of old growth for hundreds of years, while others still possess vast amounts of old growth timber. One of the pleasing side effects of this transition is that as plantation forests become a superior economic (lower-cost) source of industrial wood, they will relieve at least some of the pressures to continue to log virgin forests.

1.1. Overview of World Forests

Forests cover about 31% of the world's land surface; most (64%) of this forested area is closed forest (*Table 1.1*), meaning that there exists a substantially complete cover of trees over the whole surface of land. For the world as a whole, about 60% of the forest land area, both closed and open, is classified as hardwood and the remainder as softwood. But the species mix varies greatly across the major parts of the world. In the Northern Hemisphere the greater part of the total forest land area is composed of softwood species; in the Southern Hemisphere and the tropics the reverse is true. While timber volumes vary from region to region and site to site, the aggregate regions' timber volumes correspond roughly with the forest land area (*Table 1.2*). The USSR and North America contain *ca* 85% of the

Table 1.1 World forested area by region, 1973 [Barney (1980), Vol. 2, p 118; data on Europe, the USSR, and North America are from the ECE/FAO (1985); other data are from Persson (1974); they represent an early 1970s estimate].

	Forest land[a]	*Closed forest*	*Open woodland*	*Total land area*[b]	*Closed forest*	*Total forest*
	(10^6 ha)				[land area (%)]	
North America	734	459	(275)	1 829	25	40
Central America	65	60	(2)	272	22	24
South America	730	530	(150)	1 760	30	41
Africa	800	190	(570)	2 970	6	27
Europe	160	148	12	472	31	34
USSR	930	792	138	2 240	35	42
Asia	530	400	(60)	2 700	15	20
Pacific Area	190	80	105	842	10	23
World	4 139	2 659	(1 200)	13 105	20	31

[a] Forest land is not always the sum of closed forest plus open woodland, because it includes scrub and brushland areas, which are neither forest nor open woodland, and because it includes deforested areas where forest regeneration is not taking place.

[b] In computation of total land area, Antarctica, Greenland, and Svalbard are not included; 19% of arctic regions are included.

Table 1.2 Land area of world closed forest resources by region and type (10^6 ha) [data for Europe and the USSR from the ECE/FAO (1985); the remainder from Persson (1974)].

	Coniferous		*Broadleaf*		*Combined coniferous and broadleaf forests*[a]	
Region	*Land area*	%	*Land area*	%	*Land area*	%
North America	400	30.5	230	13.4	630	20.8
Central America	20	1.5	40	2.3	60	2.0
Africa	2	0.2	188	10.9	190	6.3
Europe	107	8.2	74	4.3	181	6.0
USSR	697	53.1	233	13.6	930	30.7
Asia	65	5.0	335	19.5	400	13.2
Oceania	11	0.8	69	4.0	80	2.6
Total world	1 312	100.0	1 719	100.0	3 031	100.0

[a] The totals for combined coniferous and broadleaf forests do not always add because no breakdowns have been given for areas in Europe and the USSR excluded by law for exploitation.

world's coniferous growing stock while Latin America and Asia contain *ca* 60% of the world's closed forest hardwood growing stock (Persson, 1974).

Table 1.3 indicates the amount of plantation forest by major region in the mid-1970s. While the portion of the world's total closed forests attributable to plantations was only about 90 × 10^6 ha or 3.4% of the world's total closed forest, the area of forest plantations has undoubtedly increased over the past 10 years. For example, it is now estimated that about 14% of the US commercial forests, or 27 × 10^6 ha, are plantations (Kulp, 1985). Also, given the substantial forest establishment in Brazil, China, and elsewhere since the mid-1970s, the total forest area in plantations has surely substantially increased.

Table 1.3 Plantation forest by region (*ca* 1975) (FAO, 1978).

Economic class and region	*Area* (10^6 ha)
Developed	
North America	11
Western Europe	13
Oceania	1
Other	10
Total	35
Developing	
Africa	2
Latin America	3
Asia	3
Total	8
Centrally planned	
Europe and the USSR	17
Asia	30
Total	47
Total world	90

Table 1.4 indicates the world's production (harvest) of wood in 1980 by major region. About 40% of the total is produced in the temperate regions of North America, Europe, the USSR, and Oceania alone. If fuelwood is excluded and only industrial wood considered, this figure jumps to 75%.

1.1.1. Forests in the temperate regions

Well over half of the world's forest lands are located in regions of temperate climate. These include the forests of North America, Europe, the USSR,

Table 1.4 Production — 1980 (FAO, 1980).

	Roundwood production		*Industrial roundwood production*	
Region	10^3 m^3	%	10^3 m^3	%
Africa	431 430	14.5	50 430	3.7
North America (US and Canada)	577 629	19.5	463 958	33.3
N. Central America	51 114	1.7	10 958	0.8
South America	282 844	9.5	65 922	4.7
Asia	902 250	30.4	206 696	14.8
Europe	333 651	11.2	291 321	20.9
Oceania	34 832	1.2	25 986	1.9
USSR	356 600	12.0	278 200	20.0
World	2 970 350	100.0	1 393 471	100.0

China, and Oceania. While these regions have large volumes of both hardwood and softwood, the softwoods predominate. Although individual regions show fluctuations in their forested area over time, the aggregate picture is' one of substantial stability. Over the 30-year period 1950–1980, the land area reported in the temperate forests increased by about 2% (Sedjo and Clawson, 1984). The regions experiencing the largest increases in forest area were Europe, China, and Oceania. Growth in these areas offset declines in forest land in North America, while the total forested area in the USSR was reported to have remained constant. Regions with an expanding area of forest lands are often regions that are experiencing active reforestation efforts. For example, China's massive reforestation of the past two decades involves tens of millions of hectares. Similar reforestation and afforestation efforts are under way on a more modest scale in South Korea, Oceania, parts of Europe, and elsewhere.

1.1.2. Tropical forests

Lying on each side of the equator around the world is an immense area of tropical forests that have special characteristics and present special problems. These consist of both tropical moist forests and tropical dry ones. One third of the tropical moist forests are in Brazil — the Amazon Basin — and another quarter are in other Latin American countries; some are in West Africa, while others are in Asia and the islands of the East Indies. The tropical dry forests are located largely in Africa and parts of Latin America, with smaller areas in Asia. There are, of course, some biological differences between these areas. Most of these tropical moist forests are characterized by extremely high volumes of vegetation per unit area and by a great diversity in the vegetative cover in each area.

Partly because of the great variety of trees grown, the number of trees of a particular species per hectare is generally low, which severely handicaps efforts at commercial exploitation of these timber stands. While there has been commercial timber harvest in some areas — notably in West Africa and certain countries of Southeast Asia and the Asia–Pacific region — these forests have not been nearly as important a source of commercial timber as their area might suggest.

The tropical dry forests are even less important as a source of industrial wood. However, in many regions they are an important source of fuelwood. The problems of deforestation associated with excessive fuelwood collection typically occur in areas of tropical dry forest, such as the Sahel in Africa and parts of India and Nepal.

Currently, a controversy exists over the extent and seriousness of tropical deforestation (see Chapter 3). While some have argued that the rate of tropical deforestation has reached crisis proportions (Barney, 1980; Guppy, 1984), others maintain that the extent of the problem has been overstated and is not supported by the data (Sedjo and Clawson, 1983).

1.1.3. Plantation forests

While less than 1% of the forests of Latin America are industrial plantations, about one third of the region's industrial wood output comes from industrial forest plantations. Furthermore, the total area in industrial forest plantation in Latin America is projected to increase by 300% between 1979 and the year 2000, when it is expected that more than half of the greatly expanded industrial wood production of Latin America will be produced from plantation forests (IDB, 1982, p 17). A similar situation exists in the US. Kulp (1985) has estimated that, "Plantation will produce half of the wood fiber [of the US] by the year 2000 and this fraction will increase thereafter as more land is transferred to plantation use and forest technology advances." The figures in *Table 1.3* suggest that this phenomenon is quite widespread. The foregoing not only attests to the potential of forest plantations to replace the natural forests as the principal source of industrial wood, but also indicates the extent to which relatively small areas of highly productive forest plantations can substitute for natural forests as producers of society's industrial wood needs. Therefore, simple comparisons of areas deforested and areas in forest plantations must be interpreted with care.

It is only in very recent times that plantation forestry has been a factor that affects the world's forests. Although some conscious tree planting took place in parts of Europe and in China as far back as the fourth century BC, the vast majority of reforestation to date has been through natural regeneration. However, the incidence of artificial regeneration has increased dramatically since World War II and particularly after 1960.

Forest plantations are defined as man-made, artificially generated forests, and are the result of conscious management. Commonly, plantations of the temperate Northern Hemisphere are established on land that has recently been logged. Often it is in the same species as the harvest, e.g., Douglas fir in the Pacific Northwest and Scotch pine in the Nordic Countries. However, other species may be introduced, e.g., lodgepole pine in parts of northern Europe. In many cases in the Northern Hemisphere the plantation is established on lands that have not recently been forested. This is the case, for example, in parts of the US South, where farmlands have been converted into forests. In China most of the plantation activities occur on previously unforested lands.

In recent years increased attention has been given to plantation activities in the tropics and subtropics, and in the Southern Hemisphere temperate regions. While it is commonly believed that massive areas of plantation are being established in the tropics, the data indicate that only a small portion of forest plantations are situated in the tropics. Rather, the majority of the plantation lands are in the subtropics and typically are established on lands that have not been forested in recent years. In some cases these lands have never been in forest. Today, major industrial forest plantation activities are under way in Brazil, Chile, Venezuela, South Africa, India, the Philippines, Australia, New Zealand, and a host of other tropical and Southern Hemisphere countries. Brazil alone established over 250 000 ha per year of forest plantations during the decade of the 1970s. Projections by Lanly and Clement (1979) for the year 2000 indicate that the industrial plantations in the tropics and subtropics will cover 21×10^6 ha, thrice that of the mid-1970s.

While forest plantations in the tropics and Southern Hemisphere appear to offer great promise, a cautionary note is in order since experience is limited and there are some serious ecological concerns over the possible dangers of insects, disease, and so forth.

1.2. Major Industrial Wood-Producing Regions

1.2.1. The European forest

Europe is one region where the forest area and growing stock have been expanding. This has certainly been true since World War II and probably since early in the nineteenth century. Thus, the development of vegetation types in the European region is to be related not only to such evident factors as the diversity of climate and soil conditions, but also to the prolonged influence of man due to the high density of population over several centuries. FAO has estimated (*Table 1.3*) plantation forests in Europe, *ca* 1975, to cover an area of about 30 × 10^6 ha. These forests are found in both Western and Eastern Europe, as well as in the USSR.

The boreal forests cover large areas in the Nordic Countries of Finland, Sweden, and Norway. The species composition of the boreal forests of Europe is predominantly pine and spruce. The subalpine forests dominated by evergreen coniferous extend far south, even into the Mediterranean peninsulas, as the air temperature decreases with increasing altitudes. Pine, spruce, larch, and fir constitute most of the subalpine forests of Western and Central Europe, extending southwards into Southern Europe.

The ecotone mixed forests constitute a transition between previous types of coniferous forests and the nonconiferous deciduous communities of the humid regions. Main species are pine, spruce, silver fir, oak, birch, and beech.

Finally, the evergreen mixed forests, which were once widely spread over the Mediterranean area, have gradually been modified by intense human activity and are now confined to relics or to degraded forms. The original woodland vegetation now appears mainly as scattered clumps of helm oak, cork oak, and pine.

Europe's industrial wood resource

Table 1.5 shows that, of the total land area in Europe (468 × 10^6 ha), 155 × 10^6 ha, or just about one third, is classified as forest and other wooded land. The Nordic Countries have the highest proportion of land covered by forests and other woods (53%), followed by Eastern Europe (32%) and Western Europe (26%).

Exploitable forest covers some 126 × 10^6 ha in Europe, or 79% of the total of forest and other wooded land. In all three regions the proportion of exploitable forest in the total is broadly the same — between 70 and 80%.

Unexploitable forest covers about 12 × 10^6 ha in Europe, or 8% of the total of forest and other wooded land. The reasons for classifying forests as unexploitable may be either because of legal restrictions on commercial cutting due to protective and other nonwood producing functions or because of economic or physical inaccessibility.

For many centuries, the forests of Europe were cleared to make space for an expanding agricultural economy. Toward the end of this phase of contraction of the forest, large quantities of wood were required for industrial as well as domestic fuel, in addition to meeting the demand of the construction and shipbuilding sectors. The turning point, when the area of

Table 1.5 Europe: main land-use categories by region, late 1960s/early 1970s (10^6 ha) (ECE/FAO, 1986).

	Total, (excl. water)	*Forest and other wooded land*[a] *(% of total)*	*Exploitable forest (% of forest and other wooded)*	*Unexploitable forest*	*Other wooded*	*Nonforest*	
						Agricultural	*Other*
Nordic Countries	112.4	59.9 (53%)	48.3 (81%)	3.6	8.0	9.8	42.7
Western Europe	234.2	60.6 (26%)	42.6 (70%)	7.5	10.5	131.0	42.6
Eastern Europe[b]	125.4	39.8 (32%)	35.6 (89%)	1.1	3.1	73.6	12.0
Total Europe[c]	472.0	160.3 (34%)	126.5 (79%)	12.2	21.6	214.4	97.3

[a] "Other wooded land" — defined as having a tree cover of less than 20%.
[b] Including Albania and Yugoslavia.
[c] Excluding Cyprus, Israel, and Turkey.

forest began to increase again in Europe as a whole, probably came during the nineteenth century, although it varied from country to country, according to the pace of industrialization and the substitution of wood by other forms of fuel (ECE/FAO, 1976).

Nordic Countries. In 1980 the Nordic Countries had 38% of Europe's exploitable forest, 29% of the growing stock, and 31% of the increment. Growing stock on exploitable lands in the Nordic Countries amounts to 4407×10^6 m^3 [2] with a net annual increment of 146×10^6 m^3. This corresponds to an average standing volume of 91 m^3/ha with a net annual increment of 3.0 m^3/ha, both well below the European average. Despite this relatively low level of annual increment per hectare, the Nordic Countries have an average (3.3%) rate of increment in relation to growing stock. Coniferous species represent approximately 84% of growing stock (ECE/FAO, 1986).

Western Europe. Western Europe held over one third of Europe's exploitable forest land and a similar proportion of the growing stock in 1970. France and the FRG alone account for almost half of the region's forest inventory. There is a high proportion of conifers in the FRG, where the growing stock per hectare, 145 m^3, and the increment per hectare, 4.8 m^3, are well above the average. Conversely, broadleaved species account for nearly two thirds of the growing stock in France, where the standing volume and increment per unit area are much closer to the average.

Switzerland has by far the highest volume per unit area of exploitable forest anywhere in Europe, 392 m^3/ha. This partly reflects the Swiss forest structure of a high dense forest of fairly large diameter trees with a high volume per hectare and insufficient renewal. Austria also has a high growing stock per hectare.

The situation of some countries, such as Ireland, is affected by a high proportion of young plantations of quick-growing species in the growing stock, resulting in the case of, e.g., Ireland having an annual increment almost double the average, which subsequently corresponds to a higher proportion of the growing stock. Italy has a fairly extended area of exploitable forest, but a low standing volume and a low net annual increment. Portugal and Spain have relatively high rates of growth, because of the importance of fast-growing, exotic plantations, as well as of the favorable climatic conditions.

Eastern Europe. The proportions of growing stock and increment in this region differ from those of other exploitable forests of Europe. In about 1980, Eastern Europe accounted for 28% of the exploitable forest area, but for 36% of Europe's growing stock and 28% of the increment, indicating a volume of growing stock of 155 m^3/ha, well above the European average. The net annual increment is 133×10^6 m^3, which is equivalent to 3.7 m^3/ha, or 2.4% of the growing stock volume, the highest of the three regions.

In terms of growing stock, Eastern Europe also has the greatest balance of hardwoods and softwoods. Coniferous species account for a little over half of the growing stock and annual increment per year. However, the composition of the standing volume and the share of conifers and broadleaved species varies substantially among the countries within the region. Czechoslovakia, the German Democratic Republic, and Poland are predominantly coniferous, in contrast to Bulgaria, Hungary, Yugoslavia, and Romania, where the larger part of the growing stock is broadleaved (ECE/FAO, 1986).

1.2.2. The USSR

The USSR is the world's leading nation in terms of the extent of forested area and forest resources within its borders. In 1978, the USSR accounted for 21% of the world's forested area and for more than 25% of the world's growing stock (UNIDO, 1983). The softwood growing stock in the forests of the USSR makes up half of the world's total. About one third of the word's volume of temperate hardwood growing stock is also among USSR's forest assets (USDA Forest Service, 1982).

A breakdown of the exploitable forest area in 1966 by major region and type is presented in *Table 1.6*. Estimates of the total volume of wood from potentially exploitable forests were at levels of 47×10^9 m^3 in 1964 and 48×10^9 m^3 in 1966. A subsequent estimate in 1969 of the total volume in then currently accessible reserves was 36.5×10^9 m^3, indicating the difference of what was accessible and what was potentially exploitable around the mid- to late-1960s (Sutton, 1975).

Table 1.6 The USSR — area of exploitable forests (Sutton, 1975, p 112).

	Forest area (10^6 ha)			
Type	*Total USSR*	*European Region*	*Siberia and the Far East*	*Other Regions*
Coniferous species, excluding larch	147.1	73.5	72.6	1.0
Larch	84.6	–	84.6	–
Total coniferous	231.7	73.5	157.2	1.0
Total nonconiferous	96.7	44.3	47.4	5.0
Total exploitable	328.4	117.8	204.6	6.0

Distribution of the resource

The forest resource of the USSR is disproportionately distributed in relation to population and location of wood processing facilities. The area northeast of a line extending from the city of Leningrad to the junction of the Soviet, Chinese, and Mongolian borders holds over 85% of the forested area along with only about 14% of the country's population. The area south of the line supports the remaining 15% of the forested area and about 86% of the population. The southern region relies heavily on wood resources brought in from the north and the east, though there is a trend toward relocating forest-based industries into the densely forested region (Holowacz, 1974).

Siberia and the Far East dominate the picture, claiming 76% or 515×10^6 ha of the forested land and 79% or 53×10^9 m^3 of the wood reserve. They also have the highest proportion of volume in mature stands, but the poorest growth rates, averaging only 1.2 m^3/ha/yr, (1.0 in the Far East and 1.1 in Eastern Siberia). Except for the North and the Northwest, the Western regions of the USSR do not support much of the forests. Although these areas have relatively better growth rates (2.2 to 2.9 m^3/ha/yr) they have the lowest proportion of volume in mature stands (a reflection of the greater concentration of utilization in these regions) (Sutton, 1975, pp 113–115).

1.2.3. Canada

Canada has two major timber-producing regions — Eastern and Western Canada. Eastern Canada consists of Quebec, Ontario, and the Atlantic Provinces of Newfoundland, Nova Scotia, Prince Edward Island, and New Brunswick. Western Canada's production is dominated by British Columbia. So far, plantation forests have played a minor role in Canadian forestry. Total forest land in Canada amounts to about 440 $\times$ 10^6 ha, of which 340 $\times$ 10^6 has been inventoried; 260 $\times$ 10^6 of the productive acreage has been inventoried. Much of the noninventoried productive forest land is in Eastern Canada, with Quebec accounting for 31.6 $\times$ 10^6 ha and Ontario for 4.9 $\times$ 10^6 ha (Bonnor, 1982, Table 1, p 4).

Eastern Canada. Close to two fifths, or 130 $\times$ 10^6 ha, of Canada's inventoried forest land lie in Eastern Canada. This acreage includes one half, or 110 $\times$ 10^6 ha, of Canada's forest land classified as "productive" (capable of producing a merchantable stand within a reasonable length of time), with 100 $\times$ 10^6 ha of this being "nonreserved" (available for harvesting) and "stocked" (supporting tree growth; which includes seedlings and saplings) (Bonnor, 1982). The bulk of this lies in Quebec and Ontario, holding 48.9 $\times$ 10^6 ha and 33.1 $\times$ 10^6 ha, respectively. But much of the 220 $\times$ 10^6 ha considered to be the nation's productive, stocked forest land is of low quality and understocked. A unit of forest land in Canada supports much less wood than the same unit of land supports in Europe or even in the US.

Not all of Canada's productive forest land is equally accessible. Roughly 60% of that in Eastern Canada can be considered as a "primary supply" area, where large-scale logging operations are currently in progress. Limited commercial development has taken place in about another 26% of the productive forest land. While these areas are more remote and production is limited by the lack of transportation and processing facilities, they are expected to contribute to the nation's future timber supply. The remaining 14% of Eastern Canada's forest land is suitable only for local harvests due to its occurrence in scattered patches, low yields, and other factors that limit utilization to small-scale operations (Bickerstaff *et al.*, 1981, pp 22 and 36).

Four of the eight forest regions recognized in Canada are important with respect to the forest land-base of Eastern Canada. The largest proportion of area is covered by the Boreal Forest Region, which nationwide comprises over one half of the productive forest area. About half of this region is continuous forest, predominantly coniferous. Some of the more important softwoods of this region are black and white spruce, jack pine, and balsam fir; representative hardwoods are white birch and poplars. The lower Atlantic provinces (New Brunswick, Prince Edward Island, and Nova Scotia), are covered by the Acadian Forest Region. Red spruce is characteristic, but not exclusive, with black spruce, white spruce, and balsam fir also in abundance. Species of the Great Lakes–St. Lawrence Forest Region are also intermixed. This region has the highest proportion (83%) of productive forest land. The Deciduous Forest Region lies in southwestern Ontario between Lakes Huron, Erie, and Ontario. However, less than 10% of this region is currently forested.

The forests of Canada tend to be even-aged, having originated mostly after fires, insect epidemics, or harvesting. While information about the site quality of Canada's forests is incomplete, an estimate of the productive capacity and growth of Canadian forests has been made, using the mean annual increment to maturity for natural stands of average stocking as the index. It was found that the mean annual increment at rotation age of managed stands in Canada ranges from about 0.3 m^3/ha for slow-growing stands on poor sites to over 10.5 m^3/ha for very good sites. Accessible productive forest land in Canada by provinces and territories ranges from 1.3 to 2.6 m^3/ha with an average of about 2.0 m^3/ha, indicating that very good sites are in the minority.

British Columbia. In terms of total land area, British Columbia is the second largest province of Canada (only Quebec is larger) and covers about 93×10^6 ha. Forests occupy roughly 63×10^6 ha and over 80% of this, or 52×10^6 ha, is classified as productive forest land. Large-scale commercial logging operations are currently in progress on 38×10^6 of these productive hectares, making up the "primary supply area". The remaining 14×10^6 ha are subjected at present to restricted commercial development due to the limited availability of transportation and processing facilities. These secondary areas are expected to contribute to future timber supplies. Much of the inaccessible land is in the north and at higher elevations. In decreasing size order, the Forest Regions of the province are: the Subalpine, the Boreal, the Montane, the Coastal, and the Columbian.

The Subalpine Forest Region covers the uplands from the Rocky Mountains through interior British Columbia to the Pacific inlets. Spruce and lodgepole pine are predominant, while the true firs are also abundant. This region is closely related to the Boreal Forest Region, which is in the northeastern corner of the province. Much of the province's interior uplands are occupied by the Montane Forest Region, characterized by a generally dry climate. Ponderosa pine is characteristic in the south, while at higher elevations and in the north, Engelmann spruce and alpine fir, also typical of the Subalpine Region, are most common.

Relatively high rainfall and high mean temperatures are found in the Coastal Forest Region and much of this area is highly productive. This essentially coniferous forest is dominated by western hemlock and western red cedar, with Sitka spruce in the north and Douglas fir (the Coastal form) in the south. Highly productive forest land also occurs in the Columbian Region in the southeastern part of the province. This interior wet belt resembles the Coastal Region, though the species are more limited. This Region has an average growth rate of about 5.0 m^3/ha at rotation age, one of the highest regional averages throughout Canada, and holds about 35% of the province's growth potential, but contains only about 15% of the province's production forest land. The Boreal Forest Region is the least productive, having a mean annual increment at rotation age of about 1.4 m^3/ha. This region provides only 17% of the provincial growth capacity from 27% of the productive area.

Industrial wood production in Canada

Canada's pine, spruce, and fir forests have been the backbone of Canada's forest industry, providing the long-fibered softwoods, which produce light, strong-dimension lumber and white, strong pulp and paper products. In 1979, about 95% of the total timber harvested in Canada was softwood. It is possible that the hardwood timber resource could become more important in the future as a source of pulp and/or paper products (USDA Forest Service, 1982, pp 93–94). There has been a steady increase in the production of all timber products except hardwood plywood from 1950 to 1979. The greatest continued expansion has been of softwood lumber; softwood plywood rose rapidly during the 1950s and 1960s.

British Columbia is the major producer of softwood lumber, accounting for about two thirds or 29.5×10^9 m^3 of Canada's production in the late 1970s. Another one sixth of the softwood lumber production in recent years comes from Quebec and Ontario. Softwood lumber production in the Atlantic Provinces has been relatively stable and there is limited potential for expansion (USDA Forest Service, 1982, p 92).

Quebec and Ontario together produce about one half of Canada's wood pulp, which peaked at 22×10^6 tons in 1974 and has remained close to that mark since. Most of the remainder of the wood pulp comes from mills in British Columbia. The expansion of paper and board production since the late 1960s has taken place in British Columbia and the Prairie and Atlantic Provinces. Throughout this time Quebec and Ontario have maintained a relatively stable level of production at about 12×10^6 tons per year (USDA Forest Service, 1982, p 93).

1.2.4. The US

The US has several major forest areas, including the Pacific Coast forests, the Rocky Mountain forests, the Lake States forests, New England forests, and the forests of the South. The major industrial wood forests are those of the Pacific Northwest region (including Northern California) and the Southern Forest, and only these are examined in this section.

Forest plantation establishment in the US has been actively undertaken since the mid-1950s. Early efforts were justified largely on environmental considerations and were heavily subsidized. Since the mid-1960s, however, industrial plantations have been established by industrial and private landowners. In recent years about 700 000 ha per year were being established in the US with most of them in the South and most of the remainder in the Pacific Northwest.

Pacific Coastal Complex. This formation of forests is found in a belt that lies west of the crests of the Cascade Range and Canadian Rockies. Its northern end lies south of the Alaskan Range and the southern portion, termed the Coast Redwood Belt, extends along the California coast to the San Francisco area. It also appears in a modified form on the western slopes of the Rockies in Northern Idaho, Eastern Washington, Western Montana, and Southeast British Columbia. The two species that are most typical are western hemlock and western red cedar, but others, including redwood, Sitka spruce, and coastal silver fir, are relatively restricted in range. The most abundant and important species is Douglas fir, which is found widely.

The ocean has a major influence on climate, providing moisture and centralizing temperature extremes. The result is a relatively mild wet winter and a dry summer climate.

The Pacific Northwest region of the US constitutes one of the major timber producing regions of the globe. This region consists of three quite different forests (Scott, 1980). The major producing forest is that of Washington and Oregon, west of the crest of the Cascade Mountains. This region is 80% forested (see *Table 1.7*) and dominated by coastal Douglas fir. Also significant are western hemlock, western red cedar, Port Orford cedar, and Sitka spruce, as well as nonconifers such as red alder — a pioneer species that often occurs after disturbances.

The California region to the south is unique due to the combination of distinctive species and a Mediterranean climate. Forests extend across the full width of the state in Northern California and include the species Douglas fir, ponderosa, Jeffrey pines, and true firs, as well as redwoods, cedars and hardwoods.

Table 1.7 Pacific Northwest forest land (10^3 acres) (USDA Forest Service, 1978).

Western Washington	9 788
Western Oregon	13 875
California	17 944
Idaho	13 540
Montana	14 359
Eastern Washington	8 134
Eastern Oregon	10 560

The third subregion, east of the Cascades, includes the states of Idaho, Western Montana, and Northeastern Washington. This forest is considerably more arid than the coastal forests to the west. The dominant species include Douglas fir, true firs, lodgepole pine, and ponderosa pine. Virtually all of the forested area in this subregion is mountainous, with the terrain being typically rugged and steep. The climate is dominated by the prevailing westerly winds along a well-developed storm track that extends the coastal climate inland to the western slopes of the Rockies. Thus, the climate is milder than would be expected at this latitude, with winter precipitation and summer drought.

California is characterized by a central valley. Mountains surround this valley with a coastal range to the west and the Sierra Nevada range to the east. To the north lie the Klamath Mountains. The eastern range is more varied with major forest zones being associated primarily with elevation.

Southern Pine Region. The Southern Pine Region (Walker, 1980) includes the southern Atlantic and Gulf coastal pines, the Piedmont Province, and the Fall–Line Sandhills that lie between the Coastal Plain and the Piedmont. It also includes the Ozark and Ouachita mountains and the bottomlands of river courses, as well as the Mississippi Delta. The 828 800 km^2 Coastal Plain supports the most extensive and productive pine forests in the South.

The total land area of the Southern Pine Region comprises about 81 $\times 10^6$ ha in 12 states. About 60% of the land is forested, almost 40×10^6 ha in pine types. The growing stock of southern pines is about 2.1×10^9 m^3. In recent years considerable tree planting has occurred in the South — almost all of it in pine.

Most of the region has a humid, subtropical climate characterized by high temperatures and abundant precipitation. Major species in the Coastal Plain include loblolly pine (23% of the total forest), slash pine (17%), oak pine (14%), and oak hickory (19%). The Interior Highlands refers to two different, elevated provinces. The larger, lying north of the Arkansas River, is an area of broad plateaus called the Ozark Plateaus. The smaller Quachita Province lies to the south. Both have important commercial stands of short leaf pine and upland hardwood.

Southern Hardwood Region. The Southern Hardwood Region includes the bottomland hardwoods along the major river courses throughout the Coastal Plains, the Brown Loam Bluff of mixed upland hardwood along the eastern edge of the Mississippi, and the upland hardwoods of the Appalachians. Geographically, the region extends from Pennsylvania southwest along the Ohio River to southern Illinois and eastern Oklahoma, southward to the Gulf of Mexico and Florida, and northward along the Atlantic coast to the northern extremities of Chesapeake Bay. Of major importance are the upland hardwoods of Appalachia and the large areas of bottomland hardwoods located on the original flood plain of the Mississippi and its tributaries.

The commercial hardwood forest types in the South have been estimated at about 58×10^6 ha out of a total of 93×10^6. The composition of the hardwood forests of the South can best be described as heterogeneous. On bottomlands these include cottonwood and willow types, cypress tirpelo types, and mixed bottomland hardwood, e.g., sweet gum, water oaks, and water hickory.

The Appalachian Hardwood subregion is located in the unglaciated part of Eastern–Central US and encompasses most of the Appalachian Plateau, the Blue Ridge, and the Piedmont Plateau discussed elsewhere. The forest types include the mixed mesophytic forest, in which the dominant tree species include sugar maple, American beech, yellow poplar, northern red oak, and white oak, among others. This forest contains 40% of the land of the Appalachian Hardwood subregion. Mixed oak is 26% of the commercial forest of this region. Most common species include white, northern red, and chestnut oaks, shagbark hickory, and American beech.

Oak–pine forests are located primarily in the Piedmont subregion and include 35% of the commercial forest land of the Appalachian Hardwood subregion.

Industrial wood supply in the US

The US is the world's major producer of industrial wood and in 1983 it provided about 24% of the world's production. Of this, 76% was coniferous wood, of which the US's world share was 26% — again, the world's dominant producer. The US is also a major producer of most solidwood and fiber products. However, despite its high production, the US is a net wood importer due to the very large domestic markets (Sedjo and Radcliffe, 1981). The most recent published figures (USDA Forest Service, 1982) indicate that in 1976 46% of total timber harvested was in the US South and another 31% was in the Pacific Northwest. However, production has been shifting to the South, reflecting the drawdown of old growth in the West and the favorable growing and other conditions in the South. Although concern has been expressed over the adequacy of future timber supply in the South (Brooks, 1985), rather substantial amounts of plantation establishment and tree planting are currently under way. For the period 1980–1984, annual tree planting in the South averaged about 700 000 ha (Fedkiw, 1984). Overall, the US has about 27 × 10^6 ha of plantation forest, most of which is located in the South.

1.2.5. Latin America

Latin America's natural forests cover large areas from northern Mexico to near the Antarctic in Argentina and Chile [3]. The altitude range is from sea level to 3500 m. As a result of this wide latitude and altitude range, the forests are of many very different types. The natural pine forests, growing mainly in Central America and Mexico, should be distinguished from the mixed tropical and temperate hardwood forests that spread over the whole region. The natural araucaria forests, which grow mainly in Southern Brazil, have been heavily exploited and are probably of little economic importance for the future.

The total natural forests cover about 720 × 10^6 ha, or 36% of the region's total land area (*Table 1.8*). About three quarters of this is considered to be of a more closed forest type, which could be industrially utilized. No more than 3% of all forests are coniferous; the rest is mainly mixed tropical hardwood forest. Brazil, with its huge tropical forests in the greater Amazonian river basin, has the region's main natural hardwood resource.

The ownership status of forest land is not adequately defined in many Latin American countries, even though there are laws and decrees on this matter. Most of the region's natural hardwood forest area (about 80%) is state owned, while plantations are mainly private; the distribution in natural pine forest is about 60% public and 40% private. There is a trend toward increasing private ownership since more and more land from the state is being claimed by settlers.

The total growing stock in the productive natural forest is estimated as follows:

Coniferous forest: 1 180 × 10^6 m^3 (about 75 m^3/ha)
Hardwood forest: 79 110 × 10^6 m^3 (about 150 m^3/ha)

The total roundwood removals in Latin America from natural forests are about 350 × 10^6 m^3 per year. This is only 0.4% of the growing stock, which indicates that Latin America's forests are underutilized. However, there are many areas that are badly overexploited, since clearance has been concentrated on the most accessible areas and on a limited number of commercial species. The natural forests are either not being utilized at all (for industrial wood production) or are often exploited by a single phase of logging followed by burning and cattle grazing.

More than four fifths of the total wood production is for local fuelwood consumption, providing an important contribution to the basic living

Table 1.8 Latin America: forest areas, 1980 (10^3 ha) (McGaughey and Gregersen, 1983).

Subregion	*Total land area*	*Total forest area*	*% of land area*	*Natural productive forest*		*Annual deforestation*
				Coniferous	*Broadleaf*	
Mexico	197 255	46 250	23.5	11 720	12 580	530
Central America	50 862	18 679	36.7	2 512	11 682	382
Caribbean	56 435	44 511	78.9	277	34 960	21
Brazil	851 196	357 480	42.0	280	300 910	1 360
Andes	446 311	206 210	46.2	185	142 975	1 535
Southern Cone	412 727	46 605	11.3	820	28 040	155
Latin America	2 014 786	719 735	35.7	15 794	531 147	3 983

Subregion	*Total forest plantation*	*Industrial plantations*		*Annual planting area*
		Coniferous	*Broadleaf*	
Mexico	159.0	37.0	35.0	7.8
Central America	25.4	15.8	9.6	3.9
Caribbean	48.8	26.1	16.0	8.1
Brazil	3 855.0	1 232.0	741.0	158.0
Andes	372.4	181.8	115.6	26.8
Southern Cone	1 453.0	874.8	410.1	93.2
Latin America	5 913.6	2 367.5	1 327.3	297.8

needs of the rural population. Only about 53 × 10^6 m^3 per year are utilized industrially, the bulk of which (46 × 10^6 m^3) is sawlogs and veneer logs.

Pulpwood is extracted mainly from plantations (16 × 10^6 m^3 per year), with natural coniferous forests producing no more than 5.2 × 10^6 m^3 of pulpwood per year. Because logging costs in tropical hardwood forests have generally been very high and there are technical difficulties in pulping mixed species, only smaller volumes (1.2 × 10^6 m^3 per year) of pulpwood have been extracted from them. Owing to the expected increase in transport costs and relatively low production costs of plantation wood, it is unlikely that the share of pulpwood derived from natural hardwood forests will significantly increase in the region. The main future industrial use of tropical hardwood, rather, will be for sawnwood and panels. In natural pine forests (Central America, Mexico) the volume of the wood utilized for pulping will probably increase with growing demand. The industrial utilization may in some regions be limited by the growing local demand for fuelwood.

Plantations

In Latin America about 6 × 10^6 ha had been planted by 1980, but only 3.7 × 10^6 ha (60%) was considered to be in plantations of industrial size and suitable location. Most of the region's plantations are less than 10 years old. About two thirds of the total industrial plantation comprises coniferous species, mainly tropical pines, and one third is of fast-growing hardwood species, mainly eucalyptus. Argentina, Brazil, and Chile account for 85% of the region's total industrial plantation area.

It is estimated that Latin America's industrial plantation area will be tripled by the year 2000, covering about 21 × 10^6 ha. The biological potential is estimated to be almost 30 × 10^6 ha (McGaughey and Gregersen, 1983, p 80). The annual planting rates are projected to increase by no more than 10% in softwoods, but by almost 80% in hardwoods between 1980 and 2000.

While the above projections exclude fuelwood plantations, in Brazil, for example, an additional annual planting area of 100 000–200 000 ha is intended for the production of fuelwood and charcoal on an industrial scale. It is not expected that fuelwood plantations would essentially limit the availability of land for industrial plantations.

The plantation yield varies considerably between species due to the wide range of climate, elevation, and soil. In Chile monterey pine (*Pinus radiata*) can reach as much as 20–30 m^3/ha/yr, but in Argentina and Southern Brazil the annual growth of loblolly pine varies from 15 to 25

m^3/ha/yr. In Brazil there are many fast-growing eucalyptus plantations where 30–35 m^3/ha or even more can be expected. However, average figures should be much lower, since many plantations established to date are far from optimal with respect to site and species selection, and probably also to stocking.

It is estimated that by the year 2000 the wood production of industrial plantations will be almost four times higher than now and will account for about 50% of the total industrial wood. This switch from natural forests to plantations will take place mainly in Brazil and the Southern Cone. In Mexico and Central America natural pine forests will continue to be important resources at the end of the century, if they can be brought under more intensive management and control than they are today.

The plantation wood is mainly pulpwood (70%), but an increasing output of sawlogs and veneer logs is anticipated because of the increasing demand for these valuable products, which are more and more difficult to obtain from natural hardwood forests. In Chile, by contrast, the bulk of plantation wood is sawlogs, though this could change if more capital becomes available for a large expansion of pulp and paper production.

1.2.6. Asian forests

Asian forests stretch from Hokkaido in northern Japan to the dry, deciduous forest of the western Indo-Pakistan region of Southwest Asia. The majority of these forests are tropical, nonconifer forests. The vast areas of Asia's tropical forest account for about one third of the world's moist tropical forests. These include the tropical rainforests of Malaysia, Indonesia, the Philippines, Papua New Guinea, and the Solomon Islands, as well as the monsoonal forests of Continental Southeast Asia, which include Burma, Indochina, Thailand, and parts of India. Within Asia, several countries are important suppliers of timber to domestic industries, including both Japan and India.

While Japan is the world's leading importer of industrial wood, it is also a major supplier in its own right, supplying about 40% of domestic raw wood requirements in recent years. After World War II, Japan began a program of intensive reforestation in which approximately 10×10^6 ha were involved. While Japan is a major producer and user of industrial wood, the massive domestic requirements make it almost certain that it will continue to be a major net wood importer into the indefinite future.

About 90% of the production of industrial wood in the Indian subcontinent and Sri Lanka is hardwood. Almost all of the production is consumed domestically.

Certain Asian countries have been successful with major reforestation and afforestation programs, such as those recently undertaken in China and South Korea. As noted above, China has afforested 20–40 × 10^6 ha. South Korea's program, while more modest, has succeeded in the afforestation of about 4 × 10^6 ha. More limited efforts at afforestation are under way in Nepal, Pakistan, Bangladesh, and India. These efforts often combine environmental protection goals with those of fuelwood and sometimes industrial wood. Other modest plantation activities are under way in Malaysia, Indonesia, and the Philippines. Also, specialized wood (e.g., teak) has been grown in plantation forests in some parts of Asia for many decades.

Forest resources of tropical Asia

The 16 countries of tropical Asia stretch from India to Papua New Guinea and may also be logically extended to the Solomon Islands. In 1980 the total area and forests in the 16 countries was 445 × 10^6 ha, or about 47% of the land's surface (FAO, 1981). The region can be divided into four subregions: South Asia, Continental Southeast Asia, Insular Southeast Asia, and Papua New Guinea. In *Table 1.9* are presented estimates of the forest area by subregion and country.

The forests of the Asia–Pacific region are clearly the most important industrial forests within the tropical regions, accounting for over 50% of the total industrial wood harvested from tropical forests. The tropical hardwood resources of the tropical Asia–Pacific region can be separated into four forest regions. These are the Dipterocarp areas of the mainland and insular Southeast Asia, the non-Dipterocarp area of the Southwest Pacific Islands, the teak forest area of Burma and Thailand, and the Indian subcontinent plus Sri Lanka.

Commercially, the Dipterocarp area is the most important and includes the Philippines, Malaysia, Indochina, and Indonesia west of the "Wallace Line", which separates the Malukus, Lesser Sunda Islands, and West Irian from the rest of Indonesia (Takeuchi, 1974). Timber trade in the tropical Asia–Pacific region has been dominated by the export of logs of Dipterocarpus and Shorea genera, mainly from the countries of the Philippines, Malaysia, and Indonesia. The resources of Indochina are plentiful and marketable. However, the lack of political stability has prevented the development of this resource.

The forest resources in the Southwest Pacific Islands, while rich in volume, are of non-Dipterocarp species, and most are not yet known in the major markets. Currently, both the Solomon Islands and Papua New Guinea are modest exporters of logs.

Table 1.9 Areas of closed forest in tropical Asia in 1980 (FAO, 1981, p 40).

Region/Country	*Area* (10^3 ha)	*% of region*
South Asia	60 653	19.86
Bangladesh	927	0.30
Bhutan	2 100	0.69
India	51 841	16.97
Nepal	1 941	0.64
Pakistan	2 185	0.72
Sri Lanka	1 659	0.54
Continental Southeast Asia	65 904	21.57
Burma	31 941	10.46
Kampuchea	7 548	2.47
Laos	8 410	2.75
Thailand	9 235	3.02
Viet Nam	8 770	2.87
Insular Southeast Asia	144 723	47.37
Brunei	323	0.11
Indonesia	113 895	37.28
Malaysia	20 995	6.87
(Peninsular)	(7 578)	(2.48)
(Sabah)	(4 997)	(1.63)
(Sarawak)	(8 420)	(2.76)
Philippines	9 510	3.11
Papua New Guinea	34 230	11.20
Tropical Asia, Total	305 510	32.33

Burma and Thailand, together with the island of Java, have traditionally been the major sources of teakwood, with Burma being the dominant supplier.

1.3. Summary and Conclusions

This broad overview of the world's forests has focused on the industrial wood-producing regions. We have observed the process of transition from natural forests to plantation forests; the world's forests are not static, but dynamic and changing through time. Historically, the forests have changed as pressures have been placed upon them by expanding human populations and as the need for land for nonforest purposes and the demands upon the timber resource have combined to reduce the forest resource. A countervailing force arises when humans recognize the importance of the forest to environmental protection and develop the ability to plant and manage forests continuously for their timber value. While tension between forest uses and other land uses exists in much of the temperate climate world a balance has been struck which has resulted in a stabilization of the land area covered in forest. In the tropical regions of the world, by contrast, the forest area continues to contract. Fortuitously from the point of view of wood and wood fiber production, the regions of the globe from which most of the world's industrial wood is harvested are, by and large, areas where the land used in forest production is largely stabilized.

Notes

[1] Opinions about the success of China's reforestation efforts vary considerably. A recent World Bank assessment (1982) of China's environmental problems presents a pessimistic appraisal.

[2] The volumes for Europe are "overbark".

[3] This section draws heavily from McGaughey and Gregersen (1983).

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CHAPTER 2

Forests and the Changing Chemical Composition of the Atmosphere

P. Kauppi

The chemical composition of the atmosphere is changing due to the trends in the fluxes of, for example, CO_2, SO_2, and NO_x that are emitted from industrial and energy combustion processes into the atmosphere. Forest ecosystems are unlikely to react in any single, universal way, but rather there may be a large variability of ecological reactions both in time and in space. This variability is partly due to the concentration patterns of the emitted compounds. Also, in conditions of a given load of pollutants the ecological response may vary according to the ecosystem characteristics. At this stage it is extremely difficult to actually quantify the possible reactions of forest ecosystems, so all quantitative scenarios should be examined cautiously because of this uncertainty. Quantitative scenarios are not useless, however, because they provide a systematic way of ranking and evaluating the different factors of uncertainty. That, in turn, improves our understanding of the phenomena.

In this chapter we highlight three issues, all dealing with the responses of forests to the trends in the chemical composition of the atmosphere. The first issue is that of forest damage currently being observed in Europe. Acid precipitation, the stress due to sulfur dioxide, ozone, and heavy metals, and the excess amount of depositing nitrogen compounds are common denominators in this phenomenon. The two remaining issues are related to CO_2 emissions. The so-called CO_2 fertilization effect is due to the obvious possibility that the rate of tree photosynthesis will generally increase as the air is given increasing amounts of one of the main substrates to photosynthesis, i.e., carbon dioxide. The greenhouse effect is related to CO_2 and other "greenhouse gases", which all have a tendency to increase

Earth surface temperatures. The possible climatic warming in the air would affect the ecology of forests.

2.1. European Forest Damage

2.1.1. Introduction

Symptoms of what has been called a "new forest decline" have increased in Central Europe since the mid-1970s. Today, many scientists share the opinion that the new symptoms are connected to air pollution, yet no single pollutant or damage mechanism is considerd as the only cause of this so-called forest dieback. Survey results compiled by the Timber Section of the ECE/FAO Agriculture and Timber Division indicate that forest dieback has been observed over a rather large area in Central Europe. Countries such as Austria, Czechoslovakia, the FRG, Luxembourg, the Netherlands, Poland, and Switzerland report widespread damage of their forest resources.

The damage was first observed on silver fir. Currently, it is reported also on Norway spruce, Scots pine, beech, and oak. The definition of damage varies from country to country and the figures estimated from various countries are only partially comparable. Some of the figures are based on expert judgment rather than on a statistical survey. By far the largest fraction of the affected forests are only slightly damaged and may well recover. Moreover, although the estimates of the damaged area are quite high in many countries, there are no indications so far of marked increases in sanitation fellings. Such information encourages hopes that the forests in Europe, indeed, would recover. Nevertheles, the situation creates serious concern.

In the early days of industrialization it was not unusual for damage symptoms to occur on trees, for instance, in the neighborhood of a smelter. The first systematic studies of such events were carried out early in the nineteenth century (Stöckhardt, 1850, 1871; von Schröder and Reuss, 1883). Although warning of possible widespread damage was expressed in the 1960s (Knabe, 1966), the problem gained wide publicity in the early 1980s as new information became available.

Air-pollution abatement has been directed, in the first place, at improvement of the quality of urban air. Constructing high stacks has assisted in reducing maximum ground concentrations of pollutants, which has certainly been a valid goal. However, similar reduction has not been realized in rural areas. On the contrary, the rural concentrations of pollutants have increased with increasing industrial activity and the consumption of fossil fuels. Only very recently has the increase of sulfur emissions reached saturation in many industrial countries. A declining trend is now anticipated in Europe for the forthcoming years, but nitrogen emissions may still continue to increase. Locally, there may be substantial deviations from these general trends.

Forest damage is a problematic concept because it does not have a standard meaning. In Section 2.1.2 we describe different indicator variables that have been applied in order to quantify forest damage. In Section 2.1.3 we give a short review of possible cause-and-effect relationships and of models for describing the damage.

2.1.2. Concepts of damage

A definition of damage requires that the limit between acceptable and unacceptable conditions is specified. Acceptable conditions are called the "norm" and unacceptable ones, "damage". Defining the limit between norm and damage is a value judgment: What people regard as acceptable depends upon their point of view, experience, and objectives. Forest hikers and the general public are responsive to the general habitus of trees and forest landscapes. The industrial timber sector will react to changes in the potential harvest of high-value tree species. Attention is here given to visible damage, to growth reduction, and to the reduction of the standing stock. Damage variables can be defined at three levels of hierarchy: tree level, stand level, and regional or forest level.

Decrease in crown density

Tree level. Visible damage occurs as leaf necrosis, immature fall of leaves and needles, death of branches, and decline of the top. A simple variable, "crown density", has been commonly used to describe these phenomena. The crown density is relatively easy to observe in regional and national surveys as it is quick to assess. At least the FRG, the UK, Sweden, and Finland apply this variable in their national surveys of forest damage.

Crown density is assessed as the fraction of needles fallen in comparison with the norm and is not determined for suppressed trees but only for dominant or codominant trees. The damage is more difficult to quantify for deciduous trees, as their appearance changes substantially over the growing season. The percentage of necrotic leaves has been used as an indicator.

Stand level. It is a natural process for some trees in any given forest stand generally lose their vigor, mainly due to self-thinning. As trees grow larger they occupy more space and, by necessity, their number will decrease (e.g., Gorham, 1979). As crown density thus varies among individual trees, the definition of damage at "stand level" requires that one specifies what proportion of trees that show the symptoms is acceptable. A stand-specific index in the FRG takes into account both the distribution of trees according to crown density and to tree size (Schöpfer *et al.*, 1984). The index puts more weight on a large tree than on a small one. The area occupied by each tree is computed and stand damage is expressed in units of land area. In mixed stands the German method computes stand damage proportionally between species.

Forest level. Any larger forest region consists of a number of forest stands. Averaging the crown density data from all the stands in the region does provide a variable for describing forest damage. However, when comparing two forest regions one must take into account the characteristics of forests in each region and ensure that the regions, indeed, are comparable. The species distribution and the distribution of stand age must be taken into account. For example, a forest region with old stands is generally especially susceptible to air-pollution damage (*Figure 2.1*).

Growth reduction

Tree level. Tree-ring analysis is an effective method for measuring growth reduction at the tree level. Tree-ring data have the advantage in that they extend several decades back. The method is intensive and it can be used in cause-and-effect studies. Hari *et al.* (1984), for example, have applied the method to detect pollutant effects.

Comparisons between damage and norm are difficult, however, because it is not easy to describe the reference tree or the norm. The growth increment of a forest tree varies as a function of many factors, such as climate, soil conditions, tree species, genotype, and position of the tree as a suppressed tree or as a dominant one. The norm must, therefore, be expressed as a function of species, site, tree age, and the position of the tree within the stand.

Stand level. Most forest operations, such as thinnings, regeneration, and possible fertilization, are organized in practice at stand level. An important variable of damage would thus be one that expresses the growth increment at stand level. Reference conditions (the norm) are available in many areas in terms of growth curves for stands of given species and sites (*Figure 2.2*).

Forest level. Arovaara *et al.* (1984) have used the data from the surveys of forest resources to detect trends in tree growth due to changes in the chemical composition of the atmosphere. Such methods cannot be used in most

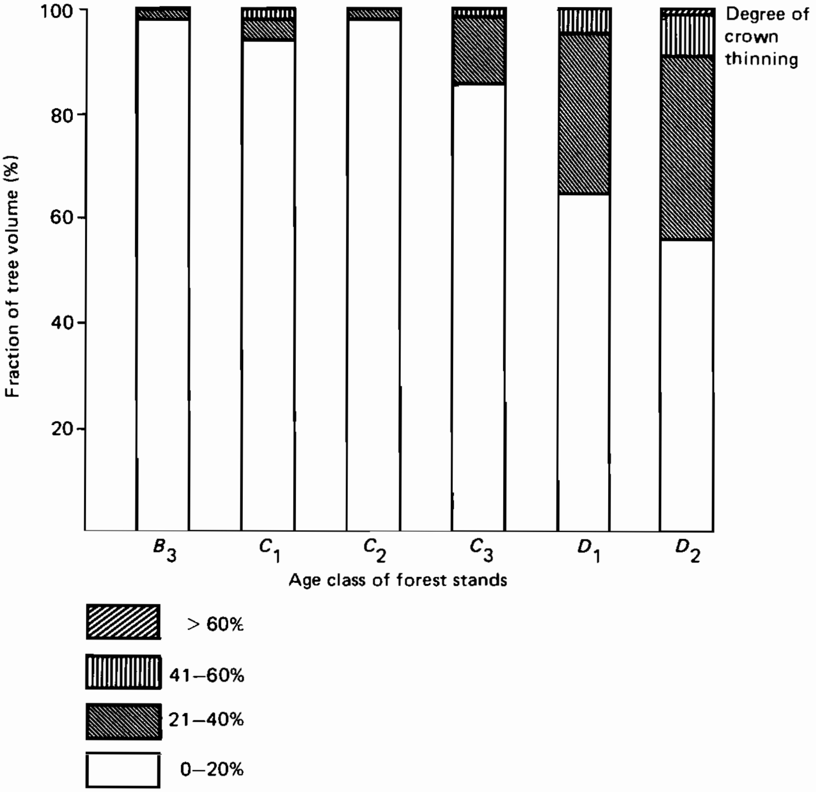

Figure 2.1 The distribution of trees, on a volume basis, into classes of crown density in different phases of stand development in Southern Sweden. Norway spruce; B_3 = young stands with average stand height > 3 m, C_1-C_3 = stands at the intermediate age, D_1-D_2 = old stands (Bengtsson, 1985).

parts of the world because the survey results are available only from restricted regions.

Stock reduction

Forest level. As old trees are particularly susceptible to forest damage it may sometimes be necessary in polluted areas to shorten the rotation period. This may only slightly decrease the average stand growth on a sustainable basis, but essentially reduce the volume of the standing stock.

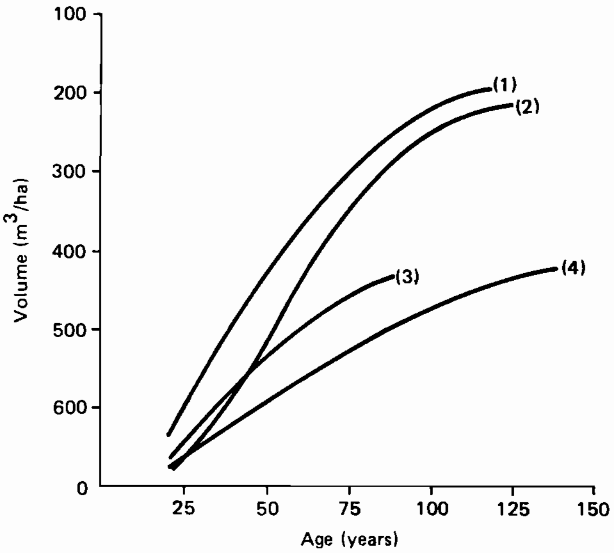

Figure 2.2 Stand volume development for some tree species and growing sites in Southern Finland (Koivisto, 1959). (1) Scots pine (*Pinus sylvestris*), *Myrtillus* site type; (2) Norway spruce (*Picea abies*), *Myrtillus* site type; (3) Silver birch (*Betula pendula*), *Myrtillus* site type; (4) Scots pine (*Pinus sylvestris*), *Cladonia* site type.

Stock reduction should hence be taken as a damage variable that is practically independent of the growth variables.

Growth of a stand typically reaches a culmination point after which it starts to decline. Standing volume, however, continues to increase. The rotation time, one of the key concepts of forest management, is selected according to economic criteria (Binkley, 1985). In most cases the rotation age is lower than that of growth culmination. Forest management maintains a control over the rotation time and, consequently, over the age distribution of forest stands.

Air pollution has the strongest effect on old stands and high pollution levels may force forest management to eliminate the oldest fraction of the stand age distribution. Shortening the rotation period by, say, 10% may decrease the standing stock of a forest region by as much as 20–30%, because old stands with the largest volumes would disappear. The average growth of the region would decrease far less because old stands do not grow very fast.

It may be, in fact, that careful attention should be given to the effects of air pollution on the standing volume of forest regions. Variables for standing stock may well be more sensitive to air pollution than growth variables. If, indeed, standing volume were strongly declining, then the timber sector should be prepared for a considerable pulse of high timber supply followed by a modest decline in the sustainable harvest.

2.1.3. Quantitative models

Wentzel (1983) has collected results from Europe concerning the relationships between damage and SO_2 concentrations. These studies are part of the Air Pollution Program of the International Union for Forest Research Organizations (IUFRO). Field observations indicate that risks of damage increase considerably as the long-time mean concentration exceeds 40–60 $\mu g\ SO_2/m^3$. Materna (1984) reports that forests at high elevations are especially sensitive to air pollution. An effect that is observed in forests 600 m above sea level within the concentration range 70–90 $\mu g/m^3$ can be observed above 1000 m in concentrations as low as 20–30 $\mu g/m^3$. IUFRO recommends that average concentrations of SO_2 in forest regions should not exceed 25 $\mu g/m^3$.

Rather close correlations have been documented between the the sulfur content of tree needles and the average age of the needle (Knabe, 1982). Nevertheless, SO_2 is no longer considered as the only major cause of pollution damage. New hypotheses about cause and effect have entered the discussion. Ozone and soil acidification, in particular, have been added to the list of potential agents of damage. Heavy metals, secondary photooxidants other than ozone, nitrogen deposition, and combinations of all these constituents also have potential damage effects.

It is illustrative to group the hypotheses on the basis of their dynamics. Such a classification has been presented by Kohlmaier *et al.* (1984), who distinguish between immediate and delayed impacts. The time scale of the delay — a week, a month, a year, or a decade — varies from one process to another and has to be specified accordingly. The delayed impacts can be further divided into delays in the physical environmental and in the biological responses.

The impact to forests can often be considered immediate if it occurs less than a year after the exposure. The acute SO_2 damage is immediate in this sense. Average sulfur concentrations in Europe have not increased for 5–10 years, so it has been argued that the new forest damage is due to ozone rather than SO_2. The concentrations of ozone still continue to increase and ozone could, therefore, explain the damage, even when assuming that the damage is acute (Prinz *et al.*, 1984).

If the damage is delayed then soil acidification is a valid hypothesis. The theory presented by Ulrich describes a gradual change in soil acidity in which several delay mechanisms are involved (Ulrich, 1983). The flow of protons into the top soil, due to sulfate and nitrate deposition, leaches calcium and magnesium ions from this soil. This process mobilizes aluminum ions that have detrimental effects on tree roots. The more protons that are deposited, the more aluminum dominates in the soil solutions. Sulfur emissions, carrying protons, gradually acidify soils through a delayed process of accumulation (van Breemen *et al.*, 1984). In the context of soil acidification the delay is of the order of years or decades. As soils acidify the trees are assumed to show damage. Reducing the emissions slows down the rate of acidification, but may not reverse it before a threshold deposition has been reached. In this way recovery is also delayed, even in the hypothetical case that all emissions are set to zero.

The recent stress hypothesis assumes that there are delay mechanisms within the tree (e.g., Schütt *et al.*, 1983) and that different stress factors can cause similar symptoms. Triggering factors include SO_2, soil acidification, and ozone. It is important to gain an insight into the processes, such as photosynthesis, respiration, and growth, that are common to all pathways of the disease.

Plant processes can, to a certain extent, cope with air pollutants and induce physiological delays that cause difficulties in identifying cause and effect. If the roots are damaged, for example, then plants allocate more photosynthates to root maintenance and less remains available for needle production. Crown density may thus react to poor soil conditions rather than to toxic effects on the needles. Such possible endogenous delays are very difficult to trace experimentally.

Dose-response models

Pollutant stresses on organisms have been analyzed using so-called dose-response models, first presented by O'Gara (1922) and further developed by, e.g., Thomas and Hill (1935) and Larsen and Heck (1976). These models are based on the idea that damage occurs after exposure to a threshold dose. The dose is not just the average concentration, but may depend on both pollutant concentration and exposure time.

In the standard form of the model, the dose is the product of the "effective" concentration and the "effective" exposure time. "Effective" concentration refers to a linear response of the strain to concentrations above a minimum threshold stress. Hence, the dose, D, is:

$$D = \sum_{i=1}^{n} (c_{ai} - c_0)$$

where c_{ai} is the ambient concentration, c_0 is the threshold concentration, and n is the duration of "effective" exposure. The model can be further simplified to compute the threshold dose as a function of exposure time. When computed in this way dose can be related to damage, for example, using a logistic function (Kauppi, 1984). As the dose–response model does not consider resistance of the plant as an explicit variable, potential differences in resistance between species and growing sites should be incorporated into the parameters of the model.

A soil-acidification model

Quantitative dose–response models for describing regional forest decline would be useful in guiding experimental research, examining the rate of expansion of forest damage, and optimizing control measures, such as emission reduction and silvicultural practices. They would also assist the timber sector to create scenarios for sanitation fellings. Such scenarios could be used in order to mitigate the possible market disturbances.

Dose–response models of regional forest damage contain much uncertainty. First, there are many variables that define damage and, moreover, those that would be of most value to the timber sector are difficult to assess at the regional level. Second, many air pollutants potentially affect trees and some of them have a number of different pathways of effect. Third, site-specific conditions — tree species, stand density, stand age, soil characteristics, climate, etc. — have a large effect on the response. Finally, quantitative dose–response models are in the early phase of development, even in applications to local and specific conditions. Efforts to develop regional models, however, generally improve our understanding of the quantitative relationships.

The IIASA Acid Rain Project maintains a model system (RAINS) that consists of several submodels, which describe processes and phenomena related to acidification in Europe (Alcamo *et al.*, 1985). The basic set of the system includes submodels on energy emissions, on the long-range transportation of air pollutants, and on ecological impacts. Using these models an analyst can select an energy pathway for European countries, compute the respective sulfur emissions, assess the transport and deposition of these emissions, and obtain a graph to describe the ecological effect. The time step of the model is one year, the time span is roughly 50 years, the spatial grid is 60 × 100 km, and the geographical coverage is Europe excluding the eastern part of European USSR. The main objective in constructing the models has been to provide policy analysts with a tool for comparing different aspects of alternative emission reduction programs in the European region. Therefore, the models operate on an interactive basis.

A model of the acidification of forest soils has been developed and incorporated into the RAINS system (Kauppi *et al.*, 1986). Input for that submodel is received as the output of upstream submodels, that is, the energy emissions model and an application of the long-range transport model of the Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP) (for details, see Alcamo *et al.*, 1985). The output of the soil-acidification submodel is the time pattern of soil pH. The dose (stress) is defined as the annual contribution of acidity due to sulfur deposition in each grid square and in each year. The resistance of soils is defined in terms of the chemical capacity of different soil types to neutralize acids. A map on the location of soil types is used as an input file. The response is calculated on an annual basis, taking into account the acid stress each year and the efficiency of the soil to neutralize that acidity. Soil pH at any given time is obtained by deducting the annual changes from the initial conditions of each soil type. Rough estimates are obtained on forests at risk by defining and examining threshold values of the lowest soil pH permitted (*Figure 2.3*).

Sensitivity runs with the IIASA model demonstrate that a simple variable, base saturation of forest soils, is very important in the assessment of acidification. Intensive measurement programs would be needed to survey and monitor this variable. In spite of uncertainties, the model bounds regions where soil acidification due to sulfur deposition is of concern. Soil acidification due to industrial emissions is neither a local nor a global, but a regional phenomenon. Northern Scandinavia, for example, appears well protected. The main factor that bounds the affected area is the average lifetime of sulfur compounds in the atmosphere.

Sulfur is mainly deposited within 1000–2000 km from the emission source, outside which sulfur deposition cannot cause major acidification. Also, within this range there are protected areas due to the efficient buffering of certain soil types. Acidification and also the direct effects of sulfur and nitrogen emissions on vegetation can act during the rather short time scales of 10 to 30 years. An especially troublesome effect as regards the forest sector can be the impact of pollutants on old forest stands. There is a risk that this effect substantially increases sanitation fellings.

(a)

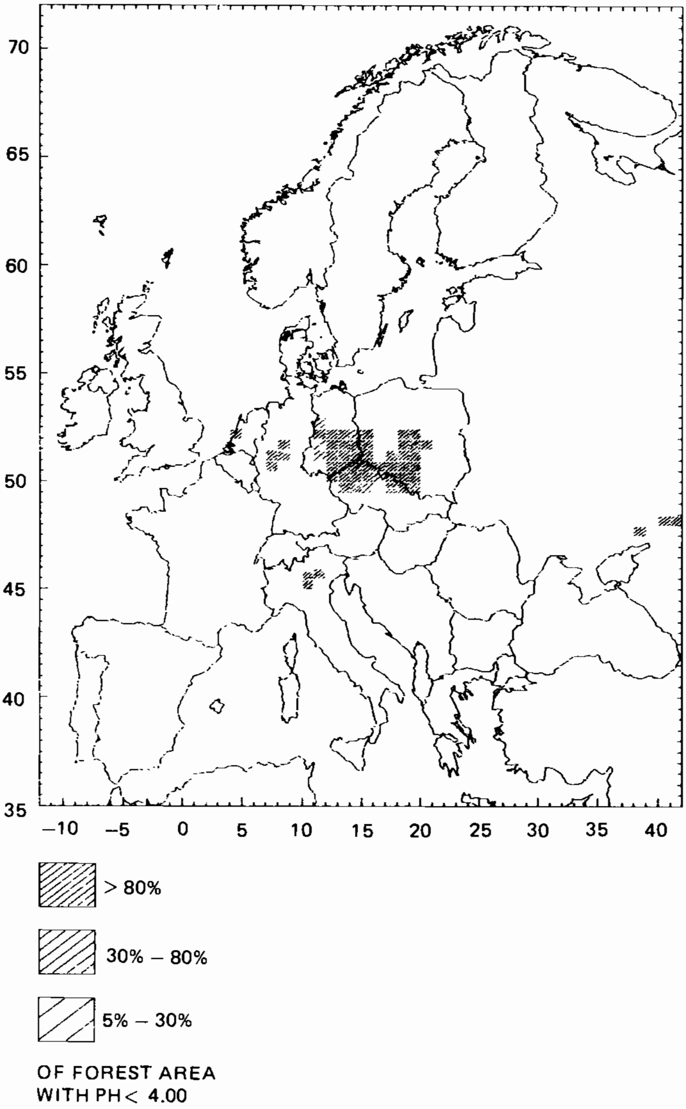

Figure 2.3 (a) The area of risk in 2010 (pH < 4.0), resulting from a low-emission scenario (from the IIASA Acid Rain Study, Alcamo *et al.*, 1985).

(*b*)

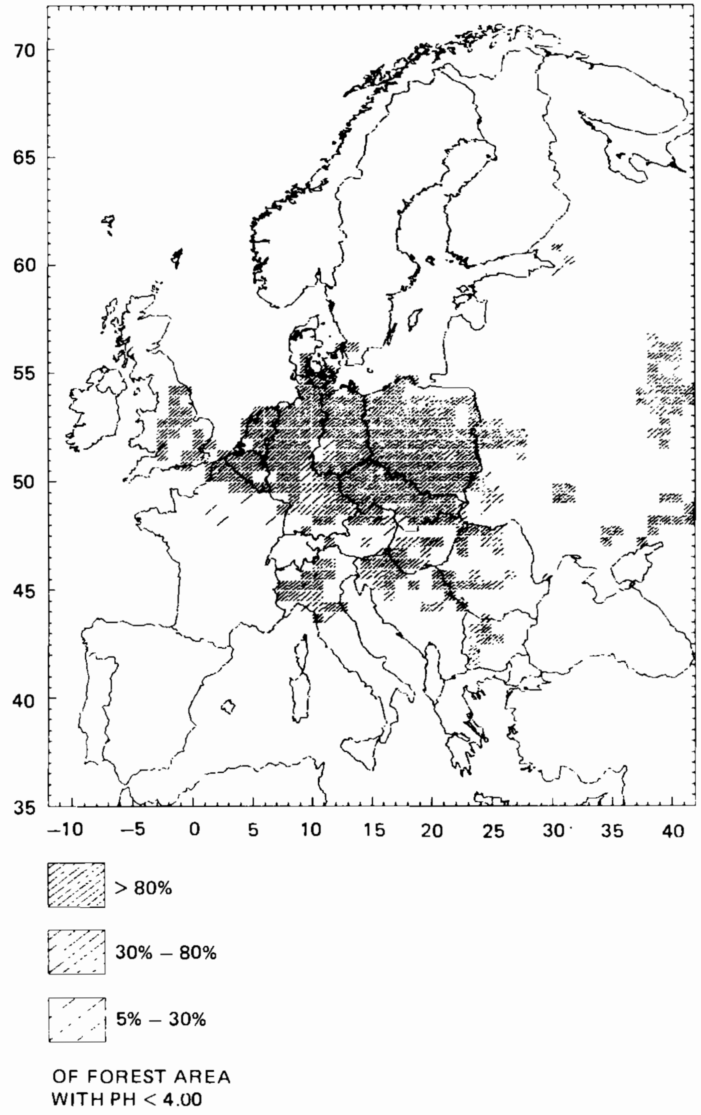

Figure 2.3 (b) The area of risk in 2010 (pH < 4.0), resulting from a high-emission scenario (from the IIASA Acid Rain Study, Alcamo *et al.*, 1985).

2.2. CO_2 Fertilization Effect

The term "CO_2 fertilization" originates from greenhouse horticulture where, quite frequently, CO_2 gas is injected into the air that surrounds the crops, since high levels of CO_2 enhance photosynthesis and yield development. There is at least one example of this practice in forestry: the Finnish Tree Breeding Foundation, a major seed producer to Finnish forest nurseries, applies CO_2 fertilization for birch seed production. Birch trees that are grown in elevated CO_2 concentrations for several growing seasons produce high seed yields. The trees also grow very fast and in this way reach a high capacity of seed production at an early stage. The application of CO_2 fertilization as a commercial practice indicates that the benefits from extra yield outweigh the costs of CO_2 injection.

A question has arisen as to whether the global increase of CO_2 in the free atmosphere would induce a CO_2 fertilization effect in natural ecosystems, including forests. This potential effect has often been called the direct effect of CO_2 on forests. The indirect effect refers to the potential climatic change associated with the increase in CO_2 levels.

From 315 p.p.m. in 1957, the average annual concentration of CO_2 in the atmosphere has increased to about 342 p.p.m. in 1984. The change has been documented with great accuracy at locations as far apart as Hawaii and the Antarctic (*Figure 2.4*). There is no doubt about the global character of this trend. The seasonal variability appears greatest in mid-latitudes, where emissions from energy production peak in winter at the time when ecosystems are dormant and do not absorb CO_2. Sea surface temperature also affects the seasonal CO_2 fluctuation.

Continuous measurements of ambient CO_2 were not available until 1957, but indirect estimates suggest that the concentration in the mid-nineteenth century was approximately 260–270 p.p.m. Analyses of air stored in glaciers and in polar ice indicate that at the end of the last glacial period, about 15 000 years ago, the atmospheric CO_2 concentration may have been as low as about 160 p.p.m. (Delmas *et al.*, 1980). There have thus been substantial changes in the atmospheric CO_2 concentration, for reasons that are largely unknown. The current rate of increase, however, is very high compared with that in prehistoric times.

2.2.1. Photosynthesis and growth

An increase in the CO_2 level in air generally accelerates photosynthesis in laboratory conditions (Koch, 1969). In other words, a high CO_2

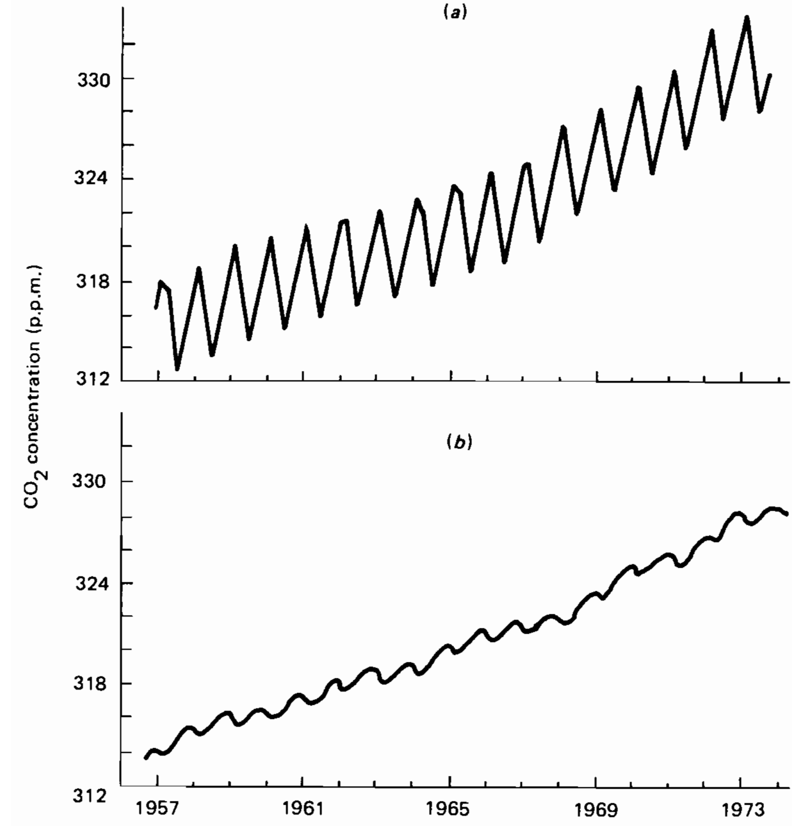

Figure 2.4 Atmospheric CO_2 concentrations (by volume, dry air) *(a)* at the Mauna Loa Observatory, Hawaii, and *(b)* at the South Pole. From measurements of Keeling and his co-workers, reproduced by Broecker *et al.* (1979). More recent data indicates that in 1984 the concentration was above 340 p.p.m.

concentration in the atmosphere provides plants with an increased flux of organic compounds to be allocated into respiratory processes and/or into the formation of plant biomass. Stomata are small openings on the leaf surface that control CO_2 uptake and plant transpiration. They are open when the plant is supplied with water and when photosynthesis is active, thus requiring CO_2 as substrate. As a rule the stomata are open by day and closed by night and have the important role of conserving water.

Based on our understanding of the functional principles of stomata, it is believed that the water-use efficiency of plants increases with increasing atmospheric CO_2 concentration. This concept is defined as milligrams of CO_2 fixed per gram of water transpired. First, owing to efficient diffusion, stomata could provide photosynthesis with an increasing flux of CO_2. Second, if photosynthesis is incapable of processing CO_2, stomata could conserve water by stomata aperture and yet fulfill the demand for CO_2 because of the high diffusion gradient. An increase in water-use efficiency with increasing CO_2 concentrations has been observed empirically (e.g., Rogers *et al.*, 1983).

Enhancement of photosynthesis has been observed on Ponderosa pine (Green and Wright, 1977) and on sweetgum (Rogers *et al.*, 1983). It is still uncertain whether this enhancement is a temporary phenomenon, since the link is tenuous between photosynthesis and growth. From a comprehensive review by Kramer (1981) it appears that many uncertainties exist, even at the plant level (tree level). All of the chemical energy bound in photosynthesis is not converted into structural biomass, but a large fraction of photosynthates are consumed in respiration (*cf.* Ågren *et al.*, 1980). Since the ratio of growth to respiration varies, there may not be a linear relationship between photosynthesis and growth. An increase in photosynthesis is a prerequisite for growth stimulation, but it does not automatically yield such a stimulation in all conditions. Physiological research has qualitatively identified the mechanisms of photosynthesis that may contribute to a CO_2 stimulation of growth. Other research disciplines are needed to quantify empirically such possible effects at stand and regional level.

Some doubt still exists as to whether the greenhouse and laboratory results are valid in natural ecosystems. In experimental or in greenhouse conditions wind is almost excluded. Goudrian and Ajtay (1979) point out that this may create a strong gradient of declining CO_2 from free air to leaf surface and to plant chloroplast. They argue that although photosynthesis responds to high CO_2 levels in laboratories and in greenhouses, the same response might be insignificant in field conditions. Wind turbulence mixes the air in the field and already assures that the leaf surface concentrations are high enough to maintain a more or less maximum photosynthesis in ambient concentrations as low as 300 p.p.m. This suggests that no essential growth stimulation would appear in natural ecosystems. The hypotheses could be tested by arranging turbulent air flows in greenhouses, but it appears that no such tests have been conducted.

A frequent argument that suggests negligible CO_2 effects on natural ecosystems refers to the "law of the limiting factors". Essentially, this maintains that plant growth is limited by one factor at a time. If this factor is, for example, water deficit then adding CO_2 is ineffective, but this is an oversimplification, as Verduin (1952) has pointed out. In fact, the reverse has been observed for wheat under drought conditions. The more severe the drought, the higher yields in high CO_2 conditions versus those in low CO_2 conditions (Gifford, 1979; Sionit *et al.*, 1980).

Doubling the CO_2 concentrations has increased the growth of tree seedlings by a factor of 1.2–2.0 (Hårdh, 1966, for Norway spruce and White spruce; and Tinus, 1972, for Ponderosa and Mountain Table pine). Tolley and Strain (1984) have reported a corresponding increase by a factor of 1.2 to 1.6 for sweetgum, although no effect for loblolly pine. These observations refer to well-watered and otherwise more or less optimal growing conditions.

There is considerable variation in experimental results on the effects of high CO_2 concentrations on plant productivity. Nonetheless, many results lend support to the view of Pearcy and Björkman (1985), who point out that the "law of the limiting factors" is sometimes misinterpreted by focusing on the absolute rather than on the relative growth effects. While CO_2 stimulation may be small in suboptimal conditions in absolute terms, it may indeed be great in relative terms. This view would have an important bearing, in particular, with respect to forests that grow in suboptimal conditions. Forestry, unlike agriculture, can operate also in conditions of low productivity because trees accumulate the wood product. If the productivity is low, one must apply long harvesting cycles, but there will, however, be sufficient amounts of yield for an economic harvest. A change of productivity, therefore, is equally important in conditions of both low and high productivity.

Field observations are necessary to examine whether long-term feedback mechanisms or the wind effect mentioned by Goudrian and Ajtay (1979) would obscure the CO_2 growth stimulation observed in laboratories and in greenhouses. Hari *et al.* (1984) conducted tree-ring investigations in low-altitude stands of Scots pine in southern Finland and provided results that are perhaps the first documentation of a possible CO_2 growth stimulation in natural ecosystems. A similar trend was also discovered using tree-ring data from two different pine species growing on high-altitude sites in the Western US (LaMarche *et al.*, 1984). Both studies report a substantial growth stimulation. A hypothesis can be formulated that a marked global CO_2 stimulation of growth has already taken place. New studies of a similar type are urgently needed from other parts of the world and from a large variety of sites.

Growth stimulation due to increasing CO_2 concentration in the atmosphere may well be a real phenomenon today. It could cover much larger forest regions than those now threatened in Europe by acid deposition and other air pollutants. CO_2 in the free atmosphere is evenly distributed in all parts of the world. Forests should theoretically differ in their responsivenes to this effect in such a way that the growth would be especially stimulated in forests that grow in arid regions. Subtropical forests could be especially responsive.

Although the effect may already exist today in large forest regions, it may have a minor impact on the global forest sector, at least in the short term. CO_2 growth stimulation might theoretically increase the sustainable harvest. There are, however, very few regions in the world where the maximum sustainable harvest directly governs the actual harvest. Forest management has several methods of increasing the sustainable harvest if so desired. These are seldom applied because the social and economic realities in most forest regions prevent it. Increasing the potential forest growth by even as much as 50% would have insignificant effects on the forest sector in many parts of the world.

CO_2 growth stimulation, unlike the European forest damage, would not have a special effect on old forest stands. It would hardly affect sanitation fellings. Whatever effect there will be, the forest sector will most likely have ample time to adapt to this change.

2.3. Possible Climatic Warming: Forest Response

Arrhenius (1896) was one of the first scientists to bring attention to the "CO_2 greenhouse effect". He computed estimates of the magnitude of the possible climatic warming on the Earth's surface, assuming that the atmospheric CO_2 concentration would increase by 100%. The physics of the "greenhouse phenomenon" are well understood. Short-wave irradiation from the Sun penetrates the atmospheric layers of CO_2 and other trace gases, but long-wave irradiation from the Earth's surface into outer space is held back. The understanding of the physics of the atmosphere has considerably improved since the time of Arrhenius and the general circulation models that are used today to quantify the "greenhouse effect" are relatively large, sophisticated ones.

A report of the US National Academy of Sciences, published in 1983, estimated that, largely depending on the future energy scenarios, the atmospheric CO_2 concentration would probably rise to 550–600 p.p.m. between the years 2020 and 2070 (Carbon Dioxide Assessment Committee, 1983; see also Clark, 1982). The concentration in 1984 was approximately

342 p.p.m. The scientific community is almost unanimously convinced that such an increase in the CO_2 level, especially as the concentrations of other trace gases, such as nitrous oxide (N_2O), are expected to rise, would cause a climatic warming. Model calculations generally propose that the Earth's surface temperature would rise by 3 (±) 1.5 °C on average. Tropical regions would experience smaller increases, whereas the boreal biome is anticipated to experience increases that are substantially larger than average. In spite of the trend in the atmospheric concentration of CO_2, a climatic warming has not yet been instrumentally recorded, because climatic fluctuations obscure the possible effects. Rainfall is also expected to change, but as this is a complicated phenomenon, mean values and spatial distribution of the change have not yet been reported generally.

A temperature increase of such a large magnitude would have very large effects, especially on boreal forests. Emanuel *et al.* (1985) have remapped world vegetation zones assuming model results for the temperature effect of CO_2 concentration increases. The present relationships were assumed between climatic variables and the large-scale biogeograpical zones (wet tropical forests, subtropical forests, temperate forests, wet and dry boreal forests, etc.). The results indicated that if the temperature increases, then large areas of boreal forests in Canada, Finland and Scandinavia, and the USSR would be replaced by temperate forests.

Precipitation, which is difficult to estimate with the current climatic models, is a comparatively insignificant ecological factor in the boreal regions. The uncertainty in estimation of precipitation is, therefore, not so crucial. The boreal coniferous forests are a particularly interesting area within the forest sector because the timber resources are of high quality and are being widely utilized for export in the world market.

Kauppi and Posch (1987) have estimated possible shifts in the productivity of the boreal forests assuming a climatic warming. Their calculation assumed temperature estimates using CO_2 concentrations expected by the mid-twenty-first century. A simple empirical regression was taken from Finland to relate forest productivity to temperature conditions (i.e., "effective temperature sum").

The results of the calculation indicated that the potential productivity would increase by as much as 100 to 300% over large regions of the boreal zone (*Figure 2.5*). These dramatic results, however, do not refer to the conditions of 50 to 70 years in the future. By that time the CO_2 concentrations may well rise to levels as high as 500 to 600 p.p.m. There will be a considerable time lag, however, in the subsequent temperature response, mainly due to the capacity of oceans to store thermal energy. An even more substantial time lag can be expected in the biological response. A typical lifetime of a tree is of the order of 100 years and the reproduction

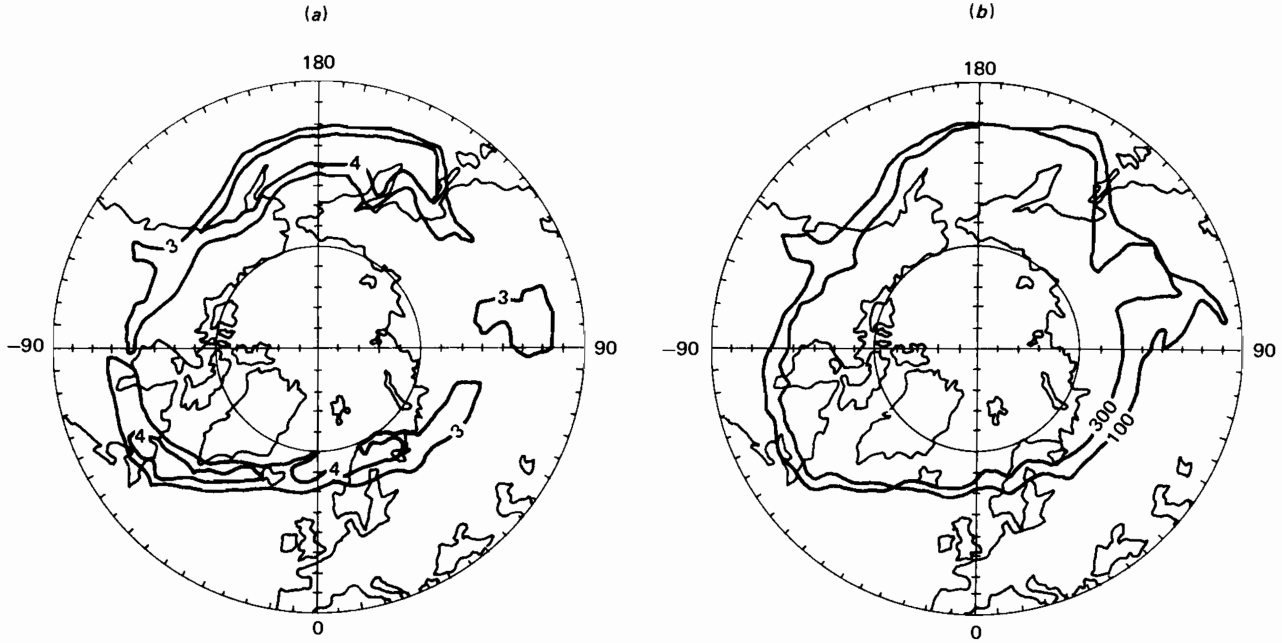

Figure 2.5 A scenario of the forestry effects of a possible climatic warning. Estimated increase in the potential productivity of the boreal forests from the baseline level of today to CO_2 conditions that are anticipated to prevail in the mid twenty-first century *(a)* in absolute units (m^3/ha/yr) and *(b)* in percentage terms (%). Note that time lags in the climatic and biological systems would, in effect, essentially postpone these kinds of forest response.

cycle in field conditions is more than 30 years. The calculation in *Figure 2.5* can be relevant to steady-state conditions very far into the future, but not to actual conditions in the twenty-first century.

A troublesome period of adaptation could be anticipated during the intermediate period of time when the climate has perhaps already changed, but the genetic properties of forests have not yet responded. The productivity of the boreal forests would, perhaps, increase in the long run, but during the time of adaptation old genetic strains would retard. This bears a risk of forest damage. Moreover, consequences of a possible climatic warming on the hot and dry margins of the mid-latitudes may more than counterbalance the possible gain anticipated in the cold forest margins. Deforestation in the tropical region often proceeds through local, unfavorable climatic changes, which should be kept in mind when constructing optimistic scenarios of a possible climatic change.

CO_2 and other trace gases that are being emitted into the atmosphere today are possibly inducing a substantial change in the global climate. Such a climatic change would particularly affect the forests that grow in the climatological margins. One possible area of a substantial change in forest vegetation is the boreal region. However, a change of the global climate is a matter for the very remote future. The time lags involved in the climatic system and the biological system will most likely prevent any major impacts in the short term.

2.4. Conclusions

A crucial factor that affects the spatial scale of the impact of pollutants is the residence time of the pollutant in the atmosphere. For CO_2 this is long enough to generate an almost even distribution of emissions in all parts of the world. The CO_2 fertilization effect and climatic effects are, therefore, global phenomena. SO_2 remains in the atmosphere for 10 to 50 hours, during which time it ascends to 2000 km in the atmosphere. The European emissions of sulfur, for example, should not induce forest damage beyond this spatial scale.

The residence time also affects the temporal variability of the compound. Compounds with relatively short residence times, such as NO_x or SO_2, occur in the atmosphere in varying concentrations. Large air masses in very remote areas are practically unaffected. Clean episodes also occur near to industrialized regions after effective scavenging by rain or, eventually, if the emissions are low. CO_2, in contrast, with a long residence time, occurs in the atmosphere in relatively stable concentrations.

The sinks of CO_2, seawater, and land biota are incapable of absorbing CO_2 at the rate that the gas is provided by the sources, energy combustion, and deforestation. Hence, CO_2 accumulates in the atmosphere. Compounds with shorter residence times do not accumulate in the atmosphere, but quite often do so in soils or in underwater sediments.

Impacts on forests of either high episodic concentrations or of the accumulated storage of emissions vary in time and in space depending on the properties of the compound and on those of the forest. Arid forests, for example, are potentially most responsive to CO_2 fertilization. Boreal forests, which grow in humid regions and are rather insensitive to the variability in precipitation, are anticipated to respond strongly to a temperature change. Mountain forests are perhaps most susceptible to the damage due to acid precipitation. In this way it is already possible to specify vulnerable forest regions where substantial changes — such as a high concentration or a possible large increase in temperature — meet with responsive reactions.

In principle, the impact of emissions on forests can, in some cases, be considered positive, especially if just the growth effect is taken into account. Adopting an optimistic view of these environmental changes, however, is quite a gamble. Ecosystems, as well as the enonomic and social structures that rely on them, are complicated. Any assessment of a possible ecological change focuses on only a few variables. What seems to be a positive change may turn out to be quite negative, especially if the new conditions fall outside the range of historical events to which all existing structures have been adapted. The consequences of such changes, which fall outside the range to which the forests have been adapted, are extremely difficult to assess.

Both similarities and differences are observed between the three issues discussed in this section as they are examined from the perspective of the forest sector. It seems possible to locate specific forest regions where one, but not all, of the issues are important. Moreover, all three issues are relevant in quite different time scales.

The issue of forest damage is being observed and anticipated, especially in continental Europe, which is a small but important area within the global forest sector. Forest damage bears the risk of rather short-term consequences because it affects not only the growth rate of the trees, but also their vitality and, consequently, the average volume of roundwood that can remain standing in the affected forests. Old trees are especially susceptible to pollutants and sanitation fellings may need to be directed at old stands. As these stands contain large amounts of timber, there is a risk of a short-term pulse of timber into the market, with subsequent adverse economic effects. "Short term" in the context of forestry would be a time span of 5–20 years. Short-term pulses, whether of high or low timber supply, are potentially troublesome as the industrial utilities and the related infrastructure have little time to adapt.

The CO_2 fertilization effect may have impacts on much larger regions than the area subjected to the European forest decline. Impacts are anticipated, especially in forests that grow in arid regions and perhaps especially in subtropical forests. Direct evidence has not been sought very effectively, but it is possible that the CO_2 fertilization effect already exists. These immediate effects, however, would be quite different from those of the European forest decline. Forests would be subject to growth enhancement rather than tree damage. Also, the possible impact to the forest sector would be very different. As there are negligible risks that old stands will lose their vigor, there is no need for a short-term adjustment of the standing volume. Infrastructures would have ample time to adapt to the new levels of productivity and to the possible shifts in species composition.

The greenhouse effect would also involve large forest regions, since the global climate, in essence, is one complicated system. Temperature and precipitation, if they change, will change in all parts of the world. Forests that grow in areas of arid climate would be susceptible, in particular, to a possible decrease in precipitation. In the boreal region over a very long time span forestry would benefit from a temperature increase as the productivity of these forests would increase. However, such scenarios are only relevant over extremely long time horizons of perhaps 500–2000 years. Within the next 50 years it is hardly realistic to anticipate any large forestry effects due to a change in the global climate. Fossil fuel combustion will possibly seed such effects within this period of time, but the actual effects are delayed because of the time lag of both the climatic and the ecological systems.

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CHAPTER 3

Deforestation Perspectives for the Tropics: A Provisional Theory with Pilot Applications

M. Palo

Major changes in forest areas in the past have been caused by changes in climate, by human actions, and by combinations of the two. The sensitivity of the value of forest goods and services to changes in forests varies a great deal according to the scale, the intensity, and the type of these changes, which may be anything from a slight selective logging of undisturbed natural forests to a total clearance of trees and a subsequent transformation of the previous forest site into nonforest uses. In the debate so far, such changes have been termed deforestation or conversion, depletion, destruction, etc.

In English-language usages in various parts of the world, the word *forest* may be a synonym for a number of other expressions, such as bush, woodland, wood, woods, brushwood, thicket, scrub forest, shrub, etc. Even the term forest as used in forestry applications has no universally adopted single definition. The terminology published by the Society of American Foresters, which is also authorized by the Joint FAO/IUFRO Committee on Forestry Bibliography and Terminology (Ford-Robertson, 1971), gives, e.g., the following four definitions for the word forest:

(1) "Generally, an ecosystem characterized by more or less dense and extensive tree cover" (ecology).
(2) "More particularly, a plant community predominantly of trees and other woody vegetation, growing more or less closely together" (ecology).

(3) "An area managed for the production of timber and other forest produce, or maintained under woody vegetation for such indirect benefits as protection of catchment areas or recreation" (silviculture/management).

(4) "An area of land proclaimed to be forest under a Forest Act or Ordinance" (law/British Commonwealth).

If an analyst was to select one of these forest definitions and begin to plan the collection of information from a total area in a country that matches this definition, he or she would run into difficulties due to the lack of operational dimensions of these definitions.

Forests are often viewed as forest systems that fit different statistical planning situations. Basically, they comprise varying kinds of complex ecosystems. In different planning situations, different sets of components and relationships of a forest system are considered as relevant for observation.

The trees are the dominating component in a forest ecosystem. The appearance of trees varies from dense high forests to scrub and open lands according to increasing aridity, elevation, and latitude, but also to increasing humidity (bogs, peatlands). The system boundaries have to be demarcated still more precisely in this respect. Such indicators as the height of trees, their density, and minimum area are applied (e.g., Loetsch and Haller, 1964; Loetsch *et al.*, 1973; Persson, 1974, 1977b; Lanly, 1982). The average height of the trees in a forest during the climax (mature) stage is defined to be at least 5–8 m.

Forests are classified, according to the predominant tree species, as coniferous (gymnospermae in botanics, yielding softwood timber) or broadleaved (nonconiferous, angiospermae in botanics, yielding hardwood timber). Particularly in the case of broadleaved forests a further division into closed forests and open woodlands is applied.

Open woodland is sometimes defined to have a tree density, measured in tree crown coverage of land surface, in the range of 5–20% (e.g., Persson, 1974). According to another definition, open woodlands are mixed, broadleaved tree and gramineous formations with a continuous dense grass layer in which the tree synusia cover more than 10% of the land surface (e.g., Lanly, 1982; FAO and UNEP, 1981a–c). Forests are sometimes defined as closed when the crown coverage of trees exceeds 20% (e.g., Persson, 1974). Closed, broadleaved forests are also defined to cover, with various tree crown storeys and undergrowth, a high proportion of the ground and not to have a continuous dense grass layer that allows grazing and the spreading of fires (e.g., Lanly, 1982; FAO and UNEP, 1981a–c).

The minimum area limit for a forest is defined as approximately 5–10 hectares. This limit is needed to separate "real" large forests from islands of woodlands or scattered groups of trees. This is a technical criterion partly due to observation problems and partly to the fact that smaller patches of forests do not easily fit any commercial forestry. However, for community forestry or for ecological purposes even the small areas of forests can be identified as forests in so far as the other criteria discussed are fulfilled.

This aspect of forest dynamics also implies an important time element in the forest concept: a cut area, even bare land, is classified as forest insofar as it is likely that natural reforestation and succession toward the natural dynamic equilibrium state of forest will take place.

The classification of forests in the tropical zone is more difficult than elsewhere due to the high complexity and variety of tropical forests. A great number of classification systems are adopted by various national and international authorities (e.g., Lanly, 1982, pp 8–18). The situation makes consistent and precise assessments of tropical forest areas difficult. In a recent assessment by FAO and UNEP (1981a–c) a UNESCO classification system (*Figure 3.1*) was adopted in order to fit together forest area data from the various national and other classifications.

Deforestation, as referred to in this chapter, transforms a previous forest area out of the adopted forest classification (*Figure 3.1*) when the area no longer fulfills the listed criteria for a forest ecosystem. Accordingly, deforestation is used in this chapter in the strict sense of a complete clearance of forests and their replacement by other use of the land (Lanly, 1982, p 74). Deforestation of tropical forests often has an irreversible nature (e.g., Eyre, 1975; UNESCO *et al.*, 1978). Various degrees of *forest degradation*, however, often occur as a consequence of selective logging and other human actions or of natural factors (e.g., storms, lightning). A degraded forest area is assumed to recover from the disturbance within a reasonable period, but under a continuous stress degradation may ultimately cause deforestation.

Some deforestation seems unavoidable in view of the fast-growing human population, with its food, energy, shelter, and space requirements, while some deforestation remains avoidable provided that its locations, paces, and mechanisms are known and that adequate political will and administrative capability exist. It is assumed in this chapter that a considerable amount of future deforestation will, in the long term, cause more social opportunity costs through erosion, decreasing supply of wood, extinction of species, deteriorating landscapes, and other disbenefits than it will bring social benefits from the, often temporal, uses of deforested sites.

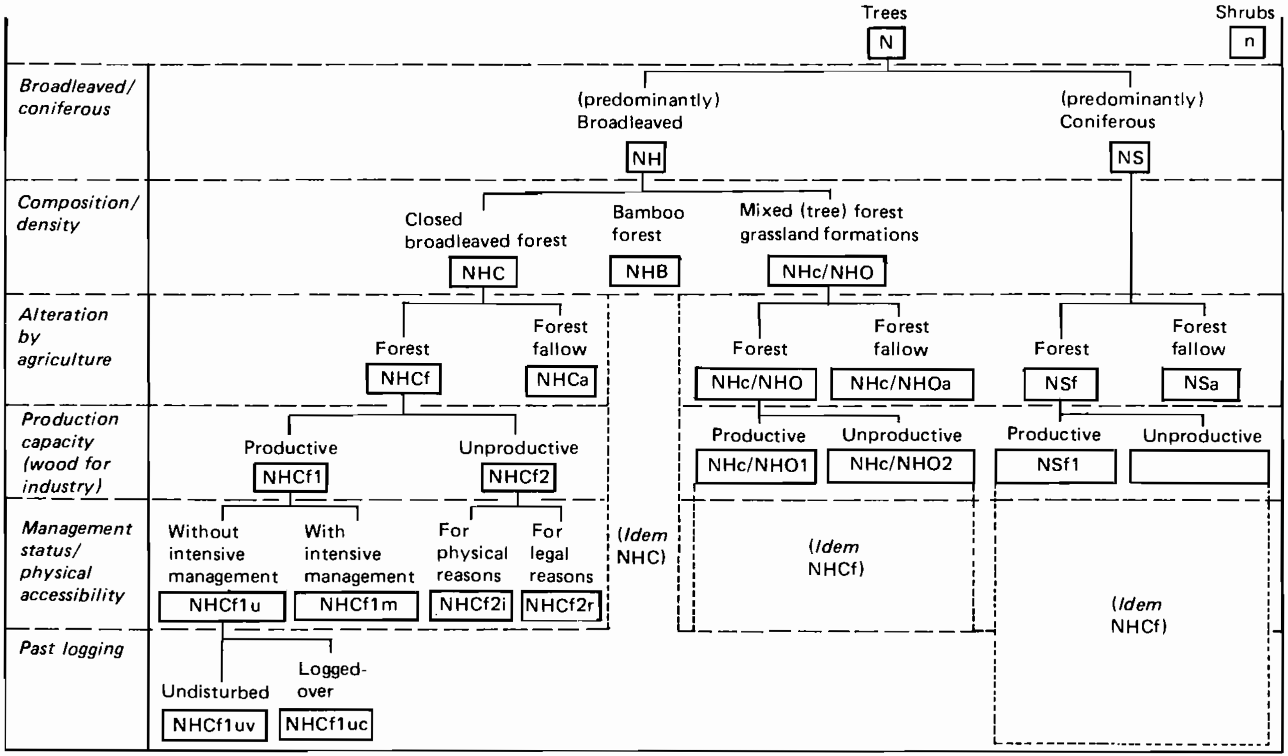

Figure 3.1 A UNESCO classification of natural forests in the tropics (applied by FAO and UNEP, 1981a–c, and by Lanly, 1982, p 11).

Deforestation is presently advancing fastest in the developing tropical countries. It has been a real threat to today's developed countries when under similar conditions, but under an industrial economy it has become stabilized, although a new threat has recently appeared in the form of air pollution and other related factors. Consequently, the focus of this chapter is primarily on the tropics.

The purpose of the chapter is, first, to review the quality of the existing deforestation statistics, especially in the tropics, second, to introduce a specific provisional theory of tropical deforestation, and, third, to present briefly the potential of the theory for empirical calculations. The establishment of future forest plantations, the potential role of future natural forestation, and empirical testing of the provisional theory are outside the scope of this chapter.

3.1. Quality of Deforestation Statistics

According to the last available estimate the closed and open forests in the tropics (76 countries) consisted of 1935 $\times$ 10^6 ha in 1980. From 1981 to 1985 an area of 11 $\times$ 10^6 ha was estimated to be deforested annually, of which 5 $\times$ 10^6 ha were lost mainly to shifting cultivation and 6 $\times$ 10^6 ha to conversion of tropical forests into other uses, such as more-or-less permanent fields and pastures, plantations, scrubs, impediments, deserts, various infrastructure uses, etc. (FAO and UNEP, 1981a–c).

The various assessments on tropical deforestation have generally differed widely in their results, due to different concepts and classifications of forests and definitions of deforestation. The principal inaccuracies, however, can be mainly attributed to shortcomings in the primary data used.

Objective, high-quality observation of tropical forest resources and their deforestation is scientifically problematic and, in practice, requires highly competent staff, funds, and other resources, and is a time-consuming undertaking (e.g., Lanly, 1973; Palo, 1978, 1983). The various existing estimates on tropical deforestation differ from each other considerably, as shown in *Table 3.1*.

FAO and UNEP agreed in 1973 to establish a joint program to monitor tropical deforestation. The project-formulation document proposed that such a monitoring system should be based mainly on satellite and SLAR (side-looking airborn radar) data (Grainger, 1984, p 46). In a pilot project to monitor tropical forest cover (Baltaxe, 1980) special attention was devoted to develop a sequential observation process based on remote sensing, along with adequate ground checks. The latest global assessment project (FAO and UNEP, 1981a–c; Lanly, 1982), however, could not produce such primary observations at two subsequent dates. Instead, only

Table 3.1 Comparison of existing estimates for tropical deforestation (10^6 ha per annum).[a]

	(FAO) Sommer, 1976	*(FAO) Persson, 1977b*	*(FAO) Lanly and Clement, 1979*	*FAO and UNEP, 1981a–c; Lanly, 1982*	*Barney, 1980; Myers, 1980*
Closed forests	11	7.5–18	6.8	7.5	18–20
Open forests	n.a.	5–10	3.1	3.8	n.a.
Total forests	n.a.	12.5–28	9.8	11.3	n.a.

[a] n.a. = not available.

secondary, derived, subjective approximations on deforestation were applied. Applying such an "observing process" enables only inadequate precision of deforestation data. This conclusion is based on elementary principles of forest inventory sampling (e.g., Loetsch and Haller, 1964; Loetsch *et al.*, 1973; Lanly, 1973, 1974). Grainger (1984, p 20) arrived at a similar conclusion: "Current estimates of the global rate of deforestation in the humid tropics are of doubtful accuracy."

Under the dynamic conditions encountered in the tropical forests recently and at present there is no accurate way: (1) to derive deforestation data from primary observations of forest areas, (2) to make *ex-post* forecasts (updating) to the end of 1980, and (3) to make *ex-ante* forecasts (predicting) up to the end of 1985 (as in FAO and UNEP, 1981a–c) without scientifically based mathematical models to explain and forecast the complex phenomenon of deforestation. Without such models only subjective, mechanistic "trends" can be approximated. Construction of such models requires assembling a relevant theoretical basis, as was attempted by Palo (1984) and as reviewed in the next section. Consequently, forest areas at a certain point of time have been estimated more precisely than deforestation areas during a period (between two subsequent points of time).

The inventory statistics concerning the forests of the industrialized countries are of considerably better quality and coverage in comparison with the developing countries. However, they also carry, to some extent, the same major shortcomings as outlined above. There exists no continuous, international monitoring system for follow-up of deforestation or increase in forest area.

3.2. Theoretical Frame of Tropical Deforestation

Considerably more effort has been given to assessment of tropical deforestation than to theoretical explanation of the phenomenon. Marsh (1874), Jacks and Whyte (1939), Pinchot (1947), Rostlund (1956), Eyre (1975), UNESCO *et al.* (1978), Baltaxe (1980), Myers (1980), Thirgood (1981), Lugo *et al.* (1981), FAO and UNEP (1981a–c), Lanly (1982), Hallsworth (1982), and other authors give a number of explanations as to why deforestation in different tropical countries and regions is progressing. No systematic global theory of tropical deforestation has been found, although the phenomenon itself seems to be so complex that without a relevant theory the understanding and control of tropical deforestation will remain inadequate. Deforestation is a socioeconomic–environmental process that is, to a great extent, external to the traditional controls of markets and governments and, as a consequence, economics or political sciences as such cannot provide a sufficient theoretical basis.

Tropical forest inventories at the national and international levels have been based, explicitly or implicitly, on the theory of forest-based economic development (Westoby, 1962). The theory explains how the forest industries, when based on domestic commercial logging, lead to socioeconomic development through their backward and forward linkages. Recently, the relevance of the theory under developing-country conditions has been challenged (Westoby, 1978; Leslie, 1980; Douglas, 1983).

Only a few areas in the tropics have been identified for which a positive, general socioeconomic development can be explained by forest-based economic development. Instead, the serious consequences of uncontrolled logging, followed by shifting cultivation, and of other uncontrolled use and clearance of forests frequently occur in the tropics. Deforestation and the consequent erosion jointly initiate a kind of *antidevelopment* process hardly touched on in the numerous publications on economic development. On the other hand, it has been argued that due to many ecological constraints (e.g., climate, poor and erosion-sensitive soils, and animal and human health hazards) the development threshold is higher for tropical countries than for the temperate-zone countries when they entered the industrial stage (Kamarck, 1976). The tropics or tropical countries referred to in this chapter lie in the zone between the tropics of Cancer and Capricorn, on both sides of the Equator.

The aims of the provisional theory of tropical deforestation, as tentatively formulated by Palo (1984), are to explain this phenomenon and to guide future observation and forecasting, as well as to facilitate the effective control of tropical deforestation. The provisional theory of tropical deforestation is primarily based on the working experience of the author in four tropical countries (Palo, 1975, 1978, 1980, 1983; Palo and Olojede, 1982). It comprises the propositions described below.

Proposition 1

Deforestation in the tropics varies widely in space and time according to variations in socioeconomic and natural causal factors.

Proposition 2

Natural factors, such as changing climate, tornados, hurricanes, earthquakes, volcanos, lightning, and erosion, do not alone initiate a large-scale deforestation within ***the time horizon of a human life.***

Although most of the causes for deforestation are man-made (e.g., Rostlund, 1956, p 639; Lugo *et al.*, 1981), the climatic changes have, through the ages, had pronounced effects on the scale and distribution of tropical forests. Current knowledge about paleoclimatology and the history of tropical climates in terms of deforestation is still small, but the instability of tropical forests against changes in climate over the ***long term*** has been adequately demonstrated. A decrease in the amount or regularity of precipitation under unchanged temperature and wind conditions can cause deforestation in arid and semiarid zones either by itself, if the effects are strong enough, or, more common, in combination with grazing, fuelwood gathering, or shifting cultivation. Climatic changes take place gradually during long periods of time, while the observation of their effects on tropical forests is problematic (UNESCO *et al.*, 1978, Ch 3).

The processes of desertification and desertization around the Sahara desert have been widely discussed recently. Statistical analysis of the existing historical data on climate has shown no systematic change, but only sequences of "dry" and "rainy" years. However, successive droughts have occurred in all epochs and cannot alone explain the accelerated desertization since World War II. Various human activities are considered to be the more basic causes of Saharan desertization (FAO, 1976).

Differences in the climates have undoubtedly greatly influenced the onset and spread of erosion, but climate is never (or only very seldom) the single cause of erosion (Jacks and Whyte, 1939, p 27). In erosion soil particles are carried away by the kinetic energy of water (rain, streamflow) and/or wind, which causes erosion only during dry periods. Erosivity refers to the effects of these two factors. The kinetic energy of tropical rains can be especially high, due to the high total annual precipitation in the humid tropics and to heavy, one-time rainfalls.

Erodability defines the resistance of soil against erosivity. Erodability is determined by the type of forest and other vegetation cover, by soil properties, and by the angle and length of slope (topography). Erodability indicates the inherent vulnerability of ecosystems to erosion. Sensitivity to the loss of soil by erosion at a particular site has been defined as erosivity × erodability.

The forest and other vegetation cover of the soil dominates all other factors in the control of erosion. Under forest cover erosion remains at a minimum level due to the protection of ground by (often multistoreys of) tree canopies. This is especially the case under high and intensive rainfall, the impact of which can be so strong as to eliminate the resistance of various soil types. Accordingly, the preservation of forest plays a key role in erosion control in the tropics (UNESCO *et al.*, 1978, Chs 2, 12).

Erosion plays a strategic role in tropical deforestation in two respects. First, without sensitivity to erosion a cleared site would often be naturally reforested, if left alone, with no further human action occurring. Second, due to the widespread sensitivity to erosion in the tropics, the most serious consequences of deforestation materialize through erosion. Even wide-scale deforestation in temperate-zone countries (e.g., Britain and Denmark) in the past have often caused only relatively small environmental problems in comparison with the tropics, due to the lower erosion sensitivity of the more temperate locations. The consequences of deforestation and erosion, however, have been most serious also in many subtropical regions (e.g., Thirgood, 1981).

Proposition 3

Deforestation is caused by man primarily in *accessible forest areas.* Steep slopes, flooding, heavy rains, rough terrain, swamps, diseases, and remoteness from the existing infrastructure prevent or decrease accessibility (e.g., Rostlund, 1956, pp 649–650; Kamarck, 1976). Accessibility measures the physical and physiological stress to be overcome in order to reach a particular forest site for tree clearance. Overcoming increasing inaccessibility consumes an increasing amount of labor, animal, machine and material inputs, time, and costs:

> The term "inaccessible" as used in the inventories has meaning only in the economy of modern industrial culture: the term implies the economic impossibility of exploiting certain forests for industrial purposes because of difficult terrain, great distance to markets, or lack of means of transportation. But these forests are not physically inaccessible to man. Aboriginal peoples — hunters, food gatherers, fisher folk, cultivators — have lived in and affected them for a very long time (Rostlund, 1956, p 650).

Historically, man has populated the various life zones in the order of their accessibility and suitability to support life. In the tropical world, the open woodlands were most accessible to primitive men, hence their wide deforestation and degradation. The moist, closed tropical forests supported, until recently, only sparse populations of hunter–gatherers with no appreciable deforestation. However, advancements in medicine and technology have improved man's ability to overcome inaccessibility, even that of moist, closed tropical forests. Still, inaccessibility, along with scarcity of forests, and often jointly with a growing sensitivity to erosion, has slowed the pace of deforestation.

Lugo *et al.* (1981, p 322) analyzed quantitatively the role of inaccessibility in the form of steep topography with a variation of forest coverage in 17 Caribbean island states. They found that the islands with steep topography had a larger share of forest coverage than the flat islands ($r = 0.77$). The relationship may refer also to the less desirable conditions for human habitation caused by the increasing moisture that accompanies elevation. Too-wet life zones are unfavorable to intensive agriculture.

Proposition 4

A number of forest-clearance and harvesting activities initiate deforestation either alone or jointly with natural factors, and also accelerate it jointly with natural factors. *The growth (growing needs) of the human population*, independently in the absence of economic development, and jointly with *poorly planned and uncontrolled economic development* (e.g., Leslie, 1980), are the driving forces behind these human activities. The role of these forces is accentuated in the tropics, along with a number of other factors, when compared with their role in the industrialized countries.

The negative relationship between forest coverage and population density has been recognized since the first systematic investigations of deforestation (e.g., Marsh, 1874):

> To sum up: the ancient human pressure on the forests of the world continues at the present time and in all probability will become more severe in the future. There are regional differences in the reasons for the pressure, but all have the same effect: the forests are losing ground, and it is generally the best and most accessible timberland that is being lost (Rostlund, 1956, p 633).

South and Southeast Asia were the objects of a study in which ten countries were analyzed to establish a correlation between the percentage of forest area (with respect to total land area) and the population density. The two essential variables appeared to be strongly negatively correlated by the rank of the countries (apparently no remarkable correlation was found between the original values of the variables): the higher the rank of population density, the lower the rank of forest coverage. The average growth of population in the ten countries was 2.7% in 1976–1977, in comparison with the world total of 1.9%. The whole region was projected to lose another 44×10^6 ha of natural, closed forest lands from 1975 to 2000 against a potential increase of 2×10^6 ha in forest plantations. Deforestation in the region was attributed to one or more of the following factors:

clearance for agriculture, shifting cultivation, increasing demand for fuelwood and other roundwood, considerable increase in livestock and grazing, and expansion of the urban, rural, industrial, communication, and transport systems (FAO, 1980b; Lanly and Clement, 1979).

The Philippines provides an illuminating case of population growth and deforestation. During the gathering and traditional shifting cultivation stages of development, until about the beginning of this century, no remarkable deforestation occurred. The population pressure did not exceed the carrying capacities of forest ecosystems. However, during the twentieth century major deforestation and forest degradation have taken place in the Philippines. The American colonization of the country brought in highly mechanized logging systems. The escalation of log exports also rapidly increased the scale of logging activities. After World War II the Government started to encourage the clearance of forests for agriculture. Strong demographic pressure (population growth for 1976–1977 was 3.3%) also expanded the shifting cultivation activities (*Figure 3.2*). These, along with a skewed land tenure, were reported as the major factors that have caused the high rate of deforestation and serious soil erosion (Palo, 1980).

Deforestation in the Wider Caribbean region was investigated by Lugo *et al.* (1981). The indigenous inhabitants of the islands had low population densities, did not practice intensive agriculture, and were living mainly on the coast. Consequently, they had only little impact on the forests. Large-scale human deforestation in the Caribbean islands began

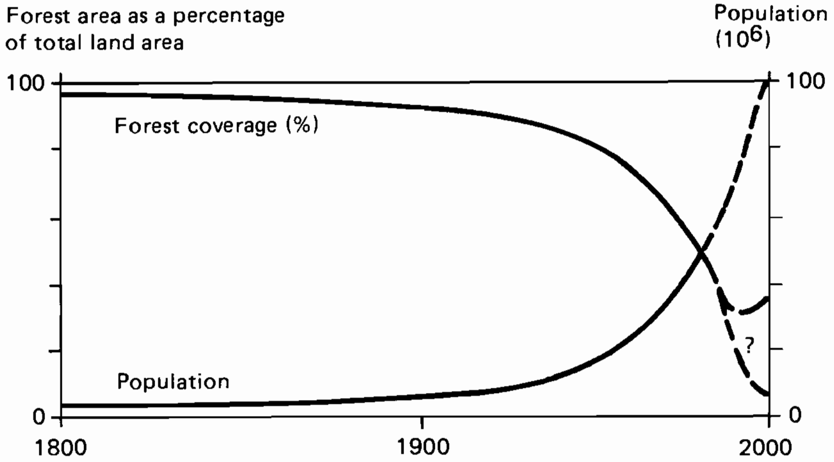

Figure 3.2 Scenario of forest coverage and human population changes in the Philippines, 1800–2000 (Palo, 1980).

Table 3.2 Forest coverage and population by region in the tropics in 1980

Subregion/ region	*Total area (including inland waters)* $(10^3\ \mathrm{km}^2)$	*Area of closed and open forests (excluding fallows)* $(10^3\ \mathrm{km}^2)$	*Forest coverage*[b] (%)
Central America and Mexico	2 472	669	27
CARICOM	254	202	79
Other Caribbean	445	265	59
Tropic South, Latin America	13 624	7 821	57
TROPICAL AMERICA	16 797	8 957	53
Northern Savanna Region	4 236	437	10
West Africa	2 121	557	26
Central Africa	5 328	3 359	63
East Africa and Madagascar	8 811	2 169	25
Tropical South Africa	1 399	510	36
TROPICAL AFRICA	21 895	7 031	32
South Asia	4 488	666	15
Continental Southeast Asia	1 192	476	40
Insular Southeast Asia	2 555	1 477	58
Centrally Planned Tropical Asia	752	364	48
Papua New Guinea	462	382	83
TROPICAL ASIA	9 449	3 365	36
Total 76 tropic countries	48 141	19 352	40

[a] Correlation coefficients, not given in Lanly, are −0.334 between forest coverage (col. 3) and total population density (col. 5) and −0.366 between forest coverage (col. 3) and agricultural population density (col. 7).

only after the establishment of European colonialism. For the 32 countries in the Wider Caribbean an inverse logarithmic relationship between population density and forest coverage was computed as $r = -0.79$.

The amounts and densities of total and agricultural populations, as well as the total land and forest areas and forest coverages in the tropics are given in *Table 3.2.* At the regional and subregional level of the tropics the population densities and forest coverages can neither be strongly correlated nor can any clear distinction between total and agricultural population densities in relation to forest coverages be established. However, Lanly (1982, p 35) concluded, as numerous authors previously, that primarily the agricultural population density was strongly related to forest regression and degradation.

The cases above have given some empirical evidence about the statistical relationship between population density and forest coverage. The (abbreviated from Lanly, 1982, p 34).[a]

Total population		*Agricultural population*	
Inhabitants (10^6)	*Density*[c] (inhabitants/ km^2)	*Inhabitants* (10^6)	*Density*[d] (inhabitants/ km^2)
93	37	37	15
4	17	1	3
22	50	10	22
203	15	73	5
322	19	120	7
30	7	25	6
114	54	65	31
48	9	35	7
150	17	116	13
2	1	1	1
344	16	242	11
895	200	580	129
83	70	54	46
217	85	119	47
65	86	46	61
3	7	3	5
1 263	134	803	85
1 929	40	1 165	24

[b] Area of closed and open forests (col. 2) divided by total area (col. 1) × 100.
[c] Inhabitants (col. 4) divided by total area (col. 1).
[d] Inhabitants (col. 6) divided by total area (col. 1).

causal mechanism, however, is indirect, as pointed out at the beginning of this discussion of *Proposition 4*, and is often conditional to other concomitant factors, as described in the later propositions. Westoby (1985) was extremely critical of the application of population pressure as a sole independent variable of deforestation.

Lanly (1982, p 74), among numerous other authors, has pointed out that the selected industrial logging of unmanaged closed forests does not cause deforestation as defined above. However, such logging and construction of access roads directly cause deforestation on steep slopes when the activities are poorly planned, poorly controlled (the usual case), and heavily mechanized. Logging plays a far more important role as an indirect agent, such as when logging improves accessibility to closed forests and facilitates the large-scale spontaneous clearance of forests for cultivation, shifting cultivation, and grazing. These spontaneous activities and spontaneous fuelwood gathering also occur on a large scale in open woodlands. Lanly (1982, pp 81–83) estimates the share of shifting cultivation in total deforestation to be around 35% in tropical America, 50% in tropical Asia, and 70% in tropical Africa.

The nature of the deforestation process is somewhat different in the humid closed forests compared with the open woodlands of the tropics. Industrial logging and water erosion are typical in the former areas, whereas grazing and fires, fuelwood gathering, wind erosion, or the combination of wind and water erosion, are typical activities in the latter. Shifting cultivation and clearance for cultivation or other uses frequently occur in both closed and open forests.

The intensity and role of the various human factors that cause deforestation vary regionally, according to indirect factors such as population pressure and economic development. The annual growth of the total human population was 2.63% from 1975 to 1980 in the tropical countries. The size of population in the tropical, moist forest countries will double in 27 years (Myers, 1980, p 30). The consequences of this increasing demographic pressure appear as subsequent increases in the demands for food, energy, infrastructure, fibers, housing, and other commodities.

The need for an accelerated economic development is natural under such conditions of high population pressure. Agriculture-based economic development leads to more clearance of forests for cultivation and pasture as well as to an increase in the number of livestock, along with more intentional and wild fires. Forest-based economic development creates more access roads and industrial logging. Other kinds of economic development activities often require more clearance of forests for roads, reservoirs, communication, housing, factories, and other urban activities.

However, such deforestation activities, which are based on a planned economic development, play a minor role in the tropics. Planned forest clearance for agriculture is most common in tropical American countries. However, inadequate planning and control of implementation frequently diminish the predictive value of such plans. The share of such planned clearance for agriculture is apparently lower in tropical Asia and lowest in tropical Africa.

Proposition 5

Public ownership of varying kinds (federal, state, provincial, communal, tribal) is predominant in the tropical natural forests (Persson, 1974; Lanly, 1982, pp 49–55), with the politicians (and senior forestry administrators) fixing the timber prices administratively, mostly with long-term concessions (Schmithüsen, 1977; Gray, 1983). The politicians and logging contractors are often either in a joint partnership of timber business or linked together by *corruption.* Under such circumstances the politicians tend to *fix low timber (stumpage) prices*, which facilitate high profits in logging or exports or in the processing of logs, the practice of which is beneficial for both parties. The phenomenon resembles the practice called the "soft state", which is typical for many developing nations:

> The soft state is characterized by social indiscipline that is manifested by deficiencies or willful neglect of rules and directives by public officials and civil servants, and the collusion of government officials and top civil servants with powerful individuals and groups whose conduct they are supposed to regulate (Gould and Amaro-Reyes, 1983, p 18).

Low timber prices cause ample wastage of timber in logging and processing and thus accelerate future logging. The monetary values of forest stands also become low. There is not much economic incentive to protect such low-valued forests against encroachments, or for the effective control of logging, or for sustained-yield forest management. Fixed, low, undifferentiated prices have no self-regulative function and give no incentives to transfer to "noncommercial" dimensions or to other tree species. The increasing scarcity of timber is not reflected in prices. The whole causal chain, starting from fixed prices, adds one more deforestation factor.

The recent role of corruption has been discussed, e.g., by Myrdal (1968, pp 937–958), by Dasgupta (1982, p 12), by Douglas (1983, p 142), and most comprehensively by Gould and Amaro-Reyes (1983). Albion (1926) and Pinchot (1947) described the powerful effects of corruption on deforestation in the history of the UK and US. In the reports by the various organizations of the UN the existence and causal effects of corruption cannot be studied or mentioned for political reasons.

Generally, it has been observed that the monopoly position of government and the confusing networks of regulations and institutions promote corruption in developing countries (Gould and Amaro-Reyes, 1983, p 19). Predominant public ownership of forests and unclear institutional aspects in the administration of forests (*Proposition 15* below) create similar conditions for tropical forests. Furthermore, "the concentration of power — political, economic, and bureaucratic — together with conditions of widespread poverty, occasionally provides fertile ground for corruption" (Gould and Amaro-Reyes, 1983, p 21). These are only some of the factors that support the assumption that corruption is widespread among the forest administrations of the tropical countries, where also nondemocratic governments dominate.

In general, it has been argued that corruption leads to economic inefficiency and waste, because of its effects on the allocation of funds, on production, and on consumption. Corruption, on the other hand, has been argued to generate conditions of violence, social unrest, and political instability. Furthermore, the effects of corruption are deemed cumulative and circular (Gould and Amaro-Reyes, 1983, pp 27–30).

Proposition 6

Although timber and some other goods and services harvested from public forests are priced, because of corruption and the lack of tradition and competent staff, as well as because of inadequate vehicles, instruments, and funds (e.g., McGaughey and Gregersen, 1983, p 171), *the public forest services are ineffective* in enforcing the required control of harvesting (e.g., McGaughey and Gregersen, 1983, pp 157–171; Palin, 1980). In such cases the unauthorized excess of quantities renders the price system inoperable. Furthermore, illegal logging frequently occurs under such circumstances. Also, a few timber buyers can exercise *monopsonistic power* to lower prices (e.g., McGaughey and Gregersen, 1983, p 53). The strengthening of forest administrations and other effective forest protection is thus hindered in tropical countries by widely practiced corruption.

Corruption generates administrative inefficiency and ineffectiveness in several ways. An atmosphere of distrust is created throughout all levels of public bureaucracies. Corruption also contributes to frustration on the part of otherwise professionally competent and honest civil servants. Under these circumstances senior administrators are discouraged from delegating authority, which is needed for successful implementation. Frequently, also, patronage and nepotism tend to fill the ranks of the civil service with inept and incompetent individuals (Gould and Amaro-Reyes, 1983, pp 28–33).

Proposition 7

Under the circumstances described in *Propositions 5 and 6*, timber, fuelwood, game, sites of forests (for clearance), and other forest-based commodities resemble *free goods*, as described in economics, in contrast of *scarce goods*. In the purchase of free goods no price needs to be paid. A household's total utility can always be increased by consuming more of any good that has a positive marginal utility. Hence, free goods will be consumed up to the point where their marginal utilities equal zero. However, the spatial character of forests always causes unavoidable harvesting costs for forest commodities.

Markets in general play a minor role in the distribution of forest commodities to consumers in tropical countries. Furthermore, markets are often ineffective because of widespread market failures, such as external effects (erosion, extinction of species, etc.), lack of competition, and lack of countervailing powers (labor unions, farmers' unions, cooperatives, protective legislation, etc.), in addition to fixed prices. Consequently, a number of economic problems are apparent in developing countries.

In general, the commonly pronounced existence of external costs in tropical forestry creates a conflict between expected net private and social benefits. If the expected net private benefits of a forest area in an alternative use (e.g., in agriculture) exceed the expected net private benefits of the same forest area in a continuous forestry use, the particular forest area will be deforested and converted into the more privately favorable alternative use, although the expected net social benefits would indicate maintaining this particular forest area in a forestry use. Ineffective public forest service and other public administration result in the spread of this phenomenon.

The tropical deforestation situation often resembles the more generally known *problem of the commons* (e.g., Barney, 1980, p 332; Sedjo and Clawson, 1984, p 133), which has been formalized and dealt with in more detail by environmental economists (e.g., Dasgupta, 1982, pp 13–40). A common property has the following features:

(1) Free access.
(2) In the absence of binding mutual agreements each agent who harvests a common resource ignores the cost imposed on the others.
(3) No individual agent has the incentive to acquire sufficient information about the ecological implications of his or her actions.
(4) No individual agent has the incentive to save the resource and, consequently, the agents harvest as fast as they can and as much as they can up to the point where their marginal costs equal their marginal revenue.
(5) The problem of the commons has two consequences: ultimately, the profits of the agents will disappear and the resource will be overused in terms of the maximization of expected net social benefits.
(6) As the resource stock becomes depleted, the unit cost of the harvest typically rises since the agents have to travel farther afield or obtain less harvest at every attempt, and thus today's harvest rates impose an intertemporal externality on the future.
(7) Also serious income-distribution consequences can occur.

Accordingly, the practices discussed in *Propositions 5* and *6* increase the harvesting and clearance of forests in excess of that produced by market pricing. The increasing scarcity of forest resources is not reflected in higher prices and the prevailing pricing system gives no automatic control of deforestation.

Proposition 8

Forestry comprises both economic and noneconomic forest-based production. *Forestry is the joint production* of wood, game, erosion protection, conservation of species, control of water and climate, recreation, and other commodities. Joint production occurs whenever the same production facility (forest) produces simultaneously two or more products. Wood, game, and other goods collected are *private goods*, which in principle can be priced and distributed to firms and households and which, after use, are no longer available in a similar condition for other users. On the other hand, erosion protection and other services of forestry are *collective "goods"*, the pricing of which is difficult, and which cannot be used by one individual to render the good unavailable to another individual. When harvests of private goods increase, the production of collective goods decreases according to the relevant production functions.

Proposition 9

Although the high number of forest-based goods and services is well documented, *the value of natural forests*, as providers of protection, conservation, and other services, or the value of sustained-yield multiple-use forestry is not appreciated by governments or the public at large (*cf. Proposition 5* above). Forests are generally viewed as a hindrance to economic development. The problem is partly related to a lack of scientific and practical knowledge on how to manage the mixed, moist tropical forest. The long-term consequences of the external disbenefits created by excessive deforestation are not adequately known (e.g., Poore, 1976; UNESCO *et al.*, 1978; McGaughey and Gregersen, 1983, p 170).

Proposition 10

When firms and individuals *maximize their profits or utilities* in the short run (instead of maximizing the expected net social benefits) by increasing the harvest of private forestry goods or by increasing forest clearance in order to expand the production of private agricultural goods (food and other crops), they simultaneously, due to the joint production principle, decrease the production of collective forestry goods and create *external costs* or adverse externalities. Firms and individuals as logging contractors, fuelwood gatherers, shifting cultivators, forest-clearance farmers, or herdsmen have no immediate incentive to prevent erosion or other external disbenefits by better planning and controlling of their activities.

A specific characteristic of forestry externalities, such as erosion and the extinction of species, is that they are *unidirectional.* Normally, a given agent (or a set of agents) imposes an externality on another (or others), whereas reciprocal externalities are generated in situations that involve the use of common property resources, where each agent imposes externalities on all the others. Unidirectional externalities are determined both by physical circumstances and by the assignment of property rights. Deforestation in one country frequently causes even transnational unidirectional externalities. Both of these problems are especially difficult to solve (e.g., Dasgupta, 1982, pp 31–37).

Proposition 11

In developing tropical countries a *short-term planning horizon* prevails due to unstable political, economic, and demographic conditions, as well as to the lack of a planning tradition. Also cultural traditions hinder long-term planning of the future (the East African case is described, e.g., by Harjula, 1975). In contrast, the consequences of erosion, extinction of species, and other external disbenefits created by deforestation become more serious only over the *long term.*

Proposition 12

Private ownership of natural forests occurs to a lesser extent in the tropics, especially in certain Latin American countries for the more highly valued Araucaria and pine forests (Lanly, 1982, p 49). Private ownership of natural forests cannot prevent deforestation because of "over long" planning horizons (rotations) for sustained-yield forestry and because of the often high private *opportunity costs* for certain forest soils and for the capital frozen in the growing stock of trees. Illegal logging, or the threat of it, also accelerates clearance of private forests. Unstable political circumstances and uncertainty of tenure have the same effect.

Proposition 13

The number of *landless rural poor* is growing fast in most tropical countries (FAO, 1980a, 1984b). The alleviation of absolute rural poverty is associated with adequate economic growth, particularly an increase in per capita agricultural production. But growth alone is not a sufficient condition. Unequal distribution of land (productive assets) and income do not allow the benefits of moderate or even fast economic growth to trickle down to the poor; simultaneous and effective land reforms and other redistributive policies are necessary (FAO, 1984b, p xi; Dasgupta, 1982, pp 38–40). On the other hand, land reforms are effectively prevented or slowed down (FAO, 1984b) by large landowners who, jointly with leading politicians (World Bank, 1982, pp 84–85) and businessmen, form the *power elite* (e.g., Gould and Amaro-Reyes, 1983, p 18; Myrdal, 1957, p 59). Instead, under accumulating pressure from the rural poor, colonization schemes for public forests have been launched or, alternatively, free access to public forests has been allowed through the ineffective or total lack of protection of forests. The *status quo* in land ownership is often supported by various foreign powers and agencies (e.g., Myrdal, 1957, p 59).

Proposition 14

With the increasing scarcity of arable land, along with unemployment, malnutrition, and starvation, the rural poor have to find new solutions for *subsistence* by migration and by the legal or illegal excessive clearance of forest for shifting cultivation and "permanent" cultivation, or by excessive fuelwood gathering, grazing, and firing:

> These rural landless, whose numbers are increasing everywhere, have no option but to invade the remaining tropical forest in an endeavour to scratch a living from soils that are both unfamiliar and fragile. The cause of tropical deforestation lies behind them on the land from which they have been driven: millions of hectares of relatively good land [and] owned by a wealthy few producing the wrong crops for the wrong people at a low level of productivity. So long as the highly skewed distribution of land, wealth and power that characterizes most tropical forested countries endures, the battle to save the tropical forest will inevitably be a losing one (Westoby, 1985, p 57).

Property and tenure are systems of authority established by governments and cultural traditions. They form a set of right-to-control assets. They affect the bargaining powers of parties and thereby the distribution of income and wealth. Reallocations of property rights occur not only legally, but also by corruption, fraud, theft, and, on occasion, by violent robbery (e.g., Dasgupta, 1982, p 38). Under unstable political conditions, land speculation is widely practiced through withholding agricultural land from its previous use, by keeping productivity of agricultural lands at a low level in comparison with their actual potential, or by purchasing property rights to natural forests and woodlands for clearance for a specific short-term purpose. The distributional effects of land speculation are likely to take their toll on the landless (Horn, 1985, p 209) and thus aggregate the pressure toward deforestation.

Proposition 15

Colonialism created many social problems that are still acute in independent developing countries. Jacks and Whyte (1939) reported from South Africa that native reserves have usually been demarcated not, primarily, on a regional basis, but rather with the purpose of separating the land most suitable for European settlements. The naturally migrant native population has been suddenly forced to adopt a settled existence in too small and often inadequately fertile mountainous areas. In this way colonization deteriorated the subsistence of the native people and increased erosion. The authors refer also to the Philippines where, during the American colonial period, the establishment of large sugar-cane estates pushed native people to more remote areas. In Mozambique, where the population density is relatively low, the pressure of Portuguese colonization also caused considerable deterioration in subsistence and marked erosion problems. Mozambique did not become independent until 1975, which is why the consequences of colonization are quite fresh (Palo, 1978). Lugo *et al.* (1981) have described the effects of European colonialism on deforestation in the Caribbean region.

Proposition 16

Numerous *institutional aspects* promote deforestation. Typically, forests are controlled partly (forest reserves) by one or more public forestry authorities and partly by colonizational, agricultural, or other public authorities. Forests can also be administered by federal, state, provincial, or local community authorities. Effective and coordinated planning, implementation, and follow-up are problematic under such circumstances. The external costs of deforestation are also, basically, *intersectoral*, so no sectoral authority can take an integrated responsibility for control (e.g., McGaughey and Gregerson, 1983, pp 160–161). Research into deforestation is also hampered by the intersectoral and *interdisciplinary* nature of the topic.

Proposition 17

Automatic control by the market ("invisible hand") and planned control by the government are the two primary mechanisms expected to control socioeconomic development toward social well-being within national economies. Both of them fail to control deforestation in the tropics. Market mechanisms provide no negative feedback loops to check deforestation and governments are neither motivated nor able to control deforestation (*Propositions 5–11*).

Proposition 18

The causal factors of this proposition are linked together as various *causal chains or mechanisms.* The mechanisms comprise positive feedback loops which tend to accelerate the process of deforestation. The only effective negative feedback loops are caused by the inaccessibility of forests and by the successive reduction of forest areas. Inaccessibility has been gradually overcome by technological and medical progress and appears to be a braking force only in the later stages of the deforestation process (*cf. Proposition 3* above).

Causal chains with only positive feedback loops resemble "vicious circles", which have been described as follows: "It was clear ... that poverty and disease formed a vicious circle. Men and women were sick because they were poor; they became poorer because they were sick, and sicker because they were poorer [Myrdal, 1957, p 11]." The reference points to a circular and cumulative process, continuously pressing levels downward, in which one negative factor is, at the same time, both the cause and effect of another negative factor.

When a vicious circle system has more than two factors, as in the tropical deforestation case, it becomes more complicated and even more difficult to stop or control. The system itself has no tendency toward self-stabilization (no negative feedback loops), but instead it is constantly moving away from a kind of initial equilibrium. A natural change in such a system does not bring forth countervailing changes but supporting changes, which move the system in the same direction as the first change, but much further. Under such circular causation a social process tends to become cumulative and often to gather speed at an accelerating rate (Myrdal, 1957, p 13).

The provisional theory of tropical deforestation as formulated in *Propositions 1–16* can be viewed as a vicious circle in the following way. Population growth and environmental deterioration in the form of deforestation and soil erosion are the basic factors. Together with inadequate land-use and forest policies, and with apparent market failures in the economic system and with lost forest-based development opportunities, a vicious circle of continuous and accelerating rural depression and deforestation can be identified (*Figure 3.3*).

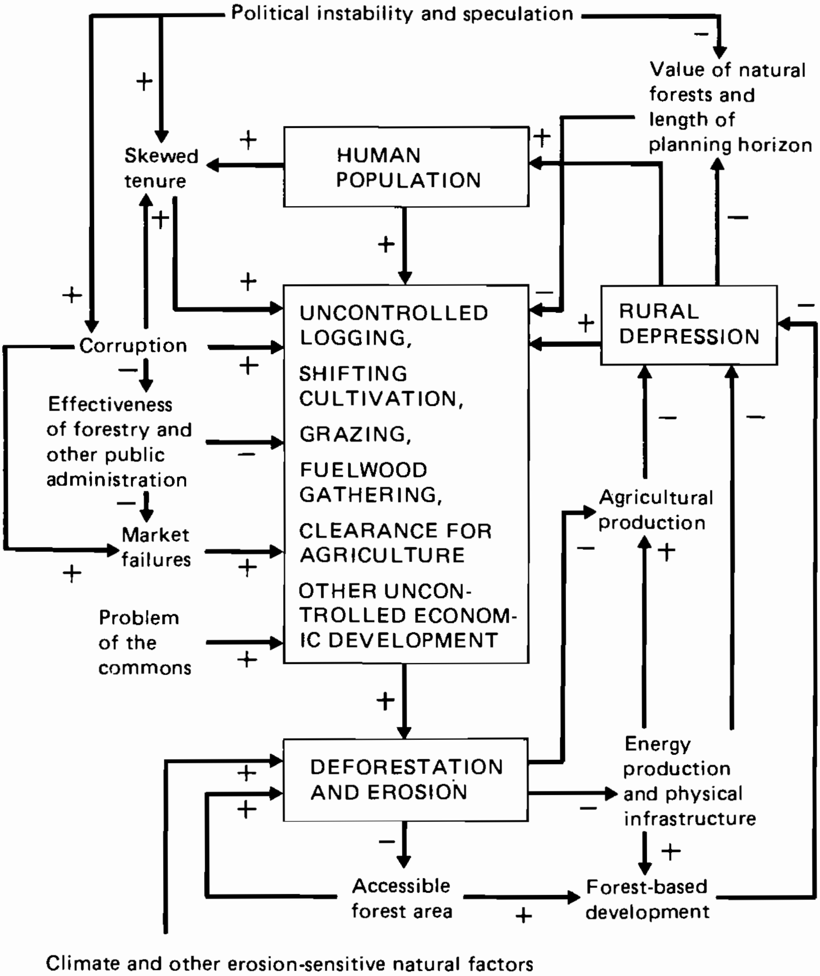

Figure 3.3 The vicious circle of population pressure, deforestation, and rural depression in the tropics.

Leslie (1980) points out that, besides a few positive cases, there exist a large number of developing countries in which heavy utilization of their forests has not produced any real forest-based economic development through industrialization. Quite often forest-based industrialization has not yet been seriously tried. In many countries most of the development potential has, in effect, been exported via huge amounts of logs. When forest industrialization has been tried it often has been badly planned and managed.

Proposition 19

Deforestation as a mathematical process is described by the reduction of an initial forest area of a certain class ($FA_{i,t}$) into a final forest area of the same class ($FA_{i,t+n}$) during a number of years (n). If the annual relative rate of deforestation ($p\%$) is assumed *constant during a certain period*, the final forest area of that period can be estimated by *discounting the initial forest area into the final date* as follows:

$$FA_{i,t+n} = FA_{i,t} \cdot (1+p/100)^{-n} \tag{3.1}$$

and then the area of deforestation (AD) is found by subtraction:

$$\sum_{t}^{t+n} AD_i = FA_{i,t} - FA_{i,t+n} \tag{3.2}$$

According to the above, if a *constant annual percentage of deforestation* is applied in the same area for successive years (*ceteris paribus*), this leads to successively decreasing annual areas of (absolute) deforestation. On the other hand, if *a constant annual area of deforestation* is applied for successive years (*ceteris paribus*), this leads in turn to successively increasing annual percentages of (relative) deforestation. In the latter case, the annual percentage of deforestation equals 100 during the last year of the total process and later deforestation can take place only if new forestation occurs.

Proposition 20

According to *Propositions 17* to *19*, *deforestation in the tropical forests will expand at an accelerated speed* until the existing negative feedback loops strengthen at a later stage of the process. This forecast will be valid unless corruption and actual forest policy and population growth can be checked, land reforms can be mobilized, agriculture on existing arable lands and pastures can be intensified, or controlled economic growth per capita can be mobilized within other industries and urban regions. In the tropical countries most liable to extensive future deforestation these reservations are not valid in the foreseeable future, unless a *radical change in the attitudes* toward deforestation by the national governments and by the individuals occurs.

A required change in attitudes could be caused by *radically improving the observation and monitoring of tropical deforestation* as well as by *radically increasing investigations into the causes and consequences of tropical deforestation*, and by effectively transmitting the results. In this way *a major part of likely future deforestation could be avoided or postponed*, if the national governments and the international organizations have *enough political will and power.* Unavoidable deforestation could also be effectively controlled in order to minimize its external disbenefits. When future costs and benefits are uncertain and when current investment decisions are irrevocable (as is the case with expansion of the exploitation of tropical, natural closed forests), current resource usage ought to be more "conservative" than when the decisions are not irrevocable, since a more "conservative" resource-exploitation policy enables the planner to maintain greater future flexibility (Dasgupta, 1982, p 200).

This provisional theory for tropical deforestation has been created in a field in which no theory previously existed. It is interdisciplinary by nature and, as such, it can be regarded as provisional and flexible to future revisions. The theory has been shaped so that it is global and covers both the *developing tropical countries* and the closed and open natural forests. Most of the propositions are *inductive generalizations*, with the relevancy and intensity of different causal factors varying according to countries and major classes of forests. Pilot empirical analyses based on this theory have been encouraging, but the main results will be published elsewhere (Palo and Mery, 1985). Only a few empirical findings are presented in the next section.

3.3. Potential for Empirical Applications

The tentative empirical analysis was based on 72 tropical countries, which lie (at least about half of the territory of each country) within the tropics of Capricorn and Cancer. All forest area variables were based on the recent FAO and UNEP (1981a–c) assessments. The total forest area variable was composed of closed and open, natural, broadleaved forest and of natural coniferous forest. GNP and energy variables are taken from World Bank

(1981) and population variables from United Nations (1982). The land area data were derived from FAO and UNEP (1981a–c) and FAO (1984a). Correlation computations were based both on the original variables and on their logarithmic transformations. In order to analyze countries of varying sizes the dependent and independent variables were transformed from absolute into relative figures.

Three alternatives were analyzed for a dependent variable of deforestation. The area of deforestation in relation to total land area and to total forest area, as well as the total forest area in relation to total land area, were examined [*Figure 3.4(a)*]. The last one clearly correlated the best with the key independent variables of population densities, which is expected because of the poor accuracy of deforested-area statistics in comparison with forest area statistics (Section 3.1). Accordingly, forest coverage (total forest area/total land area) was applied as a dependent variable, the validity of which was improved by grouping the countries.

In order to establish more homogeneous groups of countries for further analyses, geographical proximity was considered to reflect a similarity in the natural and human factors that affect deforestation (*Figure 3.3*). First, a division by continents was applied. Africa is the most heterogeneous continent and has the highest number of countries (38). Therefore, a subgrouping was executed, with the first African group being defined as 12 moist African countries, which contain the moist and predominantly closed forests occupying the western zone from Zaire in the south to Sierra Leone in the north (e.g., Persson, 1975, p 19). The second group comprises the eight most arid countries. The remaining 18 semi-moist countries were included in the third African group (Persson, 1977a).

The correlation coefficient between total forest coverage and total population density was –0.47 among the 72 tropical countries, –0.76 among the subgroup of 64 tropical countries [*Figure 3.4(b)*] and –0.84 among the subgroup of 46 tropical Latin American, Asian, and moist African countries (in most of them closed forests dominate). The equivalent correlation coefficients by the three further subgroups of the 46 countries were –0.95, –0.88, and –0.83. Also, negative coefficients (–0.65, –0.55) were computed for the 18 semimoist African and the eight arid African countries, where open forests dominate. *Total* population density correlated with forest coverage either more strongly or at about the same level as *rural* population density (no statistically significant difference between the two), which can be regarded as a novel empirical finding in contrast with previous explanations (e.g., Lanly, 1982, p 35). Semi-log transformations (the original dependent variable versus log of the independent variable) produced mostly higher correlation coefficients than original variables or their log–log transformations. Parallel data from Paranà in Brazil (a time series of nine observations, $r = -0.99$) and from 22 European countries ($r = -0.86$)

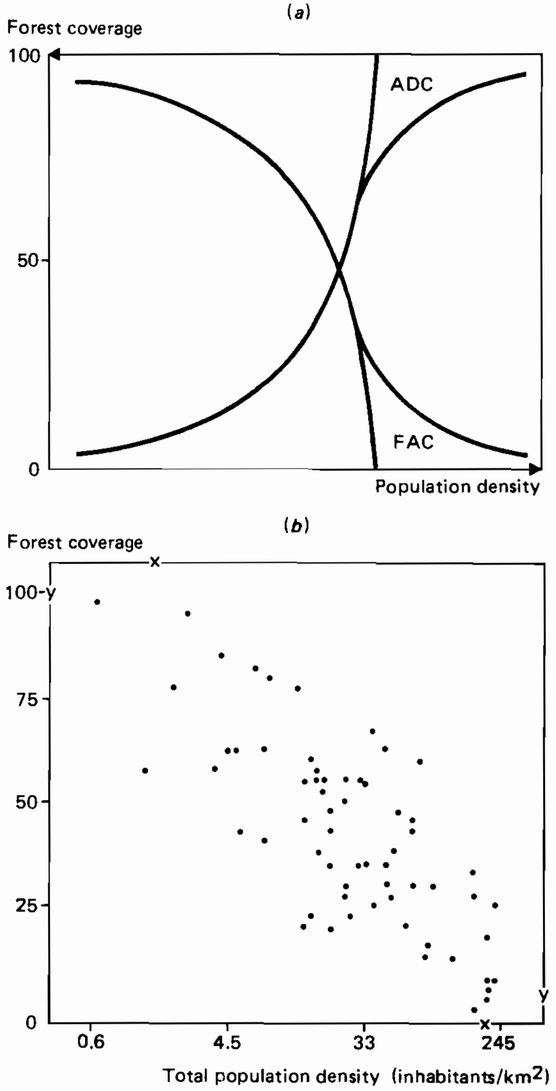

Figure 3.4 (*a*) Coverages of forest areas (FAC) and deforested areas (ADC) from total land areas as theoretical functions of population density (Palo, 1984). (*b*) Correlations of 64 tropical countries in 1980.

confirmed the negative relationship between forest coverage and population density found in the tropics.

Future tropical deforestation was analyzed tentatively using five alternative scenarios (*Figure 3.5*), three of which were based on the regression of forest coverage with total population density (B, D, and E), one assumed the present deforestation areas fixed into the future (A; Palo, 1984), and one assumed that the relative future deforestation rate over five-year periods was equal to the relative future population growth [C; equations (3.1) and (3.2) above; Palo, 1984]. Scenarios C, D, and E had nonlinear functional forms and followed more closely the provisional theory of tropical deforestation. Scenarios A and B had linear functional forms. Scenarios B to E were based on the available population predictions [see Palo and Mery (1985) for more details].

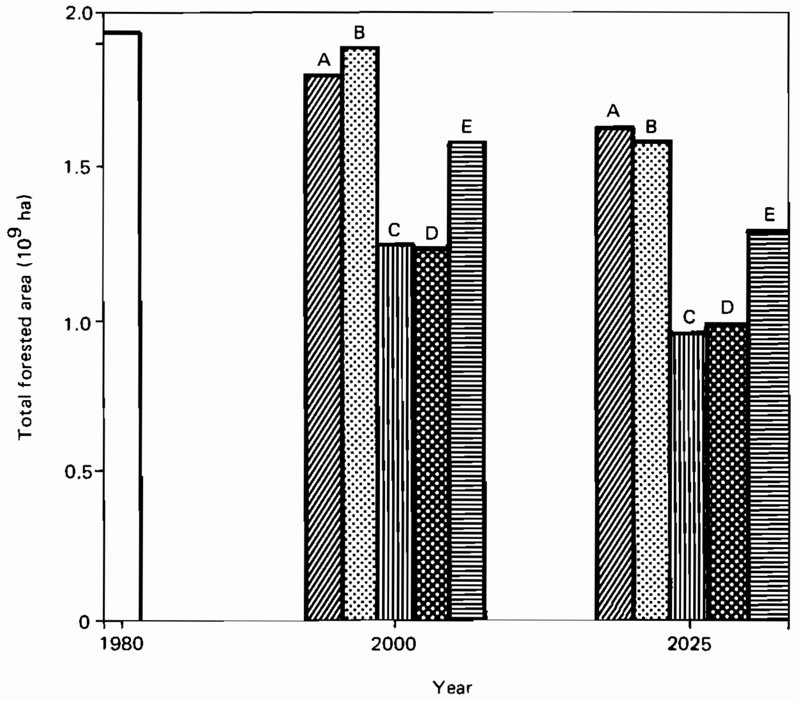

Figure 3.5 Alternative pilot scenarios for deforestation of tropical closed and open forests (see text for description of A–E).

The total forest area in the 72 tropical countries analyzed here was 1944×10^6 ha in 1980. By 2025, it is predicted to decline by −51, −50, and −34% in scenarios C, D, and E, respectively. The present deforestation pace has been assumed by most other authors to continue, which would indicate a reduction of −17% (scenario A in *Figure 3.5*).

3.4. Discussion

The provisional theory of tropical deforestation has to be further elaborated, but as it is now it already fulfills the purpose of guiding observation, prediction, and control. The fitness of the theory for subtropical, developing countries is likely, but has to be tested further. No attempt has been made here to analyze the role of future artificial or natural forestation in the tropics. It was also outside our scope to analyze the potential effects of deforestation on the future supplies of timber and fuelwood.

A decrease in forest coverage (the ratio of forest area to total land area) indicates deforestation in this analysis. The ratio of deforested area to total forest area would have been more valid for the purpose, but its statistical accuracy appeared too low for further application. The initial forest coverages in countries before human impacts on forest areas have apparently varied according to natural circumstances. One aim of grouping the countries was to eliminate satisfactorily this problem, in the absence of data on the initial national forest coverages.

Population density was measured by the ratio between number of inhabitants and total land area. The validity of this variable is weakened by the fact that, due to deserts, mountains, etc., a particular share of many countries is uninhabitable. Therefore, the population pressure on the inhabitable parts of these countries is *de facto* higher than shown by the applied population density variable. The validity could be improved by the relevant corrections.

The deforestation scenarios have to be understood as pilot results. More analyses will be needed to test the fitness of some other feasible function forms, as well as of regression equations with more than one independent variable.

The assumed key role of population growth in tropical deforestation has been given further confirmation here. Furthermore, similar negative correlations in the parallel material of Paranà and industrialized countries have strengthened the hypothesis and give us greater confidence in the consistency of this relationship in the further economic development of the currently developing countries.

The strong, empirical negative correlations between forest coverage and total population density, and the scenarios based on this regression gain more relevance in the light of a correlation matrix of 59 variables representing the various factors of ***Figure 3.3*** (Palo and Mery, 1985). The other key variables, such as gross national (or domestic) product variables, grazing and other agricultural variables, as well as a fuelwood and other roundwood production variables, were all strongly positively correlated with the total population density variable. Thus, population pressure as described in the theory of Section 3.2 and in ***Figure 3.3*** appeared to be a most powerful indirect variable in the tropical deforestation process.

In contrast to general opinion, but according to the hypothesis of the provisional theory (Section 3.2, ***Proposition 4***), the five relative GNP and GDP variables correlated mostly negatively with the dependent forest coverage variable. The correlation coefficients varied between 0.00 and –0.43 among the 72 tropical countries, between –0.13 and –0.60 among the 46 tropical countries, between –0.13 and –0.68 among the 12 moist West African countries (Palo and Mery, 1985). These results are supported by Allen and Barnes (1985) who computed correlation coefficients of –0.18 and –0.27 between deforestation and two GNP per capita variables among 28 tropical countries.

It has been shown here that theoretically based, relevant, empirical quantitative analysis concerning tropical deforestation is feasible, even by applying the available data for tropical forests when deforested areas are substituted for forest coverages. In contrast, Grainger (1984) argued that such an analysis would be feasible only after objective, international monitoring systems are created to produce more valid and reliable deforestation data. The strong requirements for such a monitoring system, as well as expanding quantitative analyses on the projections and consequences of tropical deforestation, are also emphasized here, but some analyses can also be implemented immediately.

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CHAPTER 4

Modeling Forest Dynamics

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The term "forest dynamics" refers to intertemporal changes in forest resources. These changes are often represented by projections of timber inventories that, in their simplest form, account for depletions from and additions to total growing stock. The development of the forest resource of a country or region is composed of the development of individual forests and, it follows, of stands within these forests. As a result, forest-sector resource modeling might be considered an elaborate exercise in predicting stand development. In practice, however, the broader scale of regional analysis embodies a different set of objectives, and requires different approaches than does stand-level analysis. Regional analysis does not require information on the condition of individual stands; aggregate measures are sufficient to model the interaction between resources and short-run (economic) supply at the forest sector level.

A proper specification of forest dynamics is an essential component of both long-run and short-run timber supply analyses. Short-run supply (current harvest) is determined by economic factors that are related, in turn, to the quantity and composition of the physical resource. Long-run timber supply is determined by the interaction of the sequence of short-run harvests, forest management decisions, and forest growth relationships.

Modeling the development of regional forests is the large-scale, analytical complement of modeling individual stand or forest growth and yield. Macroanalysis of forest resource dynamics emphasizes aggregate measures of resource conditions, such as total growing stock, the balance of net growth and drain, and broad categories of forest management. Macroanalysis concentrates on long-term projections that extend one or more rotations (50+ years) into the future. Finally, when the analysis of forest dynamics is used in conjunction with a model of regional production and consumption, descriptive (simulation) techniques are preferable to normative (optimization) techniques.

The choice between a descriptive and a normative methodology depends on the objectives of the analysis; the distinction between the two is not always clear. For the purposes of this discussion, descriptive approaches are those that report the development of the forest when given an explicit, exogenous specification of management and policy decision-variables. These models make no attempt to maximize selected measures, such as forest production, or to achieve specified conditions, such as a regulated forest.

A normative approach does what the descriptive method does not: computes endogenously the values of decision variables that will bring about an objective function maximum or specified optimal conditions. Key decision values, such as harvest or regeneration rates, are computed in the normative model; in the descriptive model these values are exogenous and form the basis of a "scenario" analysis.

The literature that describes the small-area analysis of forest dynamics — stand-level growth and yield modeling — is extensive. Buchman and Shifley (1983) provide a brief summary of model types; Trimble and Shriner (1981) have compiled an annotated model bibliography for the US. Examples of techniques and results from other countries are in Kuusela and Nyyssonen (1983). Alig *et al.* (1984) have reviewed analytical methods suitable for large- and small-scale problems, but emphasize the projection of timber inventories of large areas. Forest sector analysts, however, will find surprisingly little in the literature that can be applied directly to the problem at hand.

4.1. Timber Inventory Projection

An ideal model of forest resources (especially on a regional scale) would display information concerning all forest outputs: timber, wildlife, recreation, water, and forage. Nontimber outputs are receiving increasing emphasis among policy makers as well as modelers (see, for example, Alston, 1983). The goal of assembling a "complete" forest model remains elusive however, as there is, in general, insufficient data and an incomplete understanding of the joint production possibilities. In practice, a model of forest dynamics is a methodology for projecting the development of timber inventories.

Future timber inventories are determined by present resource characteristics and:

(1) Forest growth relationships.
(2) Forest management activities (including harvest).
(3) Forest succession tendencies.
(4) Factors external to the forest system (such as population growth, land-use patterns, and air pollution).

A model of forest dynamics should incorporate all these elements to effectively characterize the development of regional forests over a long period.

The relative importance of each of these elements depends, to some extent, on how far into the future forest conditions are to be projected. If the projection period is shorter than the average rotation length of the forest under analysis, then the balance between net growth and removals dominates the other factors in determining timber inventories. In this time scale (20 to 30 years, in most regions), resource production is relatively independent of both forest management and the consequences of forest succession.

Over a longer period (30 to 50 years), both the level of growth and its species composition are a function of management actions. New forests established through management effort will have time to contribute to the stock of merchantable timber; greater stocks can lead, in turn, to increases in short-run timber supply. Changes in growth and resource characteristics that occur in the absence of active management will also affect timber inventories and production opportunities. In addition, over this longer period, the cumulative effect of changes in factors external to the forest (such as patterns of land use, and atmospheric conditions) will influence the development of forest resources. A systematic method for the projection of timber inventories provides an opportunity to describe consistent, alternative views of the future that are conditioned on the biological response to timber harvest and timber management activities.

In its simplest form, forest dynamics can be expressed as:

$$I_{t+1} = I_t + G_t - R_t \tag{4.1}$$

$$G_t = g(I_t, Z_t) \tag{4.2}$$

where t is the time period, I_t is the growing stock volume (timber inventory) in time t, G_t is the net growth between period t and $t + 1$, R_t is the total removals of growing stock between period t and $t + 1$, and Z_t is a vector of the exogenous factors that influence growth in period t.

In principle, equations (4.1) and (4.2) summarize forest dynamics. Only these two equations are necessary to project a single measure of forest conditions (timber volume) into the future. All timber inventory projection methods can be seen as ways to expand the dimensions of equation (4.1) and, at the same time, to elaborate on the functional relationships of equation (4.2). That this simple relationship underlies the complex projection models is important to keep in mind when approaching the problem of modeling the forest dynamics of regions for which detailed data are unavailable.

Larson and Goforth (1974) used equation (4.1) as the "basic model" for inventory projection; Kuusela (1983) and Svensson (1983) described this as the "forest balance" equation. Kuusela (1983) used this relationship to estimate the periodic increment, using observations of starting and ending inventory, and the periodic drain. Repeated evaluations of these balance relationships are then used in the short-term evaluation of Finnish forests. Svensson (1983) described a similar application of the balance equation (4.1) to Swedish forests.

In long-term projection, all elements of the right-hand side of equation (4.1) must be known. For projection, the starting inventory (I_t) is given and the removal quantity (R_t) is supplied exogenously, for each period, so that only growth needs to be estimated. Equation (4.2) relates current growth to the inventory, eliminating the remaining unknown, and thus providing an estimate of inventory for the next period. This method is used in the IIASA Forest Sector Model (see Chapter 21).

Alig *et al.* (1984) have summarized methodologies and described models used to project inventories in regional timber supply analyses in the US. They utilized a taxonomy that distinguishes between direct and indirect projections, and they identified three general approaches. Stand table projection and yield table projection are direct methods in that the entire stand (or forest) for which the projection is to be made is the source of the data used to develop the growth relationships. Individual tree simulation methods are indirect approaches because projection for the aggregate requires that growth relationships estimated from sample areas be extrapolated to the entire stand (or forest). Direct methods are more commonly applied to the analysis of timber supply from large regions, although, in some cases, individual tree-based models have been used for long-term, aggregate projections. In this chapter we review in some detail each of these methods — stand table projections, yield table projections, and large-scale, individual-tree simulation. Some other approaches to modeling the development of the forest resources of large regions are briefly discussed in Section 4.5.

4.2. Stand Table Projection

A stand table is the frequency distribution of the number of trees per unit area, usually arrayed by diameter class. A stand table projection is the adjustment of this distribution, over time, taking diameter growth, removals, mortality, and ingrowth (the number of trees entering the smallest diameter class) into account. Stand table projection has a long history of use in forest mensuration practice (see, for example, Chapman and Meyer, 1949). Models utilizing stand table projection are described in Larson and Goforth (1974) and Tedder *et al.* (1980).

The best example of stand table projection applied to large-area timber inventory projection is the Timber Resource Analysis System (TRAS) developed by Larson and Goforth (1974) for use in the US. TRAS was designed with three objectives: to reconcile differences between sequential forest surveys; to update forest survey data sets (collected in different years) to a common date for aggregation; and to make long-term projections of timber supplies. TRAS has been used to project the development of timber inventories over a 50-year period at the regional level in the US (Adams and Haynes, 1980; USDA Forest Service, 1982).

The methodology used in TRAS is an extension and revision of observations by Meyer (1952), who points out that the frequency distribution of the number of trees by diameter class in a stand can be represented by an exponential function. The periodic increase in volume for a stand characterized in this manner depends on both the average diameter growth and the shape of the initial distribution. Although his examples were drawn from uneven-aged forests, Meyer (1952) laid the groundwork for subsequent stand-table projection models by observing that the collection of stands in any large forest area can be represented using this distribution function.

Larson and Goforth (1974) applied Meyer's (1952) results to larger areas, including aggregations of even-aged stands. Two general modifications were made to Meyer's (1952) methodology. First, when the stand is arrayed by the number of trees in each diameter class, the largest class is unlike the others, in that it must contain all trees larger than the highest specified class. Larson and Goforth (1974) overcome this by computing the cumulative number of trees in each class, adding from the highest to the lowest class. Each class then includes all trees larger than the lower limit of the class and is directly comparable with all other classes.

The second, and more restrictive, limitation of Meyer's (1952) method is that it depends on the uniformity of the exponential distribution in computing changes in the stand structure. Meyer (1952) assumed that the stand structure coefficient, q, computed as the ratio of the number of trees in successive diameter classes, is constant. That is, that the frequency distribution of trees follows a uniform geometric progression. Because conditions observed in most forests are likely to deviate from a uniform distribution, Larson and Goforth (1974) calculated a unique coefficient for each diameter class. This introduces flexibility, which allows projections to more closely follow actual stand development.

In TRAS the forest is represented by the function:

$$N = K^{*}\mathrm{e}^{-aD} \tag{4.3}$$

where N is the the cumulative number of trees (per unit area) larger than the lower limit of diameter class i, D is the the diameter of class i (in two-inch steps), and K^{*}, a are parameters of the distribution.

Stand projection — advancing this distribution through time — requires a computation of the net change in the number of trees in each class. For each diameter class, i, this change can be defined as:

$$NC_i = IG_i - IG_{i+1} - M_i - R_i \tag{4.4}$$

where NC_i is the net change in trees in the ith class, IG_i is the ingrowth into the ith class, IG_{i+1} is the "outgrowth" (ingrowth into the next higher class), M_i is the mortality in the ith class, and R_i is the volume removed from the ith class. "Potential increase" is the difference between ingrowth into class i and ingrowth into class $i + 1$. This potential increase must be adjusted for other losses: mortality and harvesting. In TRAS, both mortality and removals for harvest are specified as a proportion of the number of trees in the class at the start of the period.

Ingrowth is estimated directly, based on an adaptation of Meyer's (1952) results, as:

$$IG_i = N_i[(Q_i)^R - 1] \tag{4.5}$$

where N_i is the the cumulative number of trees in the ith class; Q_i is the stand structure coefficient, $Q_i = N_{i-1}/N_i$; and R is the average radial growth of the ith class.

Ingrowth into the first (sapling) class is not a function of radial growth, but depends on the rate of regeneration. In TRAS, sapling ingrowth is either specified exogenously or computed in a manner that keeps the number of trees in the lowest class constant. In general, stand-table growth projections are quite sensitive to the sapling ingrowth value (when radial growth rates are constant) due to changes in the stand structure coefficients, Q_i, that different ingrowth rates imply (Larson and Goforth 1974).

The number of trees (per unit area), by diameter class, is the primary forest descriptor in the TRAS projection system. The basal area, the area in trees measured at a fixed height, is computed from the number of trees in each diameter class; total volume is computed from basal area. TRAS includes a set of equations that adjust radial growth (downward) and mortality (upward) as the basal area increases. This prevents the total stand density (measured by basal area) from reaching biologically unreasonable levels.

The first application of the TRAS projection system to regional forest inventory projection is described in USDA Forest Service (1965). The results of more recent long-term projections are reported by Adams and Haynes (1980) and in USDA Forest Service (1982). In these projections, regional diameter-class distributions are computed for each owner category from the total number of trees (either coniferous or nonconiferous), divided by the total forest area. The resulting distribution is treated as a single, aggregate stand. Each aggregate stand is then modeled separately; coniferous and nonconiferous trees are linked only through a total (aggregate) stand basal area constraint. Total regional volume is computed using area "expansion factors": exogenous projections of the total area for each owner.

The total harvest of industrial roundwood for each of these aggregate stands is exogenous to the TRAS system; each owner's stand is adjusted to reflect these removals and show radial growth and tree mortality as estimated from forest survey data. Sapling ingrowth rates are estimated from forest inventory data.

The stand-table projection method illustrated by TRAS has a number of shortcomings when used for long-term projection. First, it is necessary to assume that all stands can be treated (for modeling purposes) as uneven-aged stands. Although it may be reasonable to represent the aggregate number of trees in this manner, it is not possible to portray the wide variety of even-aged management practices common in most regions. Stand regeneration, one of the most fundamental measures of management effort, must be expressed in terms of the number of trees entering the first diameter class. A reduction in the number of trees entering subsequent diameter classes might be the consequence of either lower regeneration rates (which should reduce growth) or improved stocking (which should increase growth). Adding dimensions to the description of stands (a separate, aggregate stand for each management category, for example) would require the development of a set of procedures to model the interaction between these stands. Adams *et al.* (1982) describe the cumbersome (and largely *ad hoc*) procedures used to revise TRAS to simulate changes in management effort.

A companion to the problem of estimating changes in radial growth rates, which result from changes in management effort, is the difficulty of setting constraints on radial growth. In general, the constraint functions cannot be estimated directly because they represent the seldom observed upper limits of biological carrying capacity. That these constraints are necessary suggests that there may be difficulties in long-term projections with this method.

Many of the problems encountered in aggregate stand table projection can be attributed to the inflexibility of the composite stand. The growth of this composite average acre depends only on the stand structure and on the constrained radial growth rates, and is independent of many important factors, such as species, age, site, and management effort. The composition of the actual average acre, as well as its subsequent growth rate, is likely to change over time, but cannot do so; the initial weights for the components of the composite are maintained throughout the projection.

In spite of these shortcomings (more visible now that alternative projection systems have been developed), TRAS represented the state-of-the-art for regional timber-inventory projection systems in the US for many years. Its success can be attributed to the fact that it provided a biologically reasonable representation of the forests of large areas and it was able to project changes in timber inventories over a long time period. The recognition of additional, desirable characteristics for large-scale inventory projection methodology has led to the development of alternative methods, and to improvements in the US forest inventory database.

4.3. Yield Table Projection

In many respects, yield table projection is the simplest and most versatile approach to inventory projection, but is applicable only when regional forests can be characterized by even-aged management. The forest is represented by a vector that describes the distribution of forest area by age class (and possibly by additional stand type descriptors). Noncontiguous areas that fall into the same age category are grouped for projection purposes. The summation over all age classes and type descriptors of the product of the area vector(s) and yield per unit area vector(s) is the total timber volume of the forest. Inventory projection is reduced to a bookkeeping problem: how to keep track of the disposition of acres as they advance through age classes, through time.

The bookkeeping algorithm of the age class model can be stated as:

$$A_{i+1,j,t+1} = A_{ijt} - H_{ijt} \tag{4.6}$$

$$A_{N,j,t+1} = A_{Njt} + A_{N-1,jt} - H_{Njt} - H_{N-1,j,t} \tag{4.7}$$

$$H_{ijt} = R_{ijt}/y_{ij} \tag{4.8}$$

$$A_{0jt+1} = [\sum_{i=0}^{N} H_{ijt}]\, \boldsymbol{T}_{(j\times j)} \tag{4.9}$$

$$Y_{ij} = Y(m_i, X_{1j}, \ldots, X_{nj}) \tag{4.10}$$

$$g_{ij} = y_{i+1,j} - y_{ij} \tag{4.11}$$

where t is the period and $(t+1) - t$ is the age class interval; i is the age class, $i = 0,\ldots,N$, N is the "oldest" age class; j is a stand type descriptor, $j = 1,\ldots,j+n$; A_{ij} is the area in stands of type j and age class i; H_{ij} is the area harvested; R_{ij} is the volume harvested; A_{0j} is the regeneration area for type(s) j; $T_{(j\times j)}$ is a $(j \times j)$ matrix of regeneration transition probabilities (explained below); y_{ij} is the the volume yield per unit area; g_{ij} is the periodic volume growth per unit area; m_i is the the midpoint of age class i; and $X_{1j},\ldots,X_{nj}$ are variables that influence yield per unit area.

Equations (4.6) and (4.7) advance the forest area through age classes, after accounting for the area harvested in the current period. Harvest is specified in terms of volume, which must be allocated to each eligible age class, and converted into an area by dividing by the yield of the age class [equation (4.8)]. Regeneration into the first (0) age class in the next period is determined by the total area harvested in the current period (assuming no area enters or leaves the forest classification). In equation (4.9), regeneration into each type class, j, is determined by a Markov-type transition matrix, $\boldsymbol{T}$, which defines the probability of a harvested acre of each class regenerating into each of the classes.

The yield for each age class can be approximated with a function fitted for each descriptor class, j, as in equation (4.10). Yields can also be estimated using separate, detailed stand growth and yield models. Yields are entered into the projection model as a matrix, where the elements y_{ij} are the yields required for equation (4.8). Growth per unit area can be computed as the difference between yields in adjacent age classes [equation (4.11)].

The yields, y_{ij}, should represent empirical (observed) yields, which, for each i, j, can be approximated by dividing the existing volume by the area. When stands are aggregated, empirical yields will generally be lower than normal (potential) yields. Normal yields, representing production in fully stocked stands, are an upper bound, which yields of existing stands are expected to approach (Chapman and Meyer, 1949). The rate of this "approach to normality" is difficult to measure, however. The selection of appropriate normal yields and a rate at which to adjust (projected) empirical yields are important considerations when using the stand-table projection method.

There are a number of examples of the application of the yield table method to aggregate inventory projection. In the US, yield table models have been widely used to project inventory development in conjunction with harvest scheduling algorithms. Equations (4.6)–(4.8), with the addition of nonnegativity constraints and a volume or value-based objective function, are easily cast in a linear programming format. The TREES model (Timber Resource Economic Estimation System, Tedder *et al.*, 1980) is one example of this.

The TRIM model (Timber Resource Inventory Model, Tedder *et al.*, 1983) contains a yield-table projection system similar to TREES, but does not schedule harvests. Both models utilize forest inventory data aggregated into common age class (and species, site, etc.) categories, which are further aggregated into management groups for projection. Yield tables are derived from inventory data, and from growth and yield models. TRIM has been designed as an inventory projection model, in contrast to both the harvest scheduling function of TREES and the multiple inventory analysis objectives of TRAS. TRIM will be used to project the development of national forest resources in conjunction with the Timber Assessment Market Model (TAMM, Adams and Haynes, 1980).

Aggregate yield table projection models for New Zealand are described by Levack (1979) and Cavana and Coyle (1984). A model similar to the New Zealand model of Cavana and Coyle (1984) has been developed for Chile (Instituto Forestal, 1984). Amano *et al.* (1983) report on an age-class timber supply projection model for Japan. Brooks (1985) uses a yield-table projection model based on equations (4.6)–(4.9) to simulate the growth of forests in the southern US.

The yield-table projection method is ideal for projecting inventory development when aggregate data can be sorted into even-aged categories. This approach can easily and effectively simulate the development of plantations that are characteristic of intensive forest management in many regions. An area- and age-based representation of the forest also facilitates the analysis of many broad forest management and forest policy questions. There are, however, a number of problems encountered in aggregate yield table projection. The most important of these are the choice of appropriate stand type descriptors (the degree of aggregation), and the choice of appropriate yield functions.

The size of the yield table model is proportional to the degree to which regional data are aggregated. Expanding the number of type dimensions is conceptually easy, as each age and type cell $(i, j, \ldots, j+n)$ is a discrete unit of the forest and can be modeled as such. This expansion requires estimates of the allocation of volume removals across type classes and across the distribution within classes. Frequently the data for these allocations are not available. Yield-table models also require information (or assumptions) regarding nonharvesting sources of area change (for each i, j, and t), and the movement between type classes at the time of regeneration (the matrix $\boldsymbol{T}$). In most models, each of these is treated with simple assumptions — the result of a lack of better information. The harvest of each (eligible) age class and stand type is based on volume- or area-based proportionality assumptions. Harvested stands are assigned (regenerated) to the first age class of the same type class, disregarding forest succession dynamics.

Some models illustrate the effects of using other assumptions. The Japanese timber supply model (Amano *et al.*, 1984) incorporates data, from forest surveys, that specifies harvest probability by age class, stand size, and distance from roads. The algorithm in TRIM (Tedder *et al.*, 1983) allows acres to shift between type classes to model area change; the SPATS model (Brooks, 1985) implements the full regeneration–transition matrix of equation (4.9). In each case, the result is a better estimate of changes in the area/age distribution in future periods and thus a better estimate of future timber supply.

The problem of selecting yield tables (or functions) is even more important in long-term projections and is made more difficult by the aggregation that simplifies some of the problems described above. At any level of aggregation, however, the problem of the difference between empirical and normal yields is encountered. This arises because normal yields (often estimated from small-area data) represent ideal growing conditions that are seldom, if ever, observed throughout a region. On the other hand, the use of current, empirical yields to project future volume introduces a bias because current yields reflect the consequences of historical management practices that may not continue into the future.

Two approaches can be taken to address this problem. One is the use of a single set of yield tables that represent "likely" yields over some future time period. These are, generally, higher than the yields of existing stands, but lower than normal yields. If this approach is used, the initial volume of the forest is overstated, but estimates in subsequent periods become (increasingly) reasonable.

A second approach is to start the projection with yield tables that reflect conditions in existing stands. These yields are then adjusted, over time, to reflect an "approach to normality." This is the more appealing method when projections need to start at a point consistent with forest survey data, but introduces the problem of estimating (or assuming) the rate of this approach to normality.

4.4. Individual-Tree-Based Simulation

Individual-tree-based simulation approaches include both distance-dependent and distance-independent methods. Distance-dependent methods use the location of a tree within a stand and individual-tree characteristics to predict growth. Distance-independent methods compare nonspatial, individual-tree characteristics with those of other trees in the stand. Only the latter has been used to simulate the development of forests of relatively large areas.

The general structure of this approach is a system of equations that describes the growth of individual trees in stands. The forest is portrayed as a collection of plots, each of which is, in turn, composed of an enumeration of trees showing (for example) species, diameter class, site index, and crown ratio. The tree list for each plot is the basic data unit of the individual-tree model. An example of the set of functions which predicts changes in this list is the following (Belcher *et al.*, 1982):

$$\text{Diameter growth} = d(D,SI,CR) \tag{4.12}$$

$$\text{Modifier} = m(BA_{\max},BA) \tag{4.13}$$

$$\text{Mortality} = p(DGR,D) \tag{4.14}$$

$$\text{Crown ratio} = c(BA,D) \tag{4.15}$$

where D is the diameter class, SI is the site index, CR is the crown ratio code, BA is the current basal area (per unit area), $BA_{\max}$ is the maximum basal area expected for the species (per unit area), and DGR is the diameter growth rate. The functional forms for equations (4.12)–(4.15) vary with the resolution of the model; parameters are estimated for each species.

The individual-tree simulation model utilizes a more detailed representation of the biological processes of forest dynamics than either the stand table or yield table methods. Potential diameter growth [equation (4.12)] is determined by explicit tree characteristics (such as current diameter and live crown ratio), and by plot characteristics (site index). The growth modifier function [equation (4.13)] is similar in purpose to the radial growth rate constraint in TRAS, and is required because the potential growth of individual trees may not be realized due to competition. In equation (4.13) growth limits are computed as a function of the current basal area of the species and a pre-specified maximum basal area for the species on that plot.

Tree mortality is determined by both current diameter and diameter growth [equation (4.14)]: higher mortality is expected for trees at either end of the range of diameter sizes, as well as for slower growing trees of any size. The crown ratio function [equation (4.15)] introduces a mechanism which links potential growth to changes in stand density.

Inventory projection with the individual-tree simulation approach is done by computing a revised tree list, using equations (4.12)–(4.15) to describe the birth, growth, and death of individual trees. Harvest, management, and regeneration for each plot must be specified exogenously. Plots are projected individually and independently, and revised aggregate statistics are computed by summing volume (and other data) across the plots.

An example of the individual-tree simulation system applied to multiple species and large areas is the Stand and Tree Evaluation and Modeling System (STEMS), described by Belcher *et al.* (1982) and Lundgren and Essex (1979). The description of the structure of the individual-tree projection model (above) is based on STEMS. Jakes and Smith (1983) describe the only application of STEMS to long-term (regional) inventory projection in the US.

Siitonen (1983) also describes an individual-tree simulation and optimization model (MELA) for Finnish forests. In the MELA model, which simulates the development of forests country-wide, stands are grouped to be homogeneous with regard to present stand characteristics and expected future management. Each stand is, in turn, represented by one or more sample plots, and each plot with a set of sample trees.

Alig *et al.* (1984) summarize the advantages and disadvantages of the individual-tree simulation approach as compared with alternative inventory projection methods. Models such as STEMS and MELA have the advantage of using conventional inventory data, are able to represent any age structure or species mix, and can provide detailed information on tree and stand development and the response to management. The disadvantages are, however, the complexity of the models, the expense of adapting this approach to large-scale analysis, and the existence of some degree of bias in representing aggregate stands (Moeur and Ek, 1981).

4.5. Other Approaches to Modeling Forest Dynamics

There are a number of methods used to model forest dynamics that do not fit easily into any of the previous categories, although they may, in some cases, bear a close relationship. These include dynamic simulation (Vályi and Tóth, 1984; Shugart *et al.*, 1973) and the matrix approach used by Usher (1966) and Kallio *et al.* (1985).

Shugart and West (1980) reviewed approaches taken to modeling forest dynamics and emphasize those models in which forest succession is explicit. These are formulations that attempt to determine changes in species composition (among other ecosystem attributes) over long time periods. Succession models examine forest changes beyond the life span of individual species (or species groups) and usually project 100 to 200 years into the future.

Shugart *et al.* (1973) formulated and implemented a large-region forest succession model using a set of linear differential equations with the form:

$$\mathrm{d}X_i/\mathrm{d}t = f_i + \sum_{j=1}^{n} a_{ij}X_j \qquad \text{for} \qquad i = 1,\ldots,n \tag{4.16}$$

where X_i are state variables, $i = 1,\ldots,n$ states; f_i is the exogenous input to the ith state; and a_{ij} is a transfer coefficient.

The state variables, X_i, represent forest area arrayed by stages of forest succession, such as cover types. Shugart *et al.* (1973) use two descriptors: cover type and size class. The transfer coefficients, a_{ij}, indicate the rate of transfer from state j to state i; transfer coefficients are either positive or negative, depending on the location of the state in the successional hierarchy.

The drawback of this approach is that, in practice, the successional gradient is assumed to be smooth and independent of both natural and human-caused disturbances. The long time horizon of the analysis and the emphasis on the impact of ecological developments justify, to some extent, this assumption. As a consequence, however, succession models are of little use in simulating the development of regional forests in response to short-run timber harvests and forest management practices.

An approach that combines elements of the succession model and the more traditional stand distribution models utilizes a Markov-type probability structure to examine transitions among vectors that describe the forest. The model is:

$$\boldsymbol{N}_{t+1} = \boldsymbol{P}\boldsymbol{N}_t \tag{4.17}$$

where $\boldsymbol{N}$ is a $(n \times 1)$ vector describing the forest, and $\boldsymbol{P}$ is a $(n \times n)$ probability matrix.

Each element of $\boldsymbol{P}$ is the probability that the individual (tree or area) in the ith class at time t will be in the $(i+1)$th class at time $t+1$. The first row of $\boldsymbol{P}$ represents the reproduction rate for each group.

Usher (1966) used this method to examine the structure of a Scots pine forest. Kallio *et al.* (1985) formulated a dynamic linear programming model for Finnish forests using a similar approach, where the vector $\boldsymbol{N}$ indicates the distribution of trees by age and species. The development of the forest is described by an expansion of equation (4.17) to:

$$\boldsymbol{N}_{t+1} = \boldsymbol{P}\boldsymbol{N}_t + \boldsymbol{P}_1\boldsymbol{A}_t - \boldsymbol{P}_2\boldsymbol{H}_t \tag{4.18}$$

where $\boldsymbol{A}_t$ is a vector of planting activity, $\boldsymbol{H}_t$ is a vector of harvest activity, and $\boldsymbol{P}_1$, $\boldsymbol{P}_2$ are matrices.

In one sense, this is a variant of the diameter distribution model in which a vector that specifies the age distribution of trees is projected using a Markov-type "growth matrix". The difficulty with this, and the succession models, is in estimating the values of the elements of the matrix $\boldsymbol{P}$.

Finally, Vályi and Tóth (1984) constructed a dynamic simulation model of Hungarian forests. Their approach is both a variant of the yield table (age distribution) models and an extension and elaboration of the forest succession model described by Shugart *et al.* (1973). In this case, area by species and age group is the basic simulation unit, and forest dynamics are defined as:

$$\boldsymbol{X}_{t+\mathrm{d}t} = \boldsymbol{X}_t + \mathrm{d}t f(\boldsymbol{X}_t,t) \tag{4.19}$$

where $\boldsymbol{X}_t$ is a vector representing the state of the system, and $f(\boldsymbol{X}_t,t)$ is a nonlinear function describing system behavior.

Functions that describe growing stock, growth, forest decay, aging, harvesting, and forest area/afforestation relationships are defined. This is, in principle, a full definition of forest dynamics. As with other examples of dynamic simulation (such as individual-tree simulation) the derivation of simulation parameters valid for the region as a whole presents problems. The model can be used, nevertheless, to simulate the relative effect of alternative forest policies (Vályi and Tóth, 1984).

4.6. Summary

The treatment of forest dynamics includes projections of timber inventories in conjunction with adjustments to short-run timber supply functions.

Both components are essential in estimating long-run timber supply. There are a number of methods available for timber inventory projection, but, to date, few have been used in conjunction with large-scale models of production and consumption. To some extent this is because of the difficulty of extending established stand-growth modeling techniques to large areas, which requires aggregation over stand and forest characteristics often considered important to the reliability of growth estimates.

The most serious difficulty encountered in assembling a model of forest resource dynamics is not, however, the choice of an appropriate methodology, but the lack of consistent, comparable data for many regions. The extent of US experience in developing and using timber inventory projection models can be attributed to the existence of continuous forest inventory data collected for over 30 years. This empirical foundation, in conjunction with policy questions relating to the long-term condition of forest resources, has stimulated the development of a variety of approaches.

The inventory projection methodology that can be applied to all regions in a global forest sector model is likely to be the simplest approach. The minimum requirements for a model of forest dynamics are given by equations (4.1) and (4.2). This represents a starting point, to which elaborations can be added as data are available, and as detail is required in the representation of the forest resource component of a model of production, consumption, and trade.

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CHAPTER 5

Economic Models of Timber Supply

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Timber supply models link ecological information on forest growth and development to the economic system. Taken narrowly, economic variables must be considered to explain how forest owners in market economies manage their forests. More broadly, modeling timber supply requires an understanding of the optimal allocation of resources — land, labor, and capital — to the production of timber.

Modeling timber supply is complicated by the temporal linkages between current harvest levels and future forest productivity. Averaged over a long period of time, timber growth determines annual output. But, to a large degree, growth is determined by the amount of timber inventory that is held. Annual harvests deduct from the inventory and, therefore, affect the long-run output of the forest.

Early work (e.g., Duerr, 1960) recognized these linkages, but for many years the analytical tools required for a complete analysis of the problem were not available. Consequently, timber supply analyses developed along two lines. Long-run supply models examined a steady-state world in which prices and costs were known and enough time was available for the inventory level to adjust to economically optimal levels. Because of its historical importance and continuing practical utility for some long-range planning problems, we begin this chapter with a discussion of the long-run supply model.

Short-run models recognize that significant fluctuations in harvest levels accompany the observed annual fluctuations in timber prices. The problem is to explain the relationship between annual harvest levels and prices, without concern for the long-run development of the timber inventory itself. Because of their comparatively strong empirical foundations, these models have proved to be quite useful in describing stumpage prices and harvest levels on a quarterly or annual basis. Consequently they have found wide application in forest sector analysis. This approach is dealt with in Section 5.2.

Work during the past decade has attempted to unify the short- and long-run theories of timber supply. One branch of analysis retains the positive elements of the earlier long-run theory — that forest owners make decisions as though they were maximizing the net present value of timber receipts — but explicitly models the transition from the current timber inventory to the long-run steady-state. While the behavioral assumptions of this approach are restrictive, a small body of empirical work supports its use. These transition models of timber supply are discussed in Section 5.3.

The second branch of recent work has broadened the positive model of behavior to include utility derived from both the timber and nontimber outputs from the forest and has also explicitly modeled the transition process. These models, similar in structure to household production models, are discussed in Section 5.4.

None of these models is wholly suitable for forest sector analysis. The empirical short-run models, in wide use today, lack an adequate theoretical basis. On the other hand, there is not sufficient empirical experience with the more theoretically satisfactory models to permit their use in forest sector analyses. In Section 5.5 we detail these shortcomings and suggest some particularly important avenues for further research.

5.1. Long-Run, Steady-State Models

The period of analysis for the long-run, steady-state model is adequate for the capital stock to adjust to the economically optimal steady-state level. The period of time necessary for this condition to be met depends on the initial age structure of the forest, the level of demand, and the underlying biological productivity of the forest; it might range from less than a decade to more than a century. Consequently, this model is useful primarily as a long-range planning tool to assess such problems as the amount of land needed to support a particular level of demand, and the average and marginal timber production costs. In Section 5.3 the transition to the long-run, steady-state situation is discussed.

This model of timber supply dates at least to Vaux's (1954) analysis of sugar pine production in California and has been used many times since: for the Douglas fir region of the US by the USDA Forest Service (1963) and by Hyde (1980), for California by Vaux (1970), for Sweden by Jungenfelt (1973), for pine in the southern US by Robinson *et al.* (1980), and for the spruce-fir resource in Maine by Binkley (1983a). Jungenfelt (1973), Jackson (1980), Hyde (1980), Chang (1983), and Binkley (1985a) discuss some of the theoretical aspects of the model.

Long-run supply $Q(p)$ can be divided into two parts, the supply per unit area and the area in production:

$$Q(p) = \sum_{j \in J(p)} A_j \, S_j(p) \tag{5.1}$$

Here, A_j is the area of land type j, $S_j(p)$ is the supply per unit area for land type j, and $J(p)$ is the set of land units in production. Generally, the A_js are taken as given (although land reclamation and/or the management of accreted lands could be included in the model). The index j might refer to productivity classes, timber types, access zones, ownerships, or other factors that the analyst thinks might influence supply behavior (in the discussion below the subscripts are omitted when the meaning is clear without them). The set $J(p)$ indicates which land units are in production and is a function of the price level and the other parameters of the model, such as the interest rate, biological technology, and production costs. Supply per unit area, $S(p)$, depends on management practices. We begin with a discussion of the supply per unit area, and then turn to the area in production.

5.1.1. Supply per unit area

Supply per unit area for a particular land type depends on the management decisions of the landowner, which in turn depend on timber price and other relevant parameters [1]. These decisions determine the level of timber production. Production is translated into supply through the assumption that the forest has an equal area in each age class.

Landowner behavior

The forest owner selects the rotation age t^* and level of silvicultural effort E^* that maximize the net present value, π, of timber receipts summed over an infinite planning horizon. Capital markets are taken as perfect so the forest owner can lend and borrow at a constant, known interest rate i. (Equivalently, land markets perfectly reflect the present value of partially grown stands.) Timber yield, $v(t, E)$, per unit area is a known function of stand age t and management intensity E. There is no technical change, so the yield function does not change over time. Thus, $v_t > 0$, $v_E > 0$,

$v_{tt} < 0$, $v_{EE} < 0$, and $v_{tt}v_{EE} - v_{tE}^2 > 0$, where subscripts refer to partial differentiation with respect to the subscripted variable [2]. Silviculture costs w per unit E, an amount that is constant in real terms through time and is independent of E. The even-aged forest is regenerated promptly after clear-cutting, if it is profitable to do so.

These assumptions imply that the optimal mangement problem is stationary, so the owner of land of type j solves [3]:

$$\max_{t,E} \ \pi_j(t,E) = -wE + pv_j(t,E)\mathrm{e}^{-it} + \pi_j(t,E)\mathrm{e}^{-it} \qquad (5.2)$$

The management decisions $t^*(p)$ and $E^*(p)$, and therefore the output level, vary with price. In principle, w and p might differ across land classes; we return to this point below.

The first-order optimality conditions for $t^*(p)$ and $E^*(p)$ can easily be found (see Jackson, 1980; Hyde, 1980; Chang, 1983) by solving:

$$\frac{\partial \pi_j}{\partial t} = \frac{\partial \pi_j}{\partial E} = 0 \qquad (5.3)$$

The optimal rotation problem is well studied (the bibliographic note in Samuelson, 1976, and Löfgren, 1983, give interesting historical sketches of the problem), but the management problem is of more recent interest. *Table 5.1* summarizes some of the pertinent comparative statics results.

Timber supply

Given the optimal rotation age and management intensity, how much timber will be produced? "Long run" means that capital can adjust to the economically desirable level. For timber production, this means that the steady-state forest will have no timber older than the optimal rotation age $t^*(p)$ and that each year any timber reaching this age will be harvested. Averaged over a rotation, the annual output of a unit area of forest will be $v(t,E)/t$, so the supply function per unit area for land class j is given by:

$$s_j(p) = \frac{v_j[t_j^*(p), E_j^*(p)]}{t_j^*} \qquad (5.4)$$

A "fully regulated" or "normal" forest has an equal area in each age class and therefore produces identically the long-run, average annual output each year. Even under the fairly restrictive assumptions used here, it is

Table 5.1 Long-run comparative statics (Chang, 1983).[a]

	p	w	i
t^*	$-$ a, b ? c	$+$ a, b ? c	? a, b $-$ c
E^*	$+$ a, b ? c	$-$? c	? a, b $-$ c

[a] The table gives the sign of the derivative of t^* and E^* with respect to a particular parameter:

Cases a for $V_{t_m} \leq 0$

b for $V_{t_m} > 0$ and $V_{tE} < \frac{w}{p}\, ie^{-it} < 0$

c for $V_{t_m} \geq 0$ and $V_{tE} > \frac{w}{p}\, ie^{-it}$

not clear that market forces will produce a normal forest or a constant level of output (Section 5.3, which discusses transition models, returns to this point). Given the uncertainties of demand, costs, and biological production, a constant annual output is highly unlikely. Consequently, the level of output described by the long-run supply model is best regarded as a potential level of production averaged over a fairly long period of time.

5.1.2. Land in production

For each land class, equations (5.3) and (5.4) give the supply per unit area if the land is used for timber production. Which land classes are used for timber production, which are used for other purposes, and which are left idle? The answer depends on the value of land when put to timber production relative to its value in other uses. Forest land value is endogenous to the long-run model. Under the assumptions given above, land values r_j will adjust so the net present value associated with the purchase of land for timber production will be zero (see Samuelson, 1976, on this point), or:

$$\pi_j - r_j = 0 \tag{5.5}$$

To be included in $J(p)$, a particular land class must meet the two tests:

$$r_j > \text{value in an alternative use, and} \tag{5.6a}$$

$$r_j > 0 \tag{5.6b}$$

The first [test (5.6a)] defines the intensive margin for forestry, that is, the land classes that are too valuable to be used for timber production. The second [test (5.6b)] defines the extensive margin, or the set of land types where timber production is not profitable and the land is left idle.

The details of forest land-use are poorly understood. Ledyard and Moses (1974) give perhaps the best theoretical treatment of the question. Binkley (1983b) comments on some of the shortcomings of traditional approaches to forest land-use questions.

One analytical approach to the forest land-use problem characterizes land classes by an access cost variable x per unit volume. Here, the net price $p = p' - x$, where p' is the delivered log price, and the sum in equation (5.1) becomes an integral over the access cost plane from zero to the extensive margin. The extensive margin occurs where the present value function $\pi^*(x) = 0$ or where $x = p' - wE^*(x)/ve^{-it^*(x)}$ (one might expect that $E^* = 0$ at the extensive margin).

Both t^* and E^* are functions of net price $p' - x$, so both management decisions depend on the location of the forest. (Dykstra, 1981, has reviewed the effect of spatial factors on forest management practices.) In particular, in most cases we would expect the less accessible forests to have a longer optimal rotation age and a lower optimal level of management intensity than the more accessible forests. It is therefore possible that more distant forests will have a higher level of supply per acre than the more proximate ones.

5.1.3. Practical application and limitations

The long-run supply model can be implemented with technical information on timber yield, management costs, and land characteristics. An anticipated price level is chosen and for each j equation (5.3) is solved for $t_j^*(p)$ and $E_j^*(p)$. The maximization can be done numerically or with reference to the first-order conditions (see Binkley, 1985a, for a description of the latter approach). For all land classes, $\pi_j(t_j^*, E_j^*)$ is computed using equation (5.2). Supply at that price is then found using equation (5.1), where the sum is carried out over $J(p)$ found by tests (5.6). The calculations are repeated with a range of anticipated prices until the supply curve is identified with a precision adequate for the problem at hand.

Note that the long-run forest is self-financing in the sense that annual cash receipts (pv/t) will exceed annual cash outlays (wE/t). A positive, net cash flow can be generated, even in cases where land has a negative net present value.

The long-run supply curve may bend backward (Hyde, 1980). The rotation that maximizes the average yield occurs where:

$$p = \frac{wE}{v}\left[\frac{1}{1 - \dfrac{1 - e^{-it}}{it}}\right]$$

(Binkley, 1985b), and at this point supply for a particular land class is maximized. Higher prices lead to shorter optimal rotations and to a lower supply for an individual land class. Of course, higher prices also lead to higher levels of management intensity and more land in timber production, both of which increase supply. Once the possibilities for these adjustments have been exhausted, the regional long-run supply curve will bend backward toward an asymptote determined by production costs and the biological productivity of the forest (Binkley, 1985b).

Several assumptions of the long-run model limit its utility for forest sector analysis, of which two bear particular mention here. First, by focusing on long-run production costs, the important questions of resource dynamics and short-run adjustments to changing economic conditions are ignored. Thus, the model provides little insight into price and quantity development as the timber resource moves from its initial condition toward a steady-state situation. This adjustment process is apt to take several decades, so the long-run model provides information about events well beyond the planning horizon of many decision makers.

This limitation is particularly serious in attempts to use the model for policy analysis. For example, the long-run model has been widely used to examine forest tax policies (e.g., Jackson, 1980; Chang, 1983). However, these studies implicitly ignore the short-run, transitional effects of alternative tax policies. Because changes in the long-run forest take so long to develop, the transition effects of alternative tax policies may be far more significant — in terms of the net present welfare effects, of the impact on forest product markets, and of the impact on the biological characteristics of the forest — than the long-run changes [4].

Second, forest management decisions may be taken with reference to objectives other than the maximization of timber receipts alone. Hartman (1976) extended the behavioral model to include certain types of nontimber benefits. Bowes and Krutilla (1985) have extended the theoretical treatment of this model.

Suppose nontimber values $G(v)$ from the forest can be modeled as a function of the standing inventory v. Then the net present value function can be written as:

$$\begin{aligned}\pi(t,E) = \quad & -wE + pv(t,E)\mathrm{e}^{-it} + \int_0^t G[v(z,E)]\mathrm{e}^{-iz}\,\mathrm{d}z \\ & + \pi(t,E)\mathrm{e}^{-it}\end{aligned} \tag{5.7}$$

The effect on t^* and E^* of the inclusion of nontimber benefits depends on the sign of G_v and the relative magnitudes of G and $pv(t)$. Hartman (1976) assumed that $G_v > 0$ and showed that the optimal rotation age lengthened with respect to the case in which nontimber benefits were ignored. It is also clear that the optimal level of management intensity is higher in this model than in the case where nontimber benefits are ignored [5]. Both effects — the lengthening of the rotation and the intensification of silvicultural effort — will, in general, increase supply per acre. In some cases (see, e.g., Bowes *et al.*, 1984) the presence of nontimber forest values also increases the area of land that is economically suitable for timber production. Paradoxically, then, the presence of nontimber forest values may actually increase timber supply over the situation in which those values are absent.

5.2. Short-Run Models

Many forest-sector decision problems require information about the development of timber and product prices over a relatively short period, perhaps quarterly or annually. On this time scale, timber demand is likely to fluctuate significantly. In the long-run model, anticipated demand is fixed and supply is determined by rotation age, management intensity, and land area. In the short run, however, the technical capacity to adjust these variables is quite limited. Consequently, the long-run model is not very useful in explaining the short-run development of timber prices.

Instead, attention is focused on the level of harvest from an inventory of timber, which is regarded as fixed. In principle this problem could be treated as one of expected wealth maximization with uncertain demand. The supply in one period would then depend on current prices, price expectations, and on current and expected costs, including land rents and the opportunity costs of the growing stock itself.

5.2.1. Model structure

Extant studies of timber supply have not taken this tack. Instead, timber supply is estimated statistically as a function of price, inventory, and perhaps other variables. These studies generally use time series data for large aggregations of landowners, although there is no particular reason why these models could not be estimated using cross-sectional data or pooled samples.

The general form of the aggregate short-run timber supply model is given by:

$$Q = f(p,I,Z) \tag{5.8}$$

Here, Q is the annual harvest, p is the current price, I is the current inventory level, and Z is a vector of other factors thought to influence supply.

Price generally enters with a positive sign, reflecting several different phenomena. Higher stumpage prices mean that more of the timber inventory is economically accessible for harvest, and also that the nontimber forest uses, with which timber harvest competes, have a lower value relative to timber production. In some cases, lagged variables have been used in modeling adaptive expectations.

Several variables are obvious candidates for inclusion in Z. Higher discount rates increase the opportunity cost of the timber inventory and would, therefore, be expected to have a positive association with short-run supply. The literature suggests that ownership characteristics, such as the average size of holding, the number of farm versus nonfarm owners, or the average household income, might affect timber supply (e.g., Binkley, 1981a; Boyd, 1983).

The inventory term generally has a positive sign. At higher inventory levels, the harvesting costs are likely to be lower, as will the impact of harvest on nontimber forest values.

The inventory term in the supply equation helps guarantee that an integrated forest sector model possesses the long-run behavior expected from economic theory (see Section 5.3). This theory suggests that timber prices should rise as the timber inventory is drawn down. A region becomes less competitive as its timber prices increase, so timber processing capacity should shift out of that region. Combined with a capacity adjustment model that is sensitive to profitability (see Chapter 8), specification of the short-run, timber supply equation with an inventory term will assure this pattern of adjustments.

Because the timber inventory usually changes only slowly, it is sometimes not possible to obtain usable statistical estimates of the inventory term in equation (5.8). In such cases, the supply variable can be recast as

Table 5.2 Aggregate short-run supply models.

	Region	*Product*	*Ownership detail*
Robinson (1974)	US	Softwood sawtimber used in lumber production	None
Adams and Haynes (1980)	8 regions in the US	Softwood sawtimber	Separate equation for forest industry and other private
Cardellichio and Veltkamp (1981)	3 regions in the US	Softwood sawtimber used in lumber and plywood production + log exports	Private owners together
Lange (1983)	4 regions in the US	Hardwood sawtimber	Separate equations for forest industry and other private
Binkley and Cardellichio (1985)	Eastern US	3 grades of hardwood sawtimber	None
Bränlund *et al.* (forthcoming)	Sweden	Pulpwood and sawtimber	None
Adams (1985)	3 regions in Africa	Logs	None
Kanniainen and Kuuluvainen (1984)	Finland	Sawlogs	Private nonindustrial owners
Kuuluvainen (1983) (also 1982)	Finland	Sawlogs	Private nonindustrial owners

the ratio of harvest to inventory and the inventory variable can be omitted from the right-hand side. This specification implicitly constrains the supply elasticity to be unity. For example, consider a supply function specified as:

$$Q/I = f(p,Z) \tag{5.9}$$

Variables included		
Inventory	*Z*	*Comments*
No	Interest rate	Uses lumber production to proxy for harvest
Yes ($\epsilon_I = 1$ in some cases)	None	Constrain coefficients for some regions/owners
$\epsilon_I = 1$	Lumber and plywood prices	Quarterly data, price is dependent variable, PDL on quantity
Yes ($\epsilon_I = 1$ in some cases)	None	–
$\epsilon_I = 1$	Real disposable personal income	–
No	Harvest cost and lag-one price in pulpwood equation	Discount rate not statistically significant
No	None	–
No	Sawlog stocks held by mills, lag-one price	Examines rate of sawtimber price changes
Yes	After-tax household income	Explicitly includes inventory adjustment process. Distinguishes sawtimber *sales* from *fellings*, semiannual data

The inventory elasticity of supply in this model is:

$$\epsilon_I = \frac{\mathrm{d}Q}{\mathrm{d}I} \cdot \frac{I}{Q} = f(p,Z) \cdot \frac{I}{Q} = 1 \tag{5.10}$$

Table 5.2 summarizes some of the key features of short-run timber supply studies found in the literature. Most of the extant work uses annual rather than monthly, quarterly, or semiannual data. With few exceptions, discount rates and lagged prices (variables that are, in theory, important in describing supply behavior) have been omitted from the analyses. Several of the studies lump all ownerships together, despite evidence that different ownerships have different supply characteristics. This practice is particularly inappropriate when public supply is an important factor. Most of the work treats stumpage as a homogeneous commodity without any distinction between pulpwood, fuelwood, and various quality sawlogs. Yet high-quality sawlogs might be two orders of magnitude more valuable than pulpwood or fuelwood. Little effort has been made to explicitly incorporate the impact of nontimber forest outputs on timber supply.

Kuuluvainen (1985) has taken an important step toward integrating long- and short-run supply models by explicitly incorporating timber inventory dynamics into his empirical estimates of the short-run supply function. Unfortunately, statistical considerations forced him to assume that forest growth was negligible and hence his empirical work stressed the stock rather than the renewal features of the timber inventory. He also distinguished timber *sales* from timber *harvests*, so that he could explicitly model the timber stocks held by sawmills. Consequently, timber demand can fluctuate independently from final product demand. This perspective has important implications for the derived-demand approaches discussed in Chapters 12 and 14.

An interesting line of work uses short-run, timber supply functions to examine the behavior of imperfect markets. Following the work of Lowrey and Winfrey (1974), there have been several studies of supply in markets characterized by monopsony. Johansson and Lõfgren (1983a) examined price discrimination in Swedish roundwood markets. Binkley (1981) analyzed supply in the case where a firm can either buy timber in a market over which it has monopsony control or supply it from its own lands. Johansson and Lõfgren (1985a) modeled short-run supply in Sweden as a bargaining game between the forest industry and nonindustrial timber suppliers.

5.2.2. Limitations of the short-run model

Although aggregate, short-run supply models are widely used in forest sector analysis, they have several important weaknesses. In the first place, comparatively little attention has been paid to their theoretical foundations. The work by Brännlund *et al.* (1985) is unique in this respect, analyzing short-run supply with a transition model of the type discussed in the next section. This work, however, abstracts from key issues, such as the formation of price and cost expectations, and ignores the role of non-timber forest outputs in determining timber supply. In addition, their empirical work excludes many of the explanatory variables that the underlying theory indicates are important.

In the second place, the data used to estimate these models typically are poor. To illustrate the kinds of data problems that arise, the remainder of this section describes some of the shortcomings of US data on stumpage prices, harvest levels, and timber inventory characteristics.

Regional stumpage prices generally reflect a shifting mix of different qualities of timber. The mix can change over time: as better timber is logged only lower quality or less accessible timber remains. The mix can also change endogenously as higher stumpage prices bring into the market material that would not be harvested in periods of low demand. The latter problem is particularly troublesome for short-run supply analysis. Observed stumpage prices will vary less than the appropriate "quality-adjusted" prices and the supply elasticity will be systematically overestimated.

The stumpage price series for private timber sales generally are poor, with the sampling characteristics of the data being generally unknown. In many cases only price ranges are given and it is quite difficult to develop a single measure of central tendency for a particular year. The data must be averaged across species, but the species weights generally are not known with precision.

Faced with these difficulties, the timber supply analyst is tempted to use the price records from public timber sales, particularly those from the national forests, to represent private sales. However, these sales typically carry restrictions that private sales do not and so may have quite different timber characteristics and harvest costs. Chapter 6 comments on other drawbacks of using the public timber sales series to represent private sales.

In the US there are no reliable time series on timber harvest levels. Three methods have been employed to derive these data, each with serious defects. First, the USDA Forest Service estimates timber removals as part of their forest survey responsibilities. However, these estimates are made only on a state-by-state basis, and more than 10 years may lapse between measurements. There are no published studies that estimate short-run supply models using these data as a cross-sectional sample, and my own attempts have proved disappointing.

Second, some states levy yield taxes. Combined with a time series on prices one can estimate harvest levels from these data. This procedure assumes that all timber harvests are reported and the yield tax is paid. In one state I determined that perhaps 30% of the timber harvest escaped yield-tax payments.

Third, harvest levels can be derived from published series on product output. All of the US studies to date use this approach. There are at least four potential sources of error in this procedure:

(1) The recovery rate (ratio of product output to log input) is not known with certainty. Furthermore, there is some evidence that it changes endogenously, falling in market peaks and rising in market bottoms (see Chapter 6 on this point).
(2) The product output series may be unreliable. For example, the official estimates of hardwood lumber production in the US may understate the true level by as much as one third (Cardellichio and Binkley, 1984), and the official estimates of softwood lumber production in the southern US are probably low by a similar fraction.
(3) To estimate total harvests from production data one must also estimate felling losses and other forms of harvest that are taken to be exogenous to the market at hand (e.g., sawtimber removals for pulp production). These losses are surveyed only periodically and may change in response to changes in timber price.
(4) Using production data it is not possible to identify the ownership source of the harvest. In situations where ownership characteristics are thought to be important determinants of supply this is a serious limitation.

Most of the work to date recognizes that the size of the timber inventory affects short-run supply behavior. Yet rarely is a suitable time series on this variable available. All of the US studies to date make use of four estimates — 1952, 1962, 1970, and 1977 — of timber inventory made by the USDA Forest Service. There are at least two sources of error in this procedure. First, these national estimates are aggregated from state level surveys, some of which are more than 10 years out of date. Second, annual time series are constructed either by linear trends between these points or by using a timber inventory projection system (see Chapter 4) to estimate the annual inventory levels. Thus, the annual inventory series are surely measured with error.

In sum, empirical models of short-run timber supply behavior are seriously constrained by the available data. Furthermore, the theoretical basis for the empirical models is weak. These shortcomings are particularly worrisome when the supply models are used for welfare analysis.

5.3. Transition Models

Transition models grew out of modern approaches to the problem of harvest scheduling. They explicitly link supply in one period to forest growth and supply in other periods. The assumptions are similar to those for the long-run steady-state supply model: future yields are known with precision, capital markets are perfect, the landowner maximizes the net present value of timber receipts, demand is known but (unlike the long-run model) may differ between periods. Indeed, the long-run model discussed in Section 5.1 is a special case of the transition model.

5.3.1. Forest dynamics

The simplest formulation of the problem starts with the equations that describe forest dynamics (this development follows closely that of Berck, 1976, and of Johansson and Lõfgren, 1985b) [6]. Even-aged stands comprise the forest. Period t finds x_{ti} hectares in age class i, of which $c_{ti} \geq 0$ are harvested. Each hectare of age class i produces v_i units of volume. The yield function is asymptotic so that for practical purposes, an oldest age class N can be defined (i.e., $v_i = v_N$ for all $i \geq N$).

The dynamics of the forest can then be written as:

$$x_{t+1,i+1} = x_{t,i} - c_{t,i} \qquad \text{(aging)} \qquad (5.11a)$$

$$x_{t+1,N} = x_{t,N} + x_{t,N-1} - c_{t,N} - c_{t,N-1} \qquad \text{(oldest trees)} \qquad (5.11b)$$

$$x_{t+1,0} = \sum_{i=1}^{N} c_{t,i} \qquad \text{(regeneration)} \qquad (5.11c)$$

$$Q_t = \sum_{i=1}^{N} c_{t,i} v_i \qquad \text{(annual supply)} \qquad (5.11d)$$

$$x_{t,i} \geq c_{t,i} \geq 0 \qquad \text{(harvest area restrictions)} \qquad (5.11e)$$

5.3.2. Behavioral assumptions

The system (5.11) gives the correct dynamics for an infinite planning horizon, although most applications restrict attention to the first T periods, using the argument that with discounting the residual value left after these periods can be made as small as necessary, if T is suitably chosen.

As long as the standing inventory has any positive value, this specification guarantees that the model solution will leave no timber standing after period T. To overcome this limitation one may either specify that the ending inventory meets certain restrictions or add a term to the objective function to reflect the value of the ending inventory. Here the asymptotic properties of the system provide some guidance. If, in the long run, the forest tends towards normality, one can specify that the ending inventory has an equal area in each age class. Alternatively, the objective function can include a term that reflects the steady-state value of the forest calculated using the procedures outlined in Section 5.1.

A set of demand equations, one for each period, identifies supply in the transition model. Extant work can be distinguished on the basis of the assumed properties of the demand system. *Harvest scheduling* models generally refer to an individual forest property (see Johnson and Scheurman, 1977, for a good review). At this level, demand can be regarded as perfectly elastic. The objective is then linear and the harvest schedule can be solved as a linear programming problem [7].

If prices are constant, the solution is determined entirely by the initial age class distribution of the forest (i.e., by $x_{0,i}$). In this case, the optimal harvest schedule is defined by:

$$c_{t,i} = 0 \text{ if } i < t^* \tag{5.12a}$$

$$c_{t,i} = x_{t,i} \text{ if } i \geq t^* \tag{5.12b}$$

where t^* satisfies equation (5.3). If prices are not constant, then Berck (1976) has shown that it may be optimal to harvest younger trees before older ones, so the solution cannot be characterized so simply.

Partial equilibrium models are used to examine the operation of a competitive stumpage market by choosing the harvest levels that maximize the discounted value of consumer's surplus:

$$\max_{c_{t,i}} \sum_{t=0}^{\infty} \int_{0}^{Q_t} p(z) \, dz e^{-it} \tag{5.13}$$

This problem is a comparatively simple, nonlinear programming problem because all of the constraints are linear. Berck (1976), Lyons (1981), Johansson and Lõfgren (1985b), and Lyons and Sedjo (1983) discuss the theoretical aspects of this model. It has been applied by Berck (1979) to the US Douglas fir region, and to the Pacific Northwest more broadly by the Pacific Northwest Forest Policy Project (Rahm, 1981; Bruner and Hagenstein, 1981).

Several interesting theoretical results have been obtained from the partial equilibrium model:

(1) Timber markets possess a conventional, neoclassical market equilibrium (Berck, 1976; Johansson and Lõfgren, 1985b).
(2) An increase in demand in a given period leads to an increase in supply in that period and a nonpositive change in supply in all other periods (Johansson and Lõfgren, 1985b; Binkley, 1984) [8].
(3) With constant demand, the long-run price changes are bounded (Berck, 1976).

Will the equilibrium harvest policy derived from this transition model converge over time to produce identically the long-run, average annual output each year? Probably not: Berck (1976) showed that the changes in price (and therefore in harvest levels) are bounded and he speculated that the "equilibrium model will settle to a stable equilibrium with an even age distribution if it is specified in continuous time" (p 79). Using a related continuous time model, Heaps (1984) found some evidence for convergence of the harvest levels, but only proved that they are periodic [and therefore meet the "average" supply condition given in equation (5.4)]. Mitra and Wan (1985) showed that the forest converges to a so-called "normal forest" with an equal area in each age class if the discount rate equals 0. In this case the annual output is obviously constant. They also provided counterexamples, which showed that with positive discount rates the forest will not generally converge toward normality and that the annual output will fluctuate. Kemp and Moore (1979) presented results from several special cases of a continuous time model in which the convergence was globally asymptotic. The preliminary results of a discrete-time, multiple region model of Lyons and Sedjo (1985) showed no signs of regional harvest stability, although the total harvest did converge quite smoothly. In sum, the long-run behavior of even comparatively simple transition models is not altogether clear.

5.3.3. Limitations

The power of the transition models lies in their ability to explicitly link short- and long-run supply behavior. With these models, a demand change in one period affects supply in all other periods.

This strength is precisely their weakness. The model assumes rational expectations in the sense that forest owners can perfectly anticipate demand and supply from other lands over a very long, if not infinite, planning horizon. There is some evidence that forest markets operate this way (e.g., Berck, 1979; Johnson and Libecap, 1980), but this degree of foresight remains a rather bald and unconvincing assumption.

As a practical tool for short-run price forecasting, the transition model is limited by the demand structure assumed for it. In the short run, timber demand is based on the productive capacity of timber processing facilities in the region. Mill capacity in turn depends on past and future timber prices. Consequently, short-run demand is determined endogenously, a consideration that has not been satisfactorily incorporated in transition supply models [9].

The importance of this problem depends on the length of time required for capacity to adjust compared with the forecast interval. For very long-run models with a rather large time step, the pace of capacity adjustment may be fast enough to render demand endogeneity untroublesome. For annual models, however, or for situations in which long-lived capital, such as pulp mills, is important, attention must be paid to this problem.

Finally, the transition supply approach outlined above models timber inventory dynamics as a function of stand age alone. As with the long-run model, the choice of management intensity and the allocation of land should be determined endogenously. Several implementations of this model ignore management intensity (e.g., Berck, 1976, 1979; Johansson and Löfgren, 1985b). Some of the work that treats management intensity endogenously ignores land-use questions (e.g., Lyons and Sedjo, 1983). The Forest Policy Project used a crude, iterative procedure to determine both management intensity and land use in response to demand and cost scenarios.

5.4. Household Production Model

In many parts of the world forests are owned or controlled by agents with important interests in the nontimber outputs from their land. Because the landowner "consumes" these nontimber outputs, it is natural to adopt a household production perspective on the timber supply problem. The household makes decisions as though it were maximizing utility defined over income and nontimber forest outputs. Income is generated by timber production, work off the forest, and perhaps by an exogenous endowment. Technical constraints describe the relationship between timber and nontimber outputs, as well as the development of the timber inventory over time.

A general form of the model is:

$$\max \int_0^\infty u(R,y)e^{-it}\, dt \tag{5.14a}$$

subject to

$$y(t) = y^e(t) + w\, l^w(t) + p(t)\, Q(t) - c(t) \tag{5.14b}$$

$$R(t) = F(I,Q,K,l^R) \tag{5.14c}$$

$$\dot{I} = G(I,K,l^F) - Q(t) \tag{5.14d}$$

$$L = l^w + l^R + l^f \tag{5.14e}$$

Here, $u(R,y)$ is the utility function, $u_R > 0$, $u_y > 0$, $u_{RR} < 0$, $u_{yy} < 0$, $u_{Ry} > 0$; R is the nontimber forest output; y is the income; t is the time period; $y^e(t)$ is the exogenous income; p is the stumpage price; Q is the harvest level; c is the land-holding cost (including taxes); F is the "multiple use" function; G is the forest growth function; I is the level of forest inventory; L is the labor endowment; l^w, l^R, and l^F are the times allocated to off-forest work, leisure, and forest work, respectively; w is the off-forest wage rate; and K is the capital endowment.

In versions of this model in which either there is no endogenous wage income (Binkley, 1981a; Boyd, 1983) or there is an income target (Johansson and Löfgren, 1985b), price has an ambiguous effect on timber supply. Higher timber prices increase the income of the forest owner. With a higher income, the owner values recreation more, and therefore reduces timber production in order to increase nontimber outputs. Therefore, an increase in timber price might lead to a decrease in timber supply. This income effect leads to other interesting model results:

(1) Supply is greater at lower levels of income.
(2) Increases in fixed costs, such as taxes, lead to a higher level of supply.
(3) A reduction in the wage rate leads to a higher level of timber supply.

To date, the full model (5.14) has not been studied, but various simplifications have been analyzed, as summarized in *Table 5.3.*

Household production models offer obvious advantages for forest sector analysis. The nontimber aspects of forests are explicitly considered along with the capacity of the forest to produce landowner income. The forest sector is linked, via income and wages, to other sectors of the economy, and the dynamic aspects of timber growth can be explicitly modeled. The drawbacks to the use of this sort of model are primarily empirical.

If the model is used directly, believable empirical estimates of the utility and multiple use functions are required. Estimating the multiple use function remains one of the thorniest problems in forestry.

Econometric estimation of the model requires detailed information on landowner and ownership characteristics. The requisite data are not routinely assembled in the standard sources and are expensive to collect. For some planning purposes (e.g., transportation and agriculture) considerable effort has been devoted to the estimation of these microanalytical models, but no comparable effort has been made for the forest sector.

Finally, there is the problem of aggregation. Extant, empirical household production models of timber supply have been developed to explain the behavior of individual landowners. No attempt has been made to aggregate these models to represent an entire forest region. Nor has the alternative application of the model to "representative" households been pursued. Some guidance here can be obtained from the agriculture literature (Strauss, 1986).

5.5. Conclusions

Thirty years of work on timber supply analyses have given forest sector modeling a good base of experience for further progress. What are the most important steps?

Timber supply models link the ecological and economic components of forest sector analyses, but do not do justice to the ecological information that is available. In particular, problems of scale impede the use of more realistic forest growth models. Much ecological information comes packaged in units measuring a fraction of a hectare, whereas the forest sector

Table 5.3 Household production models.

	Dynamics	*Empirical application*	*Policy analysis*	*Comments*
Binkley (1981a)	No	Logit model of harvest probability, New Hampshire	Taxation, size of holding	Includes land area, distinguishes farm and nonfarm owners
Knapp (1981)	Yes	Harvest quantity, same data as Binkley (1981a) augmented by forest survey data	Land markets	Includes analysis of forest characteristics, land markets, and interest rates
Max (1983a,b) and Max and Lehman (1985)	2-periods/ 10 period DP model	Dynamic programming model for Santa Cruz, CA	Taxation	Uses realistic timber growth function, arbitrary multiple-use function
Boyd (1983)	No	Probit model of harvest probability, North Carolina	Taxation, government financial and technical assistance programs	Explicit model of timber and nontimber production
Johansson and Löfgren (1985a)	No	None	Taxation	Emphasizes labor markets, examines income constraints
Johansson and Löfgren (1983)	2 periods	None	Taxation	Includes uncertain prices
Kuuluvainen *et al.* (1984)	No	Logit and average sales models for forest owners in Finland	Size of holdings, forestry training and planning, length of tenure	No explicit theoretical work, omits price and income variables, includes several sociological and landownership variables

analyst needs information aggregated to the level of a region or country. Ecologists have, indeed, tackled some large-scale ecological problems (air pollution, the "greenhouse" effect, and the nuclear winter are examples), but they have not provided much useful assistance in the more mundane problem of large-scale, forest growth modeling.

The quality of extant data severely constrains further empirical work on timber supply models. A unit of effort spent on improving the data series available for timber supply analysis will have a greater return than the same unit of effort spent on estimation techniques or the inclusion of additional explanatory variables. Work is needed on all the series commonly used: stumpage prices, harvest quantities, forest characteristics, and ownership variables. Household production models appear to be a promising avenue for further development. Initial steps toward improved data collection could usefully begin by supporting this line of analysis.

Certain parts of the theory of timber supply have been neglected. Tradition has lavished attention on capital, with comparative little research on land or labor. In part this distribution of research is consistent with the relative importance of the various factors of production: timber production is among the most capital-intensive enterprises known to man. In part it arises from the inability of economists who deal with forests to resist the sirens of the optimal rotation problem.

Land markets offer a particularly fruitful area for further research, since land is an important factor in timber production. The value of forest land is endogenous to most forest sector models. It is a comparatively small step to consider the value of land in other important uses — agriculture and grazing — with which timber production competes.

Furthermore, land markets are an important institution for the operation of capital markets in timber production. Rarely is a premerchantable timber stand sold without the land beneath it. For the widely accepted capital theory model of timber production to apply, land markets must reflect the capitalized value of future earnings from partially grown stands. There is very little empirical evidence that they do.

The first industrial forest plantations in the US were apparently established in the late 1940s. Since then timber prices have risen to cyclical peaks and fallen again at least seven times. A new industry has been invented — southern pine plywood — and still another threatens to take its place — structural particle boards. Real interest rates have been both positive and negative. A catalog of important changes in the forest sector since those trees entered the ground would be long indeed, yet with few exceptions timber supply analysis persist in examining a world of certainty. Short-run models could surely be improved with careful consideration of how price uncertainty affects supply behavior.

Notes

[1] Contrary to the assertions of some (e.g., Nautiyal and Fowler, 1980), the optimal management decisions are the same, whether an individual acre or an entire forest is analyzed, as long as no scale economies originate from the use of the land (see Samuelson, 1976, or Johansson and Löfgren, 1985b, on this point).

[2] Depta (personal communication) argues that for Douglas fir, $v_{EE} > 0$ over the interesting range of management technologies. In this case, the optimal management regime is a corner solution and some of the results in *Table 5.1* change sign. In particular, the return to silviculture increases with increased discount rates.

[3] To show the relative importance of capital, labor, and land in timber production, it is convenient to use a continuous time representation of the timber production process. In each period the net income for a unit of forest can be decomposed into three parts:

$$p\dot{v} = \text{gross annual income} = p\frac{\partial v(t,E)}{\partial t}$$

$$ipv = \text{annual opportunity cost of the growing stock}$$

$$r = \text{annual land rent}$$

In this context, the present value function can be written as:

$$\begin{aligned}\pi(t,E) = {} & -wE + \int_0^t p\dot{v}(z,E)\mathrm{e}^{-iz}\,\mathrm{d}z - \int_0^t ipv(z,E)\mathrm{e}^{-iz}\,\mathrm{d}z \\ & - \int_0^t r\mathrm{e}^{-iz}\,\mathrm{d}z \end{aligned} \tag{5.N3.1}$$

where z is a dummy of integration. To see that this formulation is equivalent to the more familiar point-input, point-output model (5.2), integrate the first integral in equation (5.N3.1) by parts to give:

$$\int_0^t p\dot{v}(t,E)\mathrm{e}^{-iz}\,\mathrm{d}z = pv(t,E)\mathrm{e}^{-it} + \int_0^t ipv(z,E)\mathrm{e}^{-iz}\mathrm{d}z \tag{5.N3.2}$$

Now, substituting equation (5.N3.1) into equation (5.N3.2) gives:

$$\pi(t,E) = -wE + pv(t,E)\mathrm{e}^{-it} + \int_0^t r\mathrm{e}^{-iz}\,\mathrm{d}z \tag{5.N3.3}$$

Integrating the last term, and imposing the condition that land markets are perfect [see equation (5.5)] implies:

$$\frac{r}{i} = \frac{-C + Pv(t,E)\mathrm{e}^{-it}}{1 - l\,\mathrm{e}^{-it}} \tag{5.N3.4}$$

The term on the left hand side of equation (5.N3.4), r/i, is simply the capitalized value of the annual land rents.

[4] These studies also analyze shifts in the tax burden by assumption; this is not necessary. The partial equilibrium effects of taxation are easily incorporated into the long-run supply model (see Commoli, 1980).

[5] If $G_v < 0$ and G is large compared with $pv(t)$ then the optimal rotation shortens over the case where the the standing forest has no value (see Bowes *et al.*, 1984) and the optimal level of management intensity is also reduced.

[6] Many have studied a continuous version of the transition process (e.g., Anderson, 1976; Clark, 1976), ignoring the age structure of the forest. This model is also adopted in household production models (Section 5.4). The forest dynamics are modeled as:

$$\dot{I} = F(I) - Q(t) \tag{5.N6.1}$$

Here, I is the standing inventory at time t, $\dot{I} = (\mathrm{d}I/\mathrm{d}t)$; F is the growth function, $F(0) = F(K) = 0$, $F(I) > 0$ if $0 < I < K$, $K =$ Maximum Biomass; and Q is the harvest level.

This model, while capturing some of the important characteristics of forest growth, ignores the interesting aspects related to the age structure of the forest. In particular, most biological information on forest dynamics relates to the age structure of the forest, not simply its aggregate biomass. Thus, age class model (5.11) is much more realistic for supply analysis.

What is the relationship between the biology underlying the simple inventory model (5.N5.1) and that of the age class model posed in Section 5.3?

Using the same notation as there, but taking all variables and functions to be continuous gives:

$$I(t) = \int_0^\infty x(t,j)\ v(i)\ \mathrm{d}j \tag{5.N6.2a}$$

$$Q(t) = \int_0^\infty c(t,j)\ v(i)\ \mathrm{d}j \tag{5.N6.2b}$$

In general, the dynamics can be written as:

$$x(t + \Delta, j + \Delta) = x(t,j) - c(t,j) \qquad j > 0 \tag{5.N6.3a}$$

$$x(t + \Delta, 0) = \int_0^\infty c(t,j)\ \mathrm{d}j \tag{5.N6.3b}$$

These equations may be rewritten as a system of two-dimensional partial differential equations. Optimal control can be studied in this context.

An interesting special case arises in the fully regulated forest with equal areas in each age class. Consider the case of a fully regulated, unit area forest with a rotation of T years. Without harvest, the dynamics of the forest are:

$$I(t) = \frac{1}{T} \int_{t}^{T+t} v(j)\mathrm{d}j \tag{5.N6.4a}$$

$$\dot{I} = F(I) = \frac{1}{T} [v(T+t) - v(t)] \tag{5.N6.4b}$$

In general, the underlying biological processes in the two models (i.e., F and v) are not the same (although in the special case of exponential growth they are).

[7] The harvest-scheduling problem can also be posed as a problem of imperfect competition, where the owner's objective is maximization of monopoly revenues. With a linear demand function, this is a quadratic programming problem with linear constraints, which can be solved using heuristics (e.g., Walker, 1971) or quadratic programming algorithms (e.g., Johnson, 1976).

[8] Note that this is not the same as for an increase in prices in *all* periods, which is discussed in Section 5.1, where the possibility of a backward-bending, long-run supply curve is presented.

[9] The Forest Policy Project used a heuristic, iterative approach to accommodate the dynamic interaction between timber prices and the location of the demand curve. See Cardellichio and Veltkamp (1981) or Binkley (1983c) for a discussion of this approach.

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Part II

Forest Industry

CHAPTER 6

Modeling Production Behavior in Forest Sector Models

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Production behavior plays a central role in forest sector models. The production process determines the level and shape of the product supply curve; thus, it has a significant bearing on price–quantity equilibria in the product market. The characterization of the production process also determines factor demands. Since equilibrium in the stumpage market is endogenously determined in forest sector models, the representation of factor demands critically affects the simulation properties of these models.

The analysis of production behavior is divided typically into two broad classes — the engineering approach and the economic approach. Engineers and economists are both interested in the process of producing outputs from a combination of inputs by the least-cost method. However, engineers emphasize the details of the production technique and study how the properties of inputs impact the manufacturing process. In contrast, economists focus on how price changes will affect input and output decisions and work with input–output aggregates that mean little to the engineer. Economists generally are content to understand the extent to which relative price changes induce quantity changes, even if little is known about the specific nature of the production process.

Regardless of the approach one chooses for analytical work, one would hope (at some appropriate level of aggregation) to reveal similar properties of the production process, such as returns to scale or the potential for substitution among inputs. The engineer works at an extraordinary level of detail and effectively provides a blueprint of the production process. In many ways, the economist would like to incorporate the engineer's information into his representation of production behavior; however, he must work at a higher level of abstraction to address the price-related issues that comprise his research focus. In his seminal article on the relationship between engineering and economic analysis, Chenery (1949) shows how engineering data can be invaluable in economic analysis; however, he claims that in practical applications, problem formulation and data availability have severely limited the use of engineering information in addressing economic problems. As noted by Walters (1963), the two most serious problems are combining both inputs and processes in a meaningful way.

Rather than build a model from the engineering pieces, the economist almost always constructs his model from a limited set of observations of market behavior. In the economist's search for developing useful abstractions of production behavior, three major approaches can be identified. The first two — the primal and the dual — are based on the neoclassical economic theory of producer behavior. In the primal approach, one chooses the explicit form of a production function and solves the profit-maximization (or corresponding cost-minimization) problem to determine product supply and factor demand functions. In contrast, in the dual approach one begins by selecting a functional form for the profit function or cost function, and then solves the remaining equations in the system. The equivalence of the two approaches stems from the fact that both may completely characterize all economically relevant aspects of a technology (McFadden, 1978; Varian, 1984). For the economist, these are the "theoretically" correct approaches to modeling production behavior. A third approach might be described as the statistical analysis approach to modeling production behavior. Supply and input demand functions are specified arbitrarily without explicit consideration of the underlying technology; however, in a general sense, the specification of production behavior is guided by economic principles. Final model selection depends on a variety of criteria that enhance the ability of these models to explain, forecast, and/or perform as policy simulation tools. Since the philosophy of this method is "choose what works best", it is quite popular in applied work. A brief theoretical review of these three approaches is provided in Section 6.1.

In Section 6.2 we review recent empirical work in estimating production behavior in the US forest sector. This section concludes by discussing some fundamental problems that are inherent in this work due to the limitations of extant data. Special attention is given to the measurement of sawlog prices and quantities, since this is of paramount importance in forest sector production analysis.

In Section 6.3 we discuss an alternative to relying solely on economic formulations of production behavior. This approach moves closer to the engineering end of the spectrum and was developed by Jaakko Pöyry. It has been adopted in the IIASA Global Trade Model in modeling the pulp and paper industry.

In the final section of this chapter we present conclusions and suggest directions for future research. Estimation of production behavior using the neoclassical framework is not likely to generate results that are useful in forest sector models because of the poor quality of the extant data. If analysts hope to improve upon the statistical analysis approaches to modeling production behavior that characterize most forest sector models, an increased reliance on mill-level data and engineering information is necessary.

6.1. Traditional Economic Approaches for Modeling Production Behavior

There are three primary approaches for determining product supply and factor demand equations. The first two approaches — the primal and the dual — utilize the neoclassical economic theory of producer behavior; thus, they generally are considered to be the theoretically "correct" approaches. The third approach relies primarily on statistical analysis of production and cost data. This approach downplays the importance of the underlying, formal theoretical models.

Neoclassical economic theory describes producer behavior as the solution to a programming problem, which incorporates information on both economic behavior and available technology. As a consequence of this formulation, the theoretical solution yields a *consistent* system of product supply and factor demand equations. It is this internal consistency that accounts for the strength and popularity of the neoclassical framework. Pope (1982) states:

> To many, it is unclear whether microeconomic theory based upon differentiability and other convenient regularity assumptions should be taken seriously ... What is clear, is that a model based upon structure with demands and supplies satisfying the theoretical restrictions is extremely convenient to work with because of the internal coherence of the model (so called integrability). In some cases, it seems to be nearly indispensable (p 349).

In contrast, the statistical approach lacks this consistency and thus is often criticized as *ad hoc*. Some of the theoretical implications of specifying these functions arbitrarily and estimating them independently are discussed by Just *et al.* (1982, Appendix A.5).

6.1.1. The primal (direct) approach

The typical production problem assumes that the competitive firm (price-taking in output and input markets) optimizes an objective function subject to the technological constraints of the production process. In neoclassical economic theory it is assumed that the technological (engineering) possibilities of the firm may be described by a production function. The production function denotes the maximum attainable output for each set of inputs. It should be emphasized that the primal approach is based on the assumption that the functional form of the production function is known.

The two most common objective functions are that the firm maximizes profits or minimizes costs. In the constrained profit-maximization problem the firm selects the optimal level of output and inputs. In the cost-minimization problem the firm selects the level of inputs that minimizes cost for every level of output. At any level of output, the two problems yield the same solution since profit maximization implies cost minimization.

The derivation of product supply and factor demand functions using the primal approach is provided for the Cobb–Douglas production function in the Appendix. Two important considerations are demonstrated in choosing between the cost-minimization and profit-maximization frameworks. First, since profits are unbounded in the constant-returns-to-scale case, the profit function, product supply function, and factor demand functions (all defined on prices) are not well defined. Thus, if constant returns to scale prevail, one is limited to using the cost-minimization approach. Second, if a production process is characterized by nonconstant returns to scale *or* some inputs are quasi-fixed, unbounded profits generally are no longer a problem. In cases where the optimization problem yields closed-form solutions and product supply and factor demands are well defined, either profit maximization or cost minimization may be used to derive both sets of functions.

6.1.2. The dual approach

The derivation of product supply and factor demands is straightforward when one assumes simple parametric specifications for the production function. However, the behavioral properties of these simple representations are quite restrictive and much of the behavior is assumed *a priori*; thus, these models are often of limited use in empirical work.

Duality theory in production economics allows one to derive product supply and factor demand functions directly from the profit or cost function. For example, partial differentiation of the profit function with respect to product price yields the supply function, while partial differentiation of the profit function with respect to factor price yields the factor demand functions. Since the derivation of these functions is immediate (in the sense that only one mathematical operation is required), profit–cost functions may be more flexible and still yield closed-form analytical solutions. As long as the profit–cost function meets a specified set of properties, the underlying technology will be "well behaved" [1].

The translog function is a generalization of the Cobb–Douglas function and currently is the most popular function used in the analysis of production behavior. Its flexibility is evidenced by the fact that it does not impose behavioral restrictions, such as homotheticity or constant elasticity of substitution among inputs, but allows these characteristics to be tested empirically (Nadiri, 1982, among others). In spite of these desirable features, the translog cost function is cumbersome to use analytically and is often difficult to implement empirically.

In general, it is not possible to determine the actual production function that is consistent with an arbitrarily chosen profit–cost function. For example, the translog production function cannot be derived from the translog cost function. Only a subset of functional forms (Cobb–Douglas is an example) have this self-dual property (Hanoch, 1978; Burgess, 1975). However, it should be emphasized that in forest sector modeling (as well as in the analysis of most other sectors), we generally are not interested in the product function *per se*; rather we are particularly interested in the supply and factor demand functions that may be derived from the profit–cost function.

A key difference between profit maximization and cost minimization in the dual framework is that the cost-minimization approach ignores the effect of factor price changes on the optimal output level. In the theoretical solution, the profit-maximization approach generates factor demand functions (defined on prices and quasi-fixed factors), whereas the cost-minimization approach yields conditional factor demand functions (defined on prices, quasi-fixed factors, *and* output levels). Conditional factor demand functions also have been referred to as constant-output factor demands and are analogous to Hicksian demands in consumer theory (Young, 1982, pp 367–368). This difference may lead to serious empirical consequences if one fails to properly distinguish between the two maintained hypotheses, since output effects are missing in the cost-minimization problem. Chambers (1982) has shown how to use a cost function approach, but still recognize the output effect in measuring the total impact of price changes on the production process [2].

6.1.3. Statistical analysis of cost and production data

Economists have done a great deal of work in using statistical techniques to estimate cost functions and supply functions (see, for example, Johnston, 1960; Walters, 1963; and Cohen and Cyert, 1965). The essence of this technique is to "let the data speak". The theoretical analysis is informal and bears little resemblance to the methodology described in the previous sections. Walters (1963) summarizes the theoretical rigor of these studies as follows:

> Many attempts have been made to establish the shape of cost curves by theoretical arguments. In particular, the shape of the *short run* cost function was thought to be evident from the principle of diminishing returns; and this law was either accepted as axiomatic or proved by *reductio ad absurdum* kind of arguments (pp 39–40).

Walters (1963, p 45) states that the function used by most economists to express the relationship between total cost C and output Y is quadratic:

$$C = a + bY + dY^2 \tag{6.1}$$

The first derivative with respect to output shows that the corresponding marginal cost (MC) curve is linear:

$$MC = b + 2dY \tag{6.2}$$

Arbitrary selection of functional forms that fit the data well are the basis for estimating production behavior for the large-scale forest sector policy models used in the US. Since the relationships in these models are estimated to conform to the intuition of industry experts, they constitute one important benchmark against which the results of the more theoretical efforts may be judged. Thus, we begin the research review in Section 6.2 with examples of the statistical analysis approach.

6.2. Previous Studies of Production Behavior in Forest Sector Modeling

Numerous studies have examined production behavior in the forest products sector at an aggregate level. These studies date back to the early 1960s when the CES production function was first developed by Arrow *et* *al.* (1961). The CES production function allowed the elasticity of substitution among inputs to be tested, rather than being assumed equal to one, as in previous studies that used the Cobb–Douglas model.

Aggregate studies of production behavior are generally of limited use to forest sector analysts for three reasons. First, most of these studies emphasize only two inputs, labor and capital, and exclude the consumption of raw materials. Second, many of these studies estimate only the production function, without incorporating additional information available from economic theory (as suggested by the primal approach). Finally, the level of aggregation in most of these studies is too broad — in terms of both commodity and regional detail — to provide useful results for forest sector models.

The research on production behavior that is pertinent to this review may be divided into two categories. The first category includes studies that have estimated lumber supply and timber demand functions for use in policy simulation models. These studies constitute the industry "standard" and, not coincidentally, utilize the statistical cost–supply approach. The second category includes studies that are more "pure" in their analysis of production behavior, relying on the neoclassical theory of producer behavior and not constrained to the needs of a larger modeling context. Although these studies typically are not designed to support grander policy models, they are sufficiently disaggregated to provide some information about the behavior of lumber producers, which is useful for such modeling efforts, at least indirectly. Salient features of the first category of studies are reviewed in Section 6.2.1. Recent studies utilizing the neoclassical theory of producer behavior are discussed in Section 6.2.2.

6.2.1. Statistical cost–supply studies: production behavior in extant US forest sector models

The two major forest sector market models used for policy analysis in the US — the Timber Assessment Market Model (TAMM; Adams and Haynes, 1980) and FORSIM (documented in Cardellichio and Veltkamp, 1981) — both estimate production behavior by choosing functional forms arbitrarily to fit the relevant data. TAMM and FORSIM incorporate product (lumber and plywood) supply equations that are specified independently of the timber demand equation. The assumption in both models is that sawlog input is a linearly homogeneous function of lumber and plywood output — product recovery does not depend on relative factor prices. Demand equations for other inputs are not included in these models, since other factor prices are determined exogenously.

The specification of product supply in the two models is quite different. FORSIM is designed to capture short-run price fluctuations and is estimated with quarterly data. The product supply specification reflects temporary market disequilibrium by including measures of new orders, unfilled orders, and stocks. TAMM is an annual model. At this level of temporal aggregation, behavioral equations for product supply are more straightforward and tractable. Thus, the following discussion is based on TAMM.

The domestic lumber supply equation (plywood is specified in the same fashion) in a single region may be written:

$$Q_L^t = a + b(P_L^t - w^tC^t - w^tS^t) + cK^{t-1} \tag{6.3}$$

where Q_L^t is the lumber production in year t, P_L^t is the lumber price in year t, w^t is the recovery factor (MBF log scale/MBF lumber tally) in year t, C^t is the log harvest and delivery costs and lumber milling costs ($/MBF log scale) in year t, S^t is the stumpage price ($/MBF log scale) in year t, K^{t-1} is the sawmill capacity in year $t - 1$, and a, b, and c are the estimated coefficients (Adams and Haynes, 1980; Haynes and Adams, 1985). Note that b is constrained to be the same for all prices: production actually is a function of profit margins.

Since the conversion rate between sawlog input and lumber output in a given year is fixed in TAMM, it is instructive to compare the product supply formulation with product supply from a Leontief model. Using similar notation, the Leontief specification for lumber price behavior (when capital is fixed but not a binding constraint) may be written:

$$P_L^t = w^tC^t + w^tS^t \tag{6.4}$$

which simply says that marginal cost is horizontal at the level of variable costs. The TAMM price equation may be derived by rearranging equation (6.3):

$$P_L^t = -(a/b) + (1/b)Q_L^t + w^tC^t + w^tS^t - (c/b)K^{t-1} \tag{6.5}$$

Note that equation (6.5) is in the form of a linear marginal cost curve [equation (6.2)], and thus corresponds to a total cost function that is quadratic in output.

A key difference between the two models is that the quantity supplied appears as an argument in the TAMM price specification. Estimation results for the TAMM supply equations show that the coefficient b is significantly different from zero at the 0.05 significance level in nearly all regions: the product supply curve is upward sloping (Adams and Haynes, 1980). More recent empirical work using a pooled cross-section time series approach, with identical margins across the regions, yielded a highly significant slope coefficient for the supply equation (Haynes and Adams, 1985). These results strongly suggest some critical differences between the TAMM and Leontief specifications [3].

An identical feature of product supply behavior for the two models is that a change in any production cost (on a log scale) or in the stumpage price shifts the marginal cost curve by the recovery rate, since:

$$(\partial P_L^t / \partial C^t) = (\partial P_L^t / \partial S^t) = w^t \tag{6.6}$$

Thus, at any production level, an increase in a factor cost is passed through to product price without any substitution between factor inputs; that is, the marginal cost curve shifts vertically by the amount of the increase (adjusted to a product basis) [4].

While TAMM incorporates some characteristics of the Leontief model, it appears that input substitution does occur; however, the specification and empirical results mask the nature of this substitution and it is not possible to derive the underlying production or cost function. It should be emphasized that the positively sloped supply curve in TAMM says nothing about the underlying technology of individual production units: sawmills still may combine inputs in fixed proportions.

6.2.2. The neoclassical approach to modeling production behavior: recent empirical work on the US forest sector

Recent studies by Abt (1984), Bible (1983), and Merrifield and Haynes (1983) analyze production behavior for lumber/plywood at a fairly disaggregate level of regional detail. These studies utilize state-of-the-art economic and econometric techniques in modeling producer behavior. However, the specific model assumptions and estimation techniques used in the three studies are quite different.

Merrifield and Haynes estimate a three-input — labor, stumpage, and capital — *translog production* function directly, assuming all the inputs are variable. Bible also assumes that the same three inputs may be varied in the short run, but uses duality theory to estimate a *translog cost* function.

Abt estimates a *restricted translog* cost function; labor and *sawlogs* are variable inputs and capital is quasi-fixed. As noted earlier, the translog production function is not self-dual to a translog cost function. Burgess (1975) provides evidence that the choice may lead to "very different inferences with respect to substitution possibilities between factors (p 105)."

The three studies use different data bases. Merrifield and Haynes use annual data for 1950–1976 for the Pacific Northwest (Washington and Oregon). Bible uses quarterly data for 1970–1980 for six northeast Oregon counties. Abt uses annual data for 1963–1978 for nine states, and pools the data across three "homogeneous" regions — western softwood (Washington, Oregon, and California), southern softwood (Alabama, Georgia, and South Carolina), and northern hardwood (Kentucky, West Virginia, and Pennsylvania).

There are two important economic effects that describe the demand for timber:

(1) The elasticity of the timber demand curve.
(2) The elasticity of substitution between timber and other inputs.

The first column of figures in *Table 6.1* presents the elasticity of the timber demand curve estimated in the three studies being reviewed [5]. Abt indicates that timber demand is inelastic, while Bible shows that the demand for timber is very elastic.

Conclusions regarding the substitutability between timber and other inputs also vary considerably among the three studies. Abt and Bible indicate that timber and labor are substitutes in the short run, while Merrifield and Haynes suggest that they are complements. Bible reports that short-run substitution between capital and timber does not occur, but Merrifield and Haynes show relatively high levels of substitution between these inputs.

The apparent similarity between the elasticity of substitution results reported by Abt and Bible may be somewhat misleading. It is important to note that Bible finds no significant substitution between timber and capital, whereas Abt is not able to compute the degree of substitution using his methodology. Because Abt estimates a restricted cost function with fixed capital stock, the elasticity of substitution between logs and labor is an equilibrium effect that allows for the implicit adjustment of capital services. If this adjustment is not significant, as suggested by Bible, then the results would be consistent. However, if this adjustment is large, as suggested by Merrifield and Haynes, Abt's and Bible's results would have quite different implications.

While these three studies provide quite different models of timber demand, their results concerning product supply are more disconcerting. None of the above studies support the TAMM representation of the

Table 6.1 Elasticities describing the demand for timber.

	Region	*Elasticity of timber demand*[a]	*Elasticity of substitution*	
			Timber–labor	*Timber–capital*[b,c]
Abt	Western softwood	–0.20[d]	0.60[d]	NR
	Southern softwood	–0.37[d]	0.95[d]	NR
	Northern hardwood	–0.35	0.80	NR
Bible[e]	Northeast Oregon	–1.97[d]	0.59[d]	NS
Merrifield and Haynes	Pacific Northwest	NA	–0.91	2.26

[a] NA = not available
[b] NR = not relevant
[c] NS = not significant
[d] The ratio of the estimate to the approximate standard error is greater than 2.0. Merrifield and Haynes do not report the significance of their results.
[e] The results reported for Bible are simple arithmetic averages of his results for six counties. All of the individual values are significant and range from –0.60 to –3.34 for the timber demand elasticity and 0.39 to 0.90 for the elasticity of substitution.

industry marginal cost curve as upward sloping. It is a truism that in an industry comprised of many plants of many vintages, the least efficient should enter and exit the market as prices rise and fall. It is not possible to assess directly why these studies fail to capture this effect.

The research by Abt, Bible, and Merrifield and Haynes will probably not prove useful in forest sector modeling since the results concerning product supply are counterintuitive and there is wide disparity in the results for timber demand. There are several explanations for this diversity, including different theoretical assumptions underlying the models, different estimation techniques, different size and location of regions, and different sample periods. However, the most serious difficulty is likely to lie in the complex representation of the production process. Translog functions attain their flexibility by incorporating a large number of variables and it is not possible to estimate the associated parameters with any accuracy due to the limitations of extant data bases.

6.2.3. Data problems in production function estimation

The modeling strategy that an analyst adopts should be sensitive to data availability and data quality. The limitations of extant data on lumber output and factor input quantities and prices raise serious questions about the feasibility of estimating production parameters with flexible functional forms and neoclassical assumptions. Only issues concerning the measurement of lumber output and sawlog input will be addressed in this section: they deserve special recognition in a study of the lumber industry, but have received limited attention in past studies. Labor and capital measurement have received extensive treatment in production literature and are not discussed here [6].

The physical quantities used in production-function estimation must be expressed as homogeneous units. The fact that published data on lumber volumes reflects the aggregation of many heterogeneous products is typically overlooked in defining lumber output. In fact, the lumber industry is frequently cited as a textbook case of pure competition. This definition implies that all lumber is identical — consumers are unable to differentiate between types of lumber. Operationally, the key feature of such a market is that all lumber is available at a single price. This is, of course, a gross distortion of reality. Price differentials among items classified as lumber can be substantial. For example, in December 1982, ponderosa pine 4/4 B and Better Select lumber sold for US$1070 per thousand board feet, while ponderosa pine 2-inch economy lumber sold for US$77 per thousand board feet (as cited in Ernst and Pong, 1985). Significant differences may occur due to species, thickness, and grade, but empirical work on production behavior has rarely addressed the importance of the "homogeneous-product" misconception.

Even if variations in lumber output due to definitional/quality changes are ignored, the measurement of actual changes in output levels may be subject to large errors. Recent analysis has identified serious problems with US lumber production data. Cardellichio and Binkley (1984) argue that US Bureau of Census estimates of hardwood lumber production significantly understate the actual amount of hardwood lumber produced in the US, probably by more than 25% in recent years. The softwood lumber production data for the US South have been revised by an even greater margin. For example, the original figure reported for southern yellow pine production in 1982 was 6.19×10^9 board feet. The revised data show production of 8.75×10^9 board feet, over 40% higher (US Department of Commerce, Bureau of the Census, 1985).

The only test of the sensitivity of lumber production behavior to the measure of output has been conducted by Abt. Using the standard series on lumber production by state (US Department of Commerce, Bureau of the Census, 1985), in his preliminary analysis Abt detected inconsistencies between input use and production over time and across states. As a result, he developed alternative series of lumber output based on the value of lumber shipments (unfortunately, these series include the value of chip production), and conducted his estimation using both series. One of his most striking findings was that the elasticity of substitution between sawlogs and labor for the northern hardwood region was reduced from 0.80 to 0.20 (and not significantly different from fixed proportions), when the value of shipments data were substituted for the published quantity data.

While the treatment of raw material inputs has received some attention in the literature (see Lau, 1982), the issue of sawlog measurement and aggregation has not been specifically addressed. Accurate sawlog measurement is crucial to production analyses in the solid-wood products sector; however, constructing aggregate indices of sawlog input quantities and prices is extremely difficult due to variations in size, quality, and species. Furthermore, most published data on sawlogs are already highly aggregated and methods of recovering more detailed information are limited and costly.

The aggregation of sawlog input belongs to the general class of input aggregation problems. First, one must be able to translate sawlog characteristics into standardized units so that one may define sawlog bundles that are equivalent in the production function. This requires a function that converts between vectors of characteristics, including items such as diameter, length, grade, and species. Second, the production technology must be characterized by weak separability between sawlogs and other inputs. This is a fairly restrictive condition and its implications have been discussed at length by a large number of authors, including Berndt and Christensen (1973), Diewert (1980), Fuss *et al.* (1978), Green (1964), Jorgenson (1984), Nadiri (1982), and Sato (1975).

The measurement of sawlog volume is a difficult theoretical problem in forest mensuration. Board-foot log rules are designed to measure the board feet of lumber that can be produced from a log of specified length and diameter. The ideal log rule (at least from a production function perspective) would measure different size sawlogs such that identically-scaled volumes would yield the same quantity of lumber when all other inputs are held constant. Two of the most popular log rules in the US — the Scribner log rule and the Doyle log rule — significantly understate lumber tally for small-diameter logs. Thus, even with all the attributes of a sawlog bundle the same except for diameter, a unit defined as 1000 board-feet log scale is not a perfect substitute for another unit called 1000 board-feet log scale, as a simple summation of volumes suggests. This feature of log rules is likely to introduce serious bias into the published measures of sawlog quantities (and prices) that are used in estimating production functions. Variations in log quality and species mix further increase the complexity of uniform measurement. Both factors contribute to different lumber yields in terms of total output and the grade distribution of that output [7].

For time series data, the measurement problems are of greater consequence due to the inability to isolate systematic changes in log size and quality over time. As the transition between old-growth and second-growth timber occurs in most forest economies, lumber recovery (on a cubic volume basis) will decline due to log geometry. However, because of the inadequacy of many common log rules, lumber recovery will appear to increase when these log rules are used unless explicit adjustments are made for different log diameters. Unfortunately, no data on the diameter distribution of sawlog receipts at sawmills are available (at least in North America) to identify these trends.

Aside from measurement problems due to the heterogeneity of sawlogs, sawlog input data from published sources are inadequate for several other reasons. The sawlog variable in the lumber production function should measure sawlogs delivered to the headrig, that is, sawlogs that are actually sawn into lumber. Such measurements generally are not available; as a result, data used in empirical work are usually crude proxies for this variable.

A common proxy is the volume of sawtimber (or roundwood) harvested in the region being studied. Actual removals may differ considerably from published data on estimated removals. One obvious reason for this discrepancy is that timber cruising and log scaling do not produce very exact estimates. Another reason is due to institutional and accounting conventions. For example, timber is sometimes sold on a lump-sum basis in which the cruised estimate is relevant for the purchase, but the actual harvest (which often is quite different) is not recorded.

Even if published harvest estimates were accurate, there are four important reasons why this measure does not reflect sawlog input to lumber production. First, the relationship between harvest and eventual consumption depends on the treatment of logging residues. Second, harvest data do not account for shipments of logs across regional boundaries. The direction of bias will depend on whether the region is a net importer or exporter of logs. Third, sawtimber is not delivered solely to sawmills. For example, according to US Forest Service estimates, only 59.9% of the softwood sawtimber harvested in the US in 1976 was received at sawmills, with most of the balance going to plywood and veneer mills (16.0%) and pulp mills (14.4%) (USDA Forest Service, 1982, Table 3.67). Of course, the share drops considerably when one considers total roundwood removals, since a much lower percentage of the smaller-diameter logs are delivered to sawmills. Finally, inventory adjustment at sawmill log decks and lags between harvest and consumption may exist. Whether these differences are critical depends on the time frame of the model. At a quarterly frequency, harvest levels may bear little resemblance to consumption patterns.

An alternative method for developing reasonable estimates of sawlog input is to derive these data from estimates of product output and conversion factors between product and sawlogs. Most forest sector models use data generated by this methodology, since direct estimates of sawlog consumption are grossly inadequate [8]. While this procedure provides rough estimates for general modeling purposes, the use of such data in the neoclassical estimation framework is inappropriate. To compute this variable correctly for the neoclassical model one must assume that the production function (or sawlog demand function) is known; however, these are precisely the technological and economic relationships that are being investigated.

Another alternative to obtaining estimates of sawlog input directly is to calculate these data from estimates of sawlog prices and sawlog costs. This may be the most suitable alternative for overcoming many of the difficulties in measuring sawlog input; however, the quality of available price and cost data often is poor and should be examined in each specific case.

Sawlog prices should be somewhat easier to measure since prices generally are more readily observed than quantities. However, many of the above problems that arise from stumpage heterogeneity will still occur. Aggregate sawlog prices will reflect the mix of sawlog sizes, qualities, and species in any given sale. Ideally, prices used in the estimation of production behavior should be standardized by adjusting for sawlog characteristics. Without appropriate adjustments, sawlog price data may be misleading since observed price changes may not reflect changes in the real prices faced by the firm. Sawlog price measurement also brings new complications. In most regions, the spot market for sawlogs is not sufficiently large to provide reliable data on market clearing values. The alternative method for estimating sawlog prices is to sum stumpage prices and harvest and delivery costs.

This approach raises several important questions concerning the appropriate measure of stumpage prices. The price that sawmill owners pay for stumpage is the relevant price in solving the profit-maximization problem. The bid price often is not the correct measure since there are long lags between the times when the bid is made and when the timber is actually cut (this is especially true in the US West). Bid prices reflect a complex interaction of firm expectations and market conditions, rather than the current value of timber in lumber manufacture.

Prices at the time of sale, which are available for US Forest Service timber sales, should affect the decision-making process. However, fee (company-owned) timber comprises a significant share of wood input for many firms in the forest products industry. One cannot determine the implicit price of fee timber from these data. Although the use of Forest Service cut prices for fee timber values is often rationalized by arbitrage arguments, cut prices are locked in by previous bids and may not reflect the shadow price of fee stumpage. These contracts often result in one aspect of the so-called mixing phenomenon, in which firms are able to cut high-priced Forest Service timber by mixing it with low-cost fee timber. There also are periods when the opposite effect is observed, that is, firms benefit by cutting low-cost Forest Service timber (due to prior commitments) when the shadow price of fee timber is high.

Virtually no data exist to show fluctuations in harvest and delivery costs, but these costs represent a substantial fraction of the price of sawlogs delivered to the mill. If mills alter the spatial distribution of harvest due to changes in output-input prices, this could be an important factor in delivered sawlog price variation.

The poor quality of extant data is one of the primary reasons that forest sector analysts rely heavily on statistical analysis approaches in estimating production behavior for large-scale forest sector models [9]. While these considerations often lead theorists to label such approaches as *ad hoc*, they are widespread in applied econometric work, particularly in large-scale modeling; furthermore, they appear essential if one is to construct models that produce reasonable simulation results. In his review of econometric research on price behavior, Nordhaus (1972) shows that most specifications and interpretations of price equations are not based on formal theory. Rausser and Just (1982) strongly advocate approaches that incorporate such flexibility in policy modeling. For example, in their discussion of the principles of information use, they state:

> Policy modeling must provide for the use of intuition, both in model development and updating; strong intuition should override casual implications of coincidental data in model development (p 789).

A recent effort to model the US hardwood lumber industry (Binkley and Cardellichio, 1985) has adopted a similar strategy to estimating production behavior. After reviewing available alternatives, they found this approach to be the most practical and, ultimately, the most useful.

6.3. Enhancing Production Analysis with Microdata and Engineering Information

In some ways, the "failure" of the neoclassical economic approach underscores the wisdom of the simplistic representation of production behavior in extant forest sector models. However, in many cases, forest sector models can be improved by *explicitly* recognizing the characteristics of industry structure and the diversity of producer efficiencies. Rather than ask the broad question of whether input substitution occurs at the industrial-regional level, analysts should attempt to isolate the effects of substitution at the plant from the effects of substitution due to the entry/exit behavior of plants with different technologies and cost structures. To accomplish this task, aggregate economic analyses must be supplemented with microdata (that is, data on individual facilities) and/or engineering information.

In this section we describe a methodology for estimating production behavior that explicitly recognizes the heterogeneity of mills in an industry. It is assumed that production behavior is Leontief at the plant level and that, at any point in time, the production process depends on the age of the mill. Behavioral changes at the industry level (for example, input substitution) occur due to the pattern of entry/exit decisions by individual mills. Since this approach is both engineering and economic, it is likely to be quite robust.

The methodology involves three key steps:

(1) Identifying all significant production sites and the capacity at these mills.
(2) Appraising the technical status of each mill and how this impacts the usage of major inputs in the production of a unit of output; for example, the consumption of raw materials and energy, the usage of labor, and the requirements for mill maintenance.
(3) Compiling input cost data for each location or region, along with data on distribution costs to consumer markets.

Jaakko Pöyry has implemented this procedure for all major segments of the pulp and paper industry for producers in Europe and North America and in other significant producing regions. Here the results from their market pulp analysis are presented as a case study of this approach.

Although Jaakko Pöyry has data from many individual mills, they are not complete and that which they have are confidential. Moreover, even with totally comprehensive information based on company data, it would still be a significant undertaking just to transform all the data to a common basis for comparison. Therefore, they have developed a model that combines individual mill data with general assumptions to construct a profile of the cost structure of existing mills.

6.3.1. Technical appraisal

Through its involvement in several hundred mill assignments, Jaakko Pöyry has been able to gather extensive information on the actual consumption of raw materials and energy, labor input, maintenance, etc., at many mills in most areas of the world. Actual mill data have been used to develop general correlations between important technical mill parameters (size of mill, number of lines, type of process, integration, technical condition, etc.) and the usage of important inputs (wood, energy, chemicals, maintenance, etc.) on a regional basis.

Rebuilds and modernizations, which are common in forest industries, may considerably improve the energy balances and usage of other inputs of a mill. Input consumption and the technical condition of the mill are highly correlated when the technical condition of the mill is expressed as "apparent age". By applying specific weight factors to different types of rebuilds, apparent age may be calculated as a function of the degree and time of rebuilds (see *Table 6.2*). The apparent age distribution of softwood market pulp mills is shown for several regions in *Figure 6.1.*

Table 6.2 Calculation of apparent age.

1. *Classify rebuilds*

Rebuild category	Extent of rebuild	Effect on production
1	Small	–
2	Medium	10%
3	Large	30%

2. *Weight factors for rebuilds*

Rebuild category	Weight factor
1	0.25
2	0.75
3	0.90

3. *Calculate apparent age*

Example: Mill start-up in 1962
Small rebuild in 1970
Medium rebuild in 1978

Apparent age in 1970: 0.75 × 8 = 6 years
Apparent age in 1978: 0.25 × (6+8) = 3.5 years
Apparent age in 1985: 3.5 + 7 = 10.5 years

The consumption of raw materials, energy, and other major inputs is then estimated for each region as a function of apparent age. For example, a North American mill of about the same size and apparent age as a Scandinavian mill would still consume more energy per ton of product, as depicted in *Figure 6.2.* Analogous relationships have been constructed for other inputs. Factors such as different wood density and yield in different geographical areas have been taken into account. Labor input — the actual number of employees for each plant — has been used when the figures are known. Otherwise, the number is estimated based on the technical parameters of the mill and on manning at other mills having similar parameters.

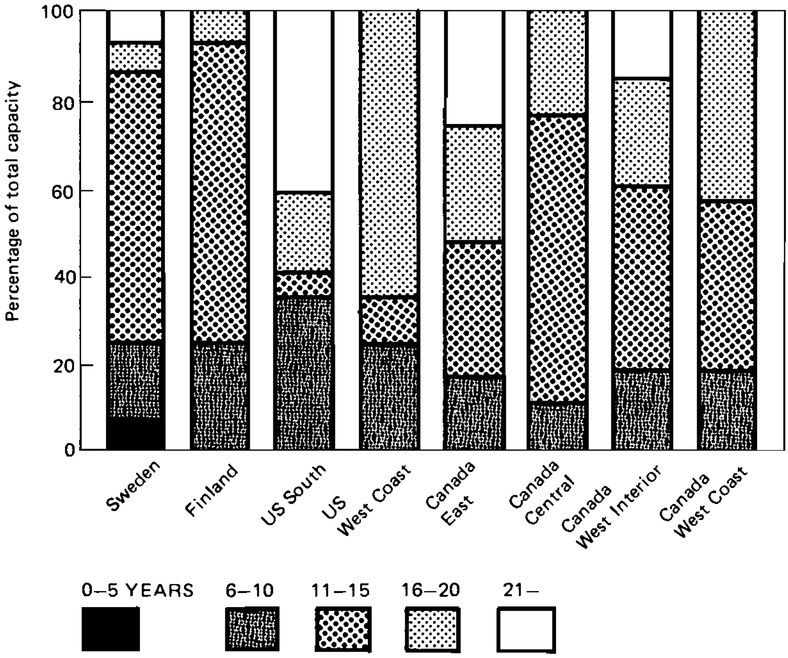
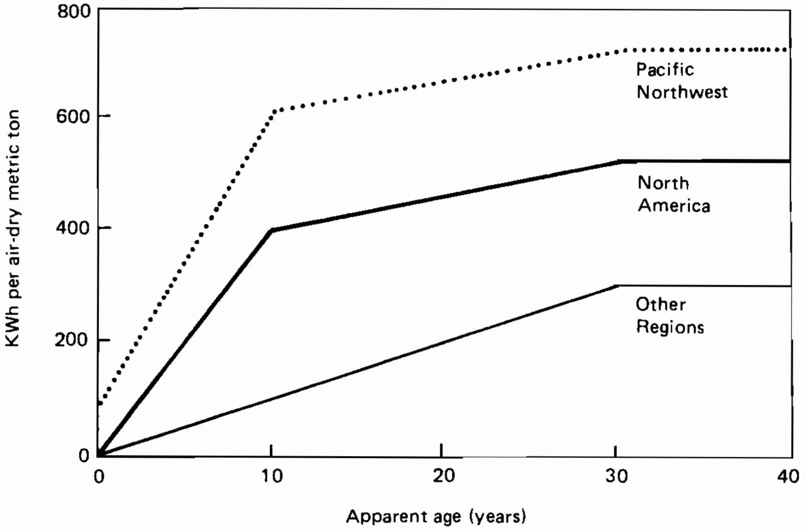


Figure 6.1 Apparent age distribution of softwood market-pulp mills.

6.3.2. Input and distribution costs

Regional unit costs from Jaakko Pöyry data banks have been used in the model. Obviously, cost differences may occur within each region among different mill locations due to, for instance, variations in transport distances. Where such differences are observed, appropriate averages are used in the model. For wood costs, the issue of transfer pricing arises since many companies own forest land and produce a significant amount of their wood furnish. In all cases, market wood prices have been selected as the appropriate costs of wood used at the mill.

Actual ocean freight costs may vary considerably with market fluctuations and the type of transport system used. For modeling purposes, these fluctuations have been smoothed; thus, ocean freight costs reflect longer-run averages. Transport systems have been selected based on consideration of the volume shipped.



Purchased power total consumption – power generation
Power generation back-pressure power + drive turbines
Condensing power is disregarded and included in purchased power.
Owing to historically low power prices, there is limited backpressure power generation in the Pacific Northwest (US and Canada)

Figure 6.2 Purchased power consumption, bleached softwood market, kraft pulp.

6.3.3. Model output

The model generates marginal cost curves for each industry for each region. Each curve is constructed so that mills are ranked in ascending order, starting with the least-cost mill at the lower left in price–quantity space. The production capacity of one or more units at the same cost level is shown as the length of the step. The curves are shaped quite differently across products and regions and they do not conform to a simple linear or logarithmic relationship.

The amount of wood used per unit of output will, in general, increase as one moves up the marginal cost curve. As a result, an important feature of this model is that the average input–output relationship for a timber product will change for different price–production levels in a region.

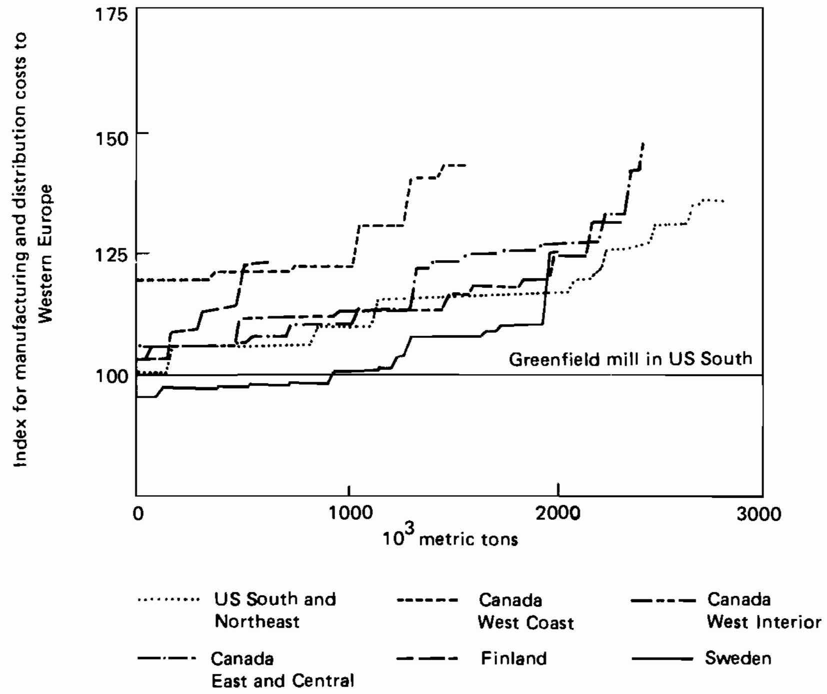


Figure 6.3 Bleached softwood market, kraft pulp (existing mills, 1984/III).

The marginal cost curves for softwood market kraft pulp producers are shown in *Figure 6.3* to compare the cost structure for mills in the US, Canada, Sweden, and Finland competing in Western European markets. Since the cost of wood is a very dominant cost item in market pulp production and since wood costs in Scandinavia are much higher than in the US Southeast, one might expect that Scandinavian pulp producers would have a difficult time competing in that market. However, the structure and technical condition of the market pulp industry is, on average, clearly better in Scandinavia than in the major competing countries. This, together with lower pulp delivery costs, appears to compensate for the higher wood and fuel prices in Scandinavia. Of course, these results are very sensitive to the exchange rate. Examples in this section are calculated using exchange rates and costs that reflect levels in the third quarter of 1984.

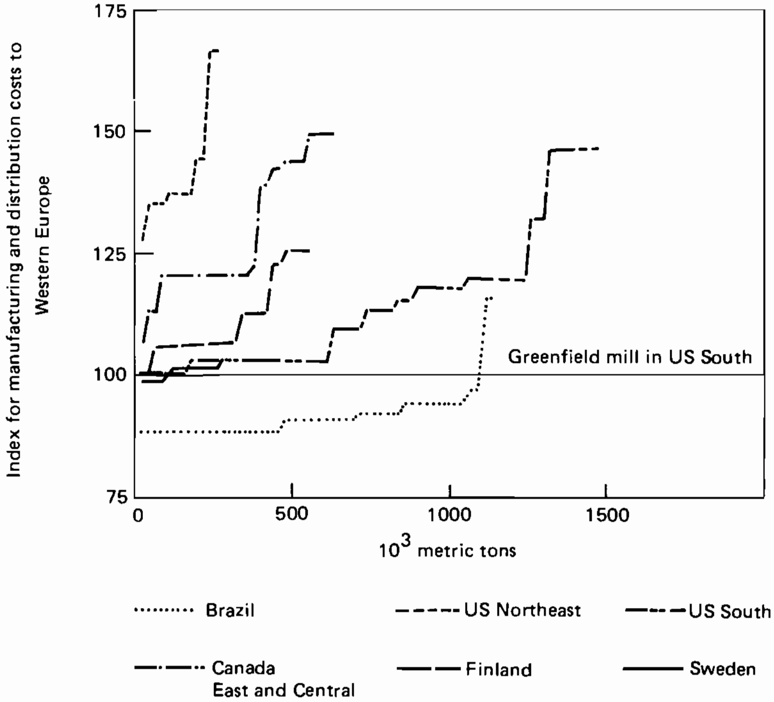


Figure 6.4 Bleached hardwood market, kraft pulp (existing mills, 1984/III).

The present version of the softwood market kraft pulp model includes the following main producing regions: Sweden, Finland, Canada East and Central, Canada West Interior, Canada Coastal British Columbia, US South (three regions), US Northeast, and US Pacific. A total of 82 mills are included in the model, which represents 81% of the world's production capacity.

Figure 6.4 depicts the marginal cost curve for hardwood market kraft pulp producers. The following seven regions are included in the model: Sweden, Finland, Canada East and Central, US South (three regions), US Northeast, Brazil, and Portugal. The 59 mills currently included in the model represent 65% of world capacity.

For each production facility, data are compiled to indicate the important cost elements. *Table 6.3* provides a typical example of how these data are generated.

Table 6.3 Cost analysis for a market pulp mill.

Mill code:	C14	Mill age:	23
Currency:	USD	Apparent age:	12
Grade capacity:	145 000	Mill personnel:	436
Mill capacity:	375 000		

Cost analysis	*10^3 units/annum*	*Units/ton*
Wood costs	45 272.0	137.25
Purchased fiber	0.0	0.0
Chemicals	17 987.9	54.53
Packing	1 375.5	4.17
Operating materials	3 277.6	9.94
Purchased power	5 574.7	16.90
Purchased fuel	7 620.1	23.10
Total variable cost	81 107.8	245.89
Personnel costs, workers	11 689.3	35.44
Personnel costs, admin. & tech.	4 365.6	13.23
Maintenance materials	5 208.0	15.79
General overhead	4 305.7	13.05
Total fixed cost	25 568.6	77.52
Total manufacturing cost	106 676.3	323.41
Depreciation	12 174.4	36.91
Interest and dividends	18 988.9	57.57
Total capital charges	31 163.3	94.48
Total mill cost	137 839.6	417.89
Distribution cost	31 995.5	97.00
Sales price requirement		
Total	169 835.1	514.89
Excluding capital costs	138 671.8	420.41

This model can be readily adapted to perform investment analysis. It is a straightforward procedure to generate cost levels of greenfield mills at desired locations. These calculations are hypothetical and are based on the optimal scale, best available technology, and average costs for the region.

6.4. Conclusion

From an economist's perspective, the neoclassical theory of producer behavior is considered to be the theoretically "correct" approach to modeling production. The appeal of the approach is its simplicity. Starting with some fairly bold assumptions about economic behavior and available technology, production behavior reduces to a straightforward optimization problem. One may then proceed to derive product supply and factor demand functions that are internally consistent. Recent empirical studies by Abt, Bible, and Merrifield and Haynes are excellent examples of how to implement the neoclassical economic approach.

Examination of the above studies leaves the distinct impression that more work of this kind — testing different model specifications, functional forms, data bases, and sample periods — will only lead to a larger collection of disparate results [10]. While there are many difficulties in estimating these models, the most serious obstacle is the plethora of data problems. The number of arguments in the production function must be fairly small to permit econometric estimation; thus, many heterogeneous commodities must be aggregated into common units. In many cases the aggregation is not practical. More importantly, published data often are already highly aggregated and of poor quality. A great deal of information is lost through this aggregation and the resulting data often do not measure the appropriate economic concepts. Finally, data that would be helpful in estimating production behavior often simply do not exist.

It is perhaps ironic that the attraction of the neoclassical model has been its ability to represent a very complex process in a very simplistic fashion: this is also probably its downfall. We believe that forest sector models should avoid the "black box" approach and focus more on understanding the important features of aggregate production behavior. Industry structure is likely to be a critical component of such an analysis. In studying industry behavior analysts should attempt to isolate the effects of plant behavior and the effects of aggregating plants of different efficiencies. This could be accomplished by relying more heavily on engineering data and on microdata for the operations of individual firms, as we have shown for the market pulp industry. Such an approach will provide more reliable and cost-effective results than repeated attempts to precisely characterize production parameters at the aggregate level.

Detailed analysis of industry structure is most feasible when the number of operating mills is relatively small. It is a much more difficult task to compile microdata for segments of the forest sector that include a large number of mills, such as the lumber industry, than for the more concentrated pulp and paper industry. Forest sector analysts who confront this dilemma should follow the lead of extant forest sector models that have relied on the statistical analysis of production and cost data. There are at least four good reasons to short-cut the more cumbersome neoclassical methodology including data availability, ease of estimation, model validity, and model tractability. These are essential criteria for architects of models that are designed for policy analysis.

Appendix 6.1: Production Behavior for the Cobb–Douglas Production Function: An Example of the Primal Approach

Assume that a mill requires only three inputs — sawlogs, labor, and capital — to manufacture lumber and that the available technology may be represented by a Cobb–Douglas production function. The first case assumes that all inputs are variable. The profit-maximization problem may be stated:

$$\prod (p_s,p_l,p_k,P_L) = \max_{Q_L,q_s,q_l,q_k} [P_L Q_L - (p_s q_s + p_l q_l + p_k q_k)] \tag{A6.1.1}$$

subject to:

$$Q_L = a\, q_s^b\, q_l^c\, q_k^d$$

where $\prod$ is the maximum profit, p_i is the price of input i, $i = s$ (sawlogs), l (labor), or k (capital), P_L is the price of lumber, Q_L is the quantity of lumber produced, q_i is the quantity of input i, and a, b, c, and d are estimated coefficients.

Solving the first-order conditions for optimal input choice yields the factor demand functions:

$$q_s = a^{1/z} b^{(1-c-d)/z} c^{c/z} d^{d/z} p_s^{-(1-c-d)/z} p_l^{-c/z} p_k^{-d/z} P_L^{1/z} \tag{A6.1.2}$$

$$q_l = a^{1/z} b^{b/z} c^{(1-b-d)/z} d^{d/z} p_s^{-b/z} p_l^{-(1-b-d)/z} p_k^{-d/z} P_L^{1/z} \tag{A6.1.3}$$

$$q_k = a^{1/z} b^{b/z} c^{c/z} d^{(1-b-c)/z} p_s^{-b/z} p_l^{-c/z} p_k^{-(1-b-c)/z} P_L^{1/z} \tag{A6.1.4}$$

where $w = b + c + d$ and $z = 1 - w$. Note that in the constant-returns-to-scale case ($z = 0$), the factor demand functions (and the lumber supply function that follows) are not well defined.

The lumber supply function may now be determined by substituting equations (A6.1.2)–(A6.1.4) directly into the production function:

$$Q_L = a^{1/z} b^{b/z} c^{c/z} d^{d/z} p_s^{-b/z} p_l^{-c/z} p_k^{-d/z} P_L^{w/z} \tag{A6.1.5}$$

Finally, equation (A6.1.5) may be used to solve for the marginal cost function (or price function, by assuming competitive conditions):

$$P_L = a^{-1/w} b^{-b/w} c^{-c/w} d^{-d/w} p_s^{b/w} p_l^{c/w} p_k^{d/w} Q_L^{z/w} \tag{A6.1.6}$$

Alternatively, suppose one chose to analyze production behavior via the cost-minimization problem. The problem may be stated:

$$C(p_s,p_l,p_k,Q_L) = \min_{q_s,q_l,q_k} (p_s q_s + p_l q_l + p_k q_k) \qquad \text{(A6.1.7)}$$

subject to:

$$Q_L = a\, q_s^b\, q_l^c\, q_k^d$$

where C is the minimum total cost.

The conditional factor demand functions may be derived by solving the first-order conditions:

$$q_s = a^{-1/w} b^{(c+d)/w} c^{-c/w} d^{-d/w} p_s^{-(c+d)/w} p_l^{c/w} p_k^{d/w} Q_L^{1/w} \qquad \text{(A6.1.8)}$$

$$q_l = a^{-1/w} b^{-b/w} c^{(b+d)/w} d^{-d/w} p_s^{b/w} p_l^{-(b+d)/w} p_k^{d/w} Q_L^{1/w} \qquad \text{(A6.1.9)}$$

$$q_k = a^{-1/w} b^{-b/w} c^{-c/w} d^{(b+c)/w} p_s^{b/w} p_l^{c/w} p_k^{-(b+c)/w} Q_L^{1/w} \qquad \text{(A6.1.10)}$$

The price function [equation (A6.1.6)] may now be derived by substituting equations (A6.1.8)–(A6.1.10) into the objective function and differentiating with respect to output. The output supply function [equation (A6.1.5)] may be obtained from this result. Note that if one substitutes this output supply function into the conditional factor demand functions, one obtains the factor demand functions [equations (A6.1.2)–(A6.1.4)] that were originally derived from the profit-maximization problem. (Alternatively, one could have derived the conditional factor demand functions by substituting the price function into the original factor demand functions.)

If one assumes some factors are quasi-fixed, some of the key differences between short-run and long-run behavior may be described. Assume q_k is fixed at level K. There are three important differences between the solution to the production problem in this case and the solution derived assuming all inputs are variable. First, with capital services quasi-fixed, there are only two factor demand functions — the demand for capital services is no longer relevant. It thus becomes essential to consider investment behavior — the mechanism for changing the level and type of capital services — in the analysis of production behavior. Second, the quantity, and not the price, of capital services enters each equation of the model. Third, the profit function is replaced with the quasi-rent function. Because quasi-fixed factors have an associated fixed cost, the return to production includes both payment to the fixed factors *and* "excess" profit. Quasi-rent may be defined as (Just *et al.*, 1982, pp 54–55):

$$R = \prod + TFC = TR - TVC \qquad \text{(A6.1.11)}$$

where R is the quasi-rent, TFC is the total fixed cost, TR is the total revenue, and TVC is the total variable cost.

Using the quasi-rent function, rather than the profit function, has no affect on behavior since fixed costs should not affect the production decisions of the firm.

The following results may be derived for the restricted Cobb–Douglas production function:

Output supply function:

$$Q_L = a^{1/x} b^{b/x} c^{c/x} p_s^{-b/x} p_l^{-c/x} K^{d/x} P_L^{u/x} \tag{A6.1.12}$$

where $u = b + c$ and $x = 1 - u$.

Price function:

$$P_L = a^{-1/u} b^{-b/u} c^{-c/u} p_s^{b/u} p_l^{c/u} K^{-d/u} Q_L^{x/u} \tag{A6.1.13}$$

Factor demand functions:

$$q_s = a^{1/z} b^{(1-c)/x} c^{c/x} p_s^{-(1-c)/x} p_l^{-c/x} K^{d/x} P_L^{1/x} \tag{A6.1.14}$$

$$q_l = a^{1/x} b^{b/x} c^{(1-b)/x} p_s^{-b/x} p_l^{-(1-b)/x} K^{d/x} P_L^{1/x} \tag{A6.1.15}$$

Conditional factor demand functions:

$$q_s = a^{-1/u} b^{c/u} c^{-c/u} p_s^{-c/u} p_l^{c/u} K^{-d/u} Q_L^{1/u} \tag{A6.1.16}$$

$$q_l = a^{-1/u} b^{-b/u} c^{b/u} p_s^{b/u} p_l^{-b/u} K^{-d/u} Q_L^{1/u} \tag{A6.1.17}$$

Quasi-rent function:

$$R = x a^{1/x} b^{b/x} c^{c/x} p_s^{-b/x} p_l^{-c/x} K^{d/x} P_L^{1/x} \tag{A6.1.18}$$

Notes

[1] Excellent discussions of the advantages of the dual approach are provided in Fuss *et al.* (1978), Varian (1984), Just *et al.* (1982), and Lopez (1982).

[2] There are numerous more subtle issues involved in assuming profit-maximization or cost-minimization behavior due to the stochastic nature of production behavior. These considerations are extensively documented in Fuss *et al.* (1978).

[3] To rigorously establish that the differences between the Leontief and TAMM marginal cost curves are statistically different, one must prove that $(1/b)$ in equation (6.5) is other than zero. This would constitute the appropriate test for indicating that the original supply curve [equation (6.3)] is not vertical.

[4] This result is sensitive to the conventions for measuring costs in TAMM. The subtleties of cost measurement will not be addressed here, but it should

be noted that input substitution may be implicitly introduced through exogenous cost adjustments.

[5] The term timber is used loosely here. Recall that Abt analyzes sawlog input, whereas Bible and Merrifield and Haynes work with stumpage data.

[6] Some of the prime examples of this work are provided by Feldstein (1967), Jorgenson (1984), Usher (1980), and Walters (1963).

[7] In a recent study of sawmilling technology, Constantino (1985) addresses the issue of changing log quality.

[8] The data on sawlog consumption in TAMM, FORSIM, and HAMM (Hardwood Assessment Market Model; Binkley and Cardellichio, 1985) are developed in this manner.

[9] There are several other important reasons for choosing the statistical analysis approach, including ease of estimation (since model updating is a key consideration) and simplicity in model design and operation.

[10] This criticism should not be misconstrued as an argument against research utilizing the methodology suggested by the neoclassical theory of producer behavior. Estimation of such models may serve a variety of purposes. Here they have been considered only as an alternative for improving our representation of production behavior in forest sector models.

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CHAPTER 7

Forest Industry Integration Provides Optimal Use of Forest Raw Material and Energy Resources

O. Lehtikoski

Planning the composition of a forest industry manufacturing complex is an important task, because of the long life of such an investment. It is not, though, an easy task. The validity of the initial planning assumptions may change with time, since the environment changes continuously; also, forestry technology is developing, new production technologies are being introduced, and, above all, changes in the forecasts of market needs all give rise to possible new solutions.

A forest industry can be evaluated from the viewpoint of obtaining the greatest economic output from the forests of a country, including provisions for ecological, environmental, and replantational factors. Such an evolution can be made on many different bases. A conventional basis is profitability, comparing the net earnings to the invested capital. Using profitability as an optimizing criterion assumes that the capital is the limiting resource for which different investment alternatives are competing. Other resources, such as raw material, labor, etc., are assumed available in abundance at certain prices, so that these place no limitations on profit optimization. However, capital is seldom the only limiting resource. Other potential limitations include:

(1) The quantity of wood raw material owned or available for purchasing as a function of the transport distance from the plant site.
(2) The alternatives of buying or producing energy.
(3) Site factors, such as soil, transport connections, water supply, climate, and environmental needs.

(4) The availability of employees as to their number and, particularly, their level of education or training.
(5) The region to supply subcontracting, chemicals, utilities, etc.
(6) The level of competing industry in the same marketing area.

All of the above factors concerning the location and the marketing area have to be taken into account in utilizing the forest resource in an optimal way.

Often the utilization of a resource is optimum when several forest products are made in the same place. This is termed geographical integration.

Production processes can be divided into three groups according to the quality of the wood raw material used (*Figure 7.1*). Processes belonging to the same group compete for the same raw material, whereas those belonging to different groups complement each other. Integration provides the optimal use of raw material, provided it uses the average forest in its area in the most profitable way. In such cases, wastes or by-products of primary and secondary processes are themselves utilized elsewhere in the integrated operations. The optimal structure of an integrated plant, specified in these terms, is based upon raw-material criteria; in other words, the usage of wood raw material is optimized.

Rising energy prices have increased the conservation and reuse of energy, but it is not always clear how all low-level energy can be utilized. This presents a difficult problem at existing mills.

When planning new plants a study of how to beneficially reuse all the available energy from different quality levels deserves consideration. *Figure 7.2* shows how the "same" energy can be reused several times in succession in different processes. This concept of "five energy levels" can be used in planning an integrated plant. If the production capacity of each process is such that there is a balanced use of energy at each level the energy costs will be minimized. This would represent an optimal design based on the energy criteria.

As a rule, it is characteristic of an integrated forest product plant that:

(1) The products are bulky commodities by nature.
(2) The relative shares of the wood and/or energy costs are high.
(3) There are environmental problems to overcome.
(4) There is a possibility for high automation.
(5) There are standard products.

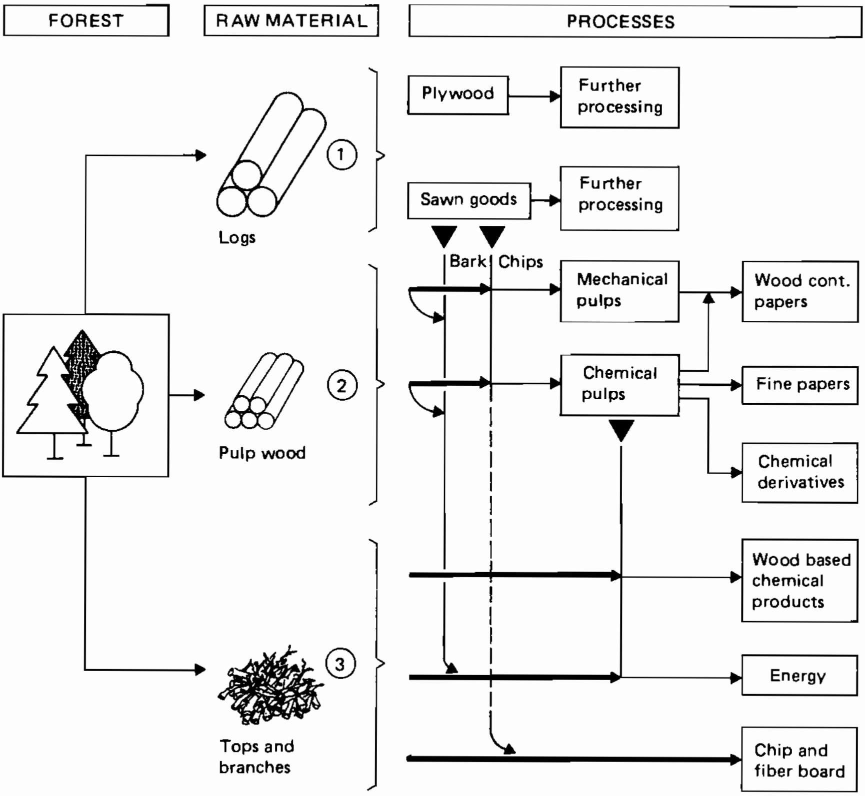


Figure 7.1 The principle of forest industry integration based on optimal wood utilization.

Producing these types of products in an integrated plant reduces production costs for several reasons:

(1) Reduced raw-material transport costs.
(2) More efficient harvesting, so reduced costs.
(3) Total usage of tree.
(4) More efficient energy utilization.
(5) Vertical process integration.

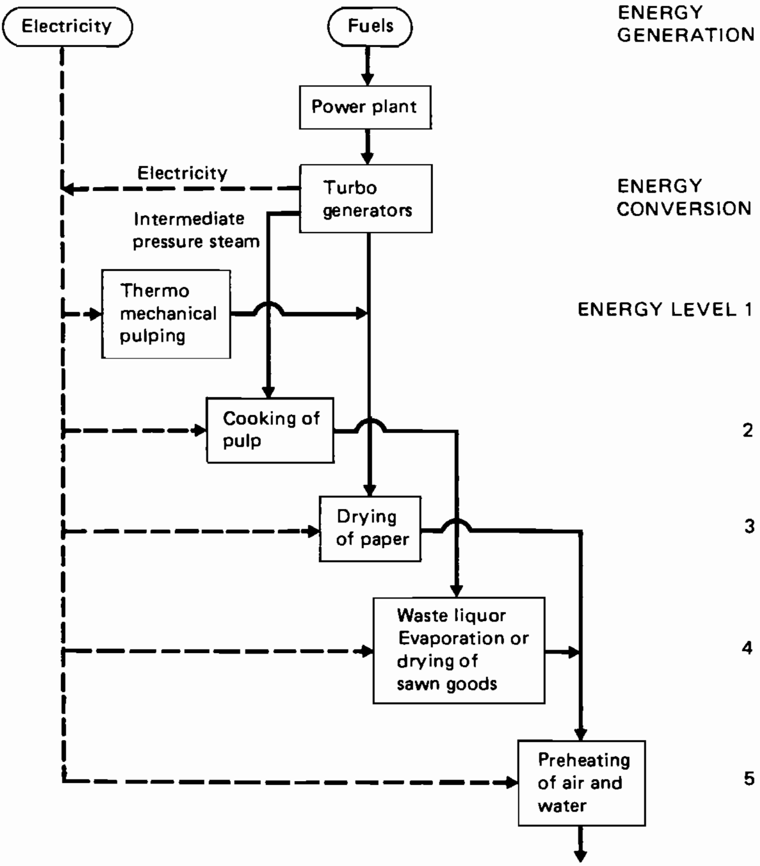


Figure 7.2 The principle of forest industry integration based on optimal energy utilization.

All bulky paper and board grades, such as newsprint, wood-free printing and writing papers, kraft papers, kraft liners, and food boards are typical products produced by integrated plants. The pulp production at an integrated plant may consist of bleached or unbleached kraft pulp and different kinds of mechanical pulps. Typical wood products from an integrated plant are sawn goods, plywood, and chip- and fiber-board. Chemical products, such as ethanol, proteins, xylitol, melange, and lignosulfonates, may also be included in the products of an integrated plant.

Paying attention to the optimization of the use and supply of wood and minimizing energy costs leads to the integration of production. At the same time the capital costs are minimized due to the scale effect. The main criterion of planning is the complete utilization of the wood resource in the harvesting area. Thus, the commercial objective is optimal raw-material utilization. The integrated manufacturing plant operates optimally when all the production lines belonging to it operate at full capacity. Balance and control problems arise when all the mills cannot run with full capacity, for example, due to the lack of orders for one of the production lines or as a result of a shortage of raw material.

7.1. Wood Raw-Material Utilization from the Integration Aspect

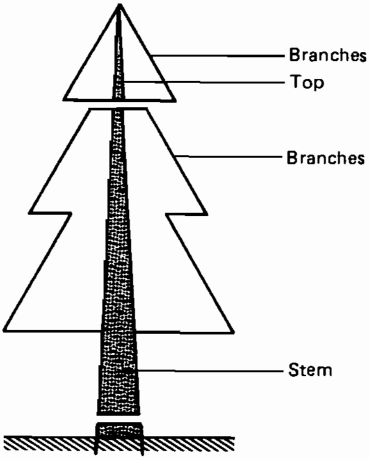
7.1.1. Usable parts of the tree

The biomass of a tree can be divided, according to the industrial use, into the log part, the pulp wood part, the branches and tops, and the roots. The relational amounts of these parts in the circumstances of the Northern Countries are characterized in *Figure 7.3*.

The relative percentages of the different parts of the tree vary widely according to the size and species of tree, but in many cases today the branches, tops, and roots, which are a large part of the biomass of the tree, are left in the forest. These residuals could be used in wall board and wood chemical manufacture or in energy production. It is not yet fully understood as to whether the productivity of the soil is harmed over long periods of removing all the biomass at the harvesting stage and replacing the removed nutrients and elements by artificial fertilizers. If there are no silvicultural restrictions against complete biomass utilization, the integrated forest products plant offers the best possibility for achieving this. In its most complete form this can be done in a so-called self-supporting integrated plant, where no outside energy is needed. The product structure of such an integrated plant is thus conveniently matched with the available natural supply of raw materials.

7.1.2. Wood supply to the integrated manufacturing plant

Harvesting and transport methods can be divided, for example, into three groups: whole-tree methods, stem methods, and product-based methods.



Part of the tree	*Species*	*Diameter at 5 ft height*				
		0–10	11–15	16–20	21–25	25–30
Tops	Pine	16.4	4.5	2.6	1.4	0.9
	Spruce	14.8	5.7	2.7	1.9	
Branches	Pine	33.4	20.8	24.8	22.1	24.1
	Spruce	63.4	47.8	41.7	40.7	

Figure 7.3 Branches and tops as a percentage of the systems.

In the whole-tree method the tree is transported to the mill site or processing station complete with branches. In the wood-processing station the tree is then topped and cut into logs and pulp wood; at the same time the branches and tops are chipped. This method permits total usage of the tree and also optimal cutting of the stem to meet the needs of the lumber market. The residual slabs and other pulp wood parts can be chipped at the same time.

In the stem method the tree is topped when felled and is transported as a stem to the wood-processing station. In this method use of the branches and tops is lost, unless they are gathered and processed separately.

In the product-based method the tree is topped and sectioned at the harvesting site. Thus, the possibility of optimized cutting is lost, in addition to the biomass of the branches and tops.

An integrated manufacturing plant can utilize the whole tree and stem methods and can therefore enjoy the advantages these provide. The relative costs of the different methods depend primarily on the local circumstances. However, harvesting and transportation technologies are developing all the time and thus changing the cost structure.

An integrated plant makes it possible to use the harvested wood totally in one location, which is very advantageous in terms of organization, method, and costs. The required wood-supply area of an integrated plant is thus smaller than the area necessary for a number of single-product plants of equivalent capacities. This factor reduces transport costs.

Wood supply is very uncertain unless the integrated plant owns or, in other ways, controls a significant part of the forest area from which it draws its supply. Ownership of over 50% of the supply area gives excellent possibilities to increase the use of owned wood to almost 100% during periods of high demand and to lower it to 20–30% during poor business conditions.

7.1.3. Impact of potential wood supply on the structure and optimal size of the integrated plant

The available supply area is a determinant of the optimal size of the integrated plant. This means that the available wood resources must be sufficient to last for the lifetime of a mill or that the annual growth is balanced with the usage by the plant.

A new mill can be sized according to the present raw-material resources of the given area. The major part of the forest must be mature and in need of replantation. In this scenario, the integrated plant will use during its lifetime all the wood that was growing in the area at the time it was built. At the same time the areas that have been logged will be replanted and will, after 40 to 70 years, again be available for terminal logging.

If the integrated plant is sized to use the annual growth from a certain area, the wood supply of the area must be two to three times as large as in the case above, if we assume that the economically efficient age of the integrated plant is 20 years and that the harvesting cycle of the forest is 50 to 60 years. The equivalent radius of the economic supply area is determined by the price of the delivered wood at the plant site. The actual distances of economic supply may be physically different, depending on local transportation facilities and topography.

The size and the product structure of the integrate must fit with the supply area conditions in terms of the wood quantity and economics of harvesting. If the forest consists mainly of resinous species of conifers, the most appropriate solution is an integrated plant consisting of a sawmill, a kraft pulp mill combined with a paper mill, and the ability to use wood waste for energy production. Energy self-sufficiency will be possible if the chemical pulp is unbleached and of high yield as, for example, for use in the manufacture of kraft liner board.

If the area consists of conifers suitable for producing mechanical pulp, the best solution might be an integrated plant that includes a mechanical pulp machine with printing and writing paper machines. If significant hardwood supplies exist, the integrated plant might include a plywood mill and a paper mill to produce diversified fine papers. All kinds of wood residuals can be utilized in a wall board mill or in a hydrolysis plant.

7.2. Wood and Energy Use in Integrated Plant Products

7.2.1. Specific consumption

The share of wood and energy costs is considerably high in the products of an integrated plant. Only a part of the used raw material is utilized in the final product, often less than 50%. The unused part can be utilized in other products or in energy production, as outlined in *Figure 7.1*. In many cases, most of the energy used in the production of one product can be recovered and utilized again in another form, as illustrated in *Figure 7.2*. In order to present this in a more concrete way, we can allocate a specific wood and energy consumption and recovery vector to each product. Elements of the vector per unit of product are: the use of primary wood, the use or recovery of waste, the use and recovery of energy, and the use of intermediate products.

Typical specific consumption and recovery figures are listed in *Table 7.1* and summarized below. Consumed raw materials and energy are marked by a negative sign and recovered materials and energy by a positive sign. The net consumption is the difference between consumed and recovered amounts. These numbers vary widely, of course, depending on the quality of the wood and the product specifications of the mill. The numbers can also be affected by the efficiency of the operation and by changes that result from the introduction of new technologies. Although achieving reasonable levels of specific consumption and recovery is very important from the mill's operational point of view, this question is not discussed further here.

7.2.2. Sawn goods

Integration of the sawmill with other products is very essential. For example, 1 m^3 of sawn goods requires 2.4 m^3 of logs, but in addition to sawn

Table 7.1 Consumption and recovery of raw material and energy per product unit (for abbreviations see text).[a]

	Raw material energy						
	Primary wood			*Secondary material*			
Products	*Logs* (m^3)	*Pulp wood* (m^3)	*Branches* (m^3)	*Chips* (m^3)	*Sawdust, etc.* (m^3)	*Waste liquid*	*Bark* (m^3)
Sawn goods (1 m^3)	-2.4			+0.7	+0.3		+0.3
Plywood (1 m^3)	-3.7			+1.8	+0.4		+0.5
GWP		-2.6					+0.3
TMP		(-2.7)		-2.3			(+0.3)
Sawn pulp (1 ton)							
blended		(-6.1)		-5.2		+2.5	(+0.9)
unblended		(-5.2)		-4.5		+2.3	(+0.7)
Chipboard (1 m^3)			(-1.2)		-1.2		
Fiberboard (1 m^3)			(-2.7)		-2.5		
Ethanol (1 ton)			(-15.0)		-14.5	+5.8	
HP steam			(-0.14)		(-0.14)	-0.13	(-0.15)

	Raw material energy						
	Energy				*Pulps*		
Products	*Electric energy* (kWh)	*HP steam* (MJ)	*LP steam* (MJ)	*Hot water* (MJ)	*Sawn pulp* (tons)	*GWP* (tons)	*TMP* (tons)
Sawn goods (1 m^3)	-80			-900			
Plywood (1 m^3)	-500		-7 000				
GWP	-1 400		-70			+1.0	
TMP	-2 100		+3 000	+2 000			+1.0
Sawn pulp (1 ton)							
bleached	-750		-10 500	+500	+1.0		
unbleached	-550		-8 000		+1.0		
dry	-100		-3 500	-1.0			
Chipboard (1 m^3)	-120		-2 050				
Fiberboard (1 m^3)	-400	-6 300					
Ethanol (1 ton)	-250		-20 000				
Kraft paper (1 ton)	-400		-5 500		-1.0		
Newsprint (1 ton)	-300		-4 600		-0.1	-0.45	-0.47
LWC paper (1 ton)	-400		-4 600		-0.3	-0.60	
Fine paper (1 ton)	-400		-4 200		-0.9		
Electric energy	+1 000	-17 500	+13 500				
HP steam		+1 000					

[a] -, primarily used; +, recovered; ( ), also possible.

goods, sawing will give 0.7 m^3 chips, 0.3 m^3 sawdust, and 0.3 m^3 bark. Without integration over half of the raw materials would have little value. Chip can be raw material for thermomechanical pulp (TMP) or sulfate pulp, sawdust can be cooked into pulp, used for energy production, or either totally or partly hydrolyzed and fermented to ethanol. One possibility worth considering is the use of both sawdust and chips of poor quality (with bark) as raw material for fiber- or chip-board, but the most natural way to use bark is in energy production.

A sawmill needs 900 MJ heat for drying and 80 kWh electric energy per m^3 of sawn goods. The heat can be supplied by hot water at 80–100°C, which is readily available from the heat-recovery systems of pulp and paper mills.

7.2.3. Plywood

A typical breakdown of the consumption of 3.7 m^3 wood per 1.0 m^3 plywood is: to plywood product, 1.0 m^3; to chip, 1.8 m^3; and to bark and sawdust, 0.9 m^3. Most plywood is made out of softwood, but in Scandinavia the traditional raw material for plywood has been hardwood, mainly different species of birch. However, the usage of conifers, such as spruce and pine, has increased continuously during the last decades, especially for inside plies. Chips, which are produced as by-products, consist of both long and short fibers and must be kept separate. The energy demand is at the level of 7000 MJ of low-pressure steam and 500 kWh of electricity per m^3 of plywood.

The quality, diameter, and length of the saw- and plywood-log are of great importance. The integrated plant's joint system for wood handling enables optimization in this respect. ***Figure 7.4*** shows how optimized sorting can divide the wood, using criteria of log diameter and quality.

7.2.4. Groundwood pulp (GWP)

Groundwood pulp is made of fresh spruce that are too small for sawing. Wood is consumed at about 2.6 m^3 per ton of 90% pulp. If the wood is dry or somehow else damaged, the consumption is greater and the quality of the pulp, for example the brightness and strength properties, is poorer than normal. This loss can be compensated in production, but only by incurring extra costs. In the grinding process organic substances are dissolved into water, accounting for about 4% by weight of the wood. In producing

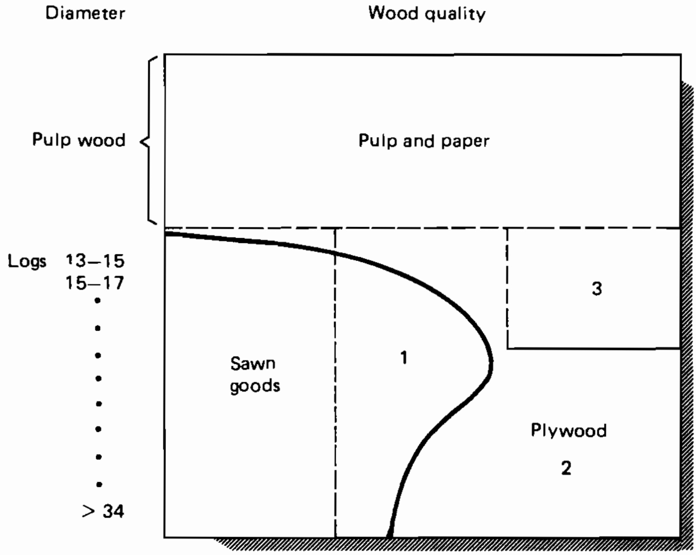


Figure 7.4 An example of the optimal use of wood.

groundwood pulp the electricity consumption is abut 1400 kWh/ton of 90% dry pulp and the heat consumption is 70 MJ/ton of 90% dry pulp.

It is possible to decrease the energy consumption and improve the strength properties considerably by so-called pressured grinding, where the grinding process is carried out under high pressure and of higher temperatures.

7.2.5. Thermomechanical pulp (TMP)

TMP requires abut 2.7 m^3 wood per ton of 90% dry pulp, the best raw materials being the less resinous trees, such as spruce. In the TMP process the organic substances that are dissolved in the water represent 5–6% of the original weight. Electricity consumption is 1.9–2.2 mWh for each TMP ton. Of this, 65–75% is recovered in the form of low-pressure steam and hot water. The recovered steam is best used for paper drying and the recovered hot water is used elsewhere in the integrated plant. The quality of the recovered steam can be improved by a slight compression.

The quality of TMP is better than that of GWP, especially due to its high tear strength. It can totally replace kraft pulp in some bulky paper grades.

7.2.6. Sulfate pulp

A sulfate pulp mill is very essential to the integrated plant, because it can utilize many different species of chips and also produce more energy than it needs, thus providing energy for other purposes. The advantages of the sulfate method are the high quality of the pulp, its applicability to different tree species, few environmental difficulties from the treated waste waters, and its high energy production. On the negative side are the low yield, the need of bleaching, and the odor.

Softwood sulfate pulp made from pine or spruce chips requires about 6.1 m^3 of wood for one ton of bleached pulp. Pulp yield on a dry/dry basis is 45%, so abut 55% of the dry wood substance is dissolved during cooking and bleaching.

Hardwood pulp, especially from birch and other heavy species, has a higher yield of approximately 48–50% bleached and requires a smaller consumption of chemicals and energy. The tear strength of hardwood kraft pulp is comparable with that of softwood sulfite pulp, but its good opacity, formation, and bulk make it a very desirable component for many printing papers and packaging boards.

In pulping, the consumption of electricity is 750 kWh/ton of 90% pulp and the consumption of heat is 10 500 MJ/ton of 90% pulp. The possible generation of heat is about 16 700 MJ/ton of 90% pulp. In drying pulp the consumption of electricity is 100 kWh and the consumption of heat is 3500 MJ/ton of 90% pulp.

7.2.7. Chipboard and fiberboard

Chipboard is made of rough particles of wood, which are bounded to each other with an organic binder, using heat and pressure. The raw material can be either waste from wood-conversion processes, such as cutter-, turner-, or barking-chips, sawdust, or chips from waste wood, or some other wood of poor value. Usually, however, it is made from pulpwood chips. The density of chipboard varies between 0.4 and 0.9, but the most common quality has a density of 0.65, that is, 650 kg/m^3. The wood and energy requirements for chipboard are about 1.2 m^3 of wood, 110–160 kWh of electricity, and 1600–3500 MJ of heat energy per m^3 of chipboard.

Fiberboard accepts as its raw material all kinds of waste wood; sawdust may also be used and tree species are not important. The consumption of wood is, depending on the method, 2.5–3.0 m^3/ton. Fiberboard pulp is made by grinding, the chips are then heated with steam to 175–180°C, and the defibering is achieved in grinders under pressure. During steaming and defibering, hemicellulose is dissolved as saccharides; the organic acids equal 7–10% by weight of the wood. The energy consumption is 400–500 kWh of electricity and 6000–6500 MJ of heat energy per ton.

In another process (Masonite) defibering occurs through "exploding" the chips into fibers by steaming and then suddenly lowering the pressure. In the Masonite process the raw material loss is 18–20%, the consumption of electricity is 150–200 kWh/ton, and the consumption of heat is 7000–8000 MJ/ton.

7.2.8. Ethanol

Wood is hydrolyzed by acids in the temperature range 130–180°C, and the hydrolyzate is then fermented to ethanol. The hydrolyzate waste can be used as a fuel after the water has been mechanically removed. Ethanol production can utilize waste wood of poorer value, such as sawdust and branch chips, etc. Ethanol production at a hydrolyze level of 55% needs 14–15 m^3 of wood per ton of ethanol. Electricity consumption is about 250 kWh and heat consumption about 20 000 MJ per ton of ethanol.

7.3. Energy Requirements of the Integrated Manufacturing Plant

7.3.1. The Sankey energy diagram

Figure 7.5 shows the energy production and consumption of a forest integrate in the form of a Sankey diagram. The quantities of energy are not based on any specific example, but are approximate and intended only for illustrating the sources and uses of energy. The recycling of recovered energy within a single plant, which nowadays plays a very important part in forest industry, is not discussed here.

An integrated forest industry complex can almost always develop part of the energy needed from raw material waste and from internal processes, such as the recycling of chemicals. Using waste for energy production is also often a component of the environmental control system.

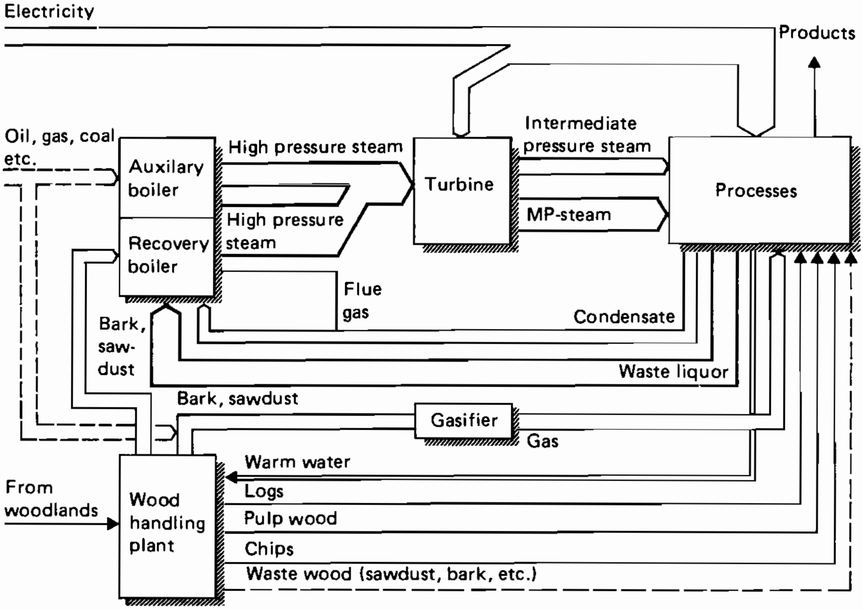


Figure 7.5 Energy diagram of an integrated wood-processing mill.

7.3.2. Fuels and electricity

Several fuels are usually available for producing energy in an integrate, such as waste liquor, bark, sawdust, whole tree or branch chips, wastes from recycling fibers, and flammable process gases (sulfur, mercaptans).

The effective heat values of typically used fuels are given in *Table 7.2*. Exothermic processes often produce remarkable amounts of reaction heat, which is recycled and is of great importance in energy economy. This secondary energy, already noted above, should be considered when choosing the process and machinery.

Because of the diversity of the fuels in an integrated plant, there are, as a rule, at least two steam boilers, one for burning black liquor from the pulping process and the other for burning other fuels. As a rule the latter is planned so that it can utilize all the solid and gaseous wastes from the plant and, if needed, external fuels, such as coal, gas, or oil. The chemical recovery boiler, especially in a sulfate mill, is part of the chemical process, as well as being an energy producer. Additional fuels are limited to oil and gas and are only used to support burning.

Table 7.2 Effective heat values for certain fuels.

Fuel	*Effective heat* (GJ)	*Dry content* (%)
Heavy oil (tons)	40.5	100
Coal (tons)	26.0	91
Peat (tons)	9.7	50
Wood (tons)	7.2	45
Bark (tons)		
pine	6.5	40
birch	8.9	40
Black liquor (tons)		
pine	8.0	65
birch	7.0	65
Sawdust (tons)	7.2	45
Tops and branches (tons)	7.5	45

An integrated plant primarily strives to utilize all the fuel available from the process steam and wastes, so that external fuels are only used when necessary. The boilers usually have the same steam operating pressure. The pressure level is usually determined by the black liquor boiler, which is seldom built for more than 100 bars, due to problems of tube corrosion at higher pressures. A common pressure level helps the joint running of the boilers and permits use of common systems: the feed water system, the back pressure turbine, and the steam distribution system. A condenser turbine is not used as a rule, because condenser energy produced on a small scale is often more expensive than purchased electricity. Occasionally, the back pressure turbine can be used as a condenser turbine. Back pressure electricity is reasonably cheap and recovers about 22–23% of the energy content of 100 bars of steam.

7.3.3. Energy independence of an integrated forest product plant

It is possible to achieve complete energy independence in an integrated plant with the appropriate selection of products. In some cases, an excess of energy may arise. A well-planned kraft pulp-mill burning waste liquor can already achieve energy independence. If the pulp is consumed in an integrated paper mill and no drying is needed, there is an excess of energy, and this increases when all the possible wastes from bark and chip sorting are burned. The excess energy, which is mainly in the form of low-pressure steam, can be used in the other plants of the integrate, such as the sawmill, paper mill, and plywood mill, and for wood handling.

A paper mill using mechanical pulp is seldom energy independent, the greatest shortage being electricity. The combination of a kraft pulp mill and a fine paper mill in an integrated complex is the optimum, from the energy-independence aspect. Also, the combination of a kraft pulp mill and a TMP/GWP paper mill is possible, but not as good. In this case there is a high consumption of electrical energy in the paper mill, whereas the excess of energy from the kraft paper mill is in the form of low-pressure steam.

The burning of wood fuels generates ash, which consists of potassium and calcium compounds that are valuable as fertilizers. The ash may be worth using as a forest fertilizer and can be granulated for easier handling.

7.4. Optimal Structure of an Integrated Manufacturing Plant

There may be several alternative locations suitable for an integrated plant. If so, two further questions arise. What should the optimal structure and size in each location be and how do the profitability of alternative locations compare with each other?

Figure 7.6 shows the different steps for specifying the optimum structure and size of an integrated plant. Essential procedures for this are:

(1) Choosing the integrated structure and the capacities of the component plants.
(2) Determining the fiber and energy balance.
(3) Introducing mechanics of the product market.
(4) Choosing the structure for energy production and supply.
(5) Finding the wood supply pattern.
(6) Calculating the financial returns and examining the feasibility of a solution.

7.4.1. Capacity costs

The capacity costs are divided into two groups, capital costs and other capacity costs. Capital costs, i.e., interest and depreciation, are calculated directly from the investment costs. The investment expenses of production plants do not grow in direct proportion to their production capacity. In general, the square-root rule can be used; in other words, when the capacity is doubled, the investment costs will be increased by a factor of $\sqrt{2}$.

This method has a significant limitation, since the sizes of the production lines have a technical or practical upper limit. For example, nowadays

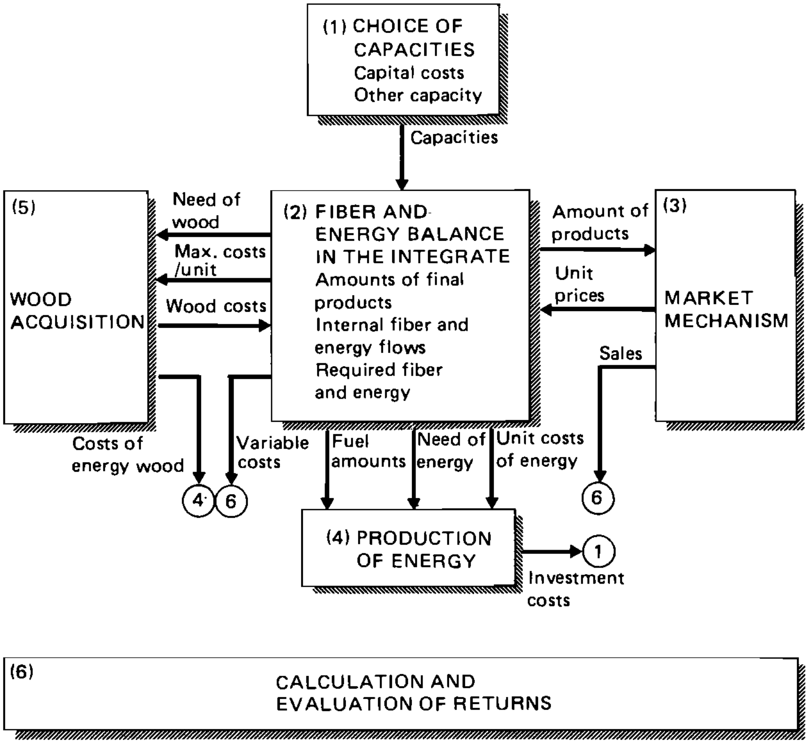


Figure 7.6 Determination of the magnitude and structure of an integrate.

a single kraft pulp cooking/washing/bleaching line cannot be built much larger than for 1000 tons/day. A newspaper machine cannot be built wider than 9 m or faster than about 1100 m/min. Thus, a limit must be imposed on the investment cost model, creating an exception to the square-root rule, with a step change occurring when the number of lines is increased.

It is better to present the investment expense as a nominal capacity per yearly ton or yearly m^3 of product. *Figure 7.7* shows the dependency of investment costs as a function of the production capacity. Other capacity costs include, for example, salaries, repairs, and maintenance, and can be divided into:

(1) The fixed costs of the whole integrated plant.
(2) The fixed costs of each individual plant.

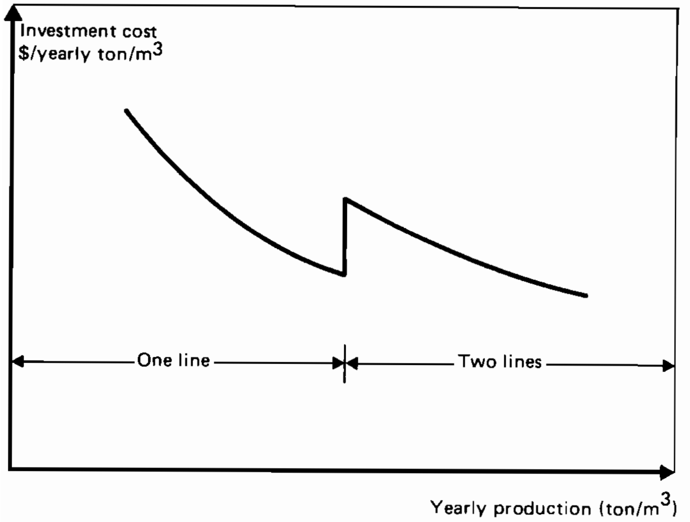


Figure 7.7 Plant investment costs as a function of production capacity.

The costs of each plant are fixed so long as the number of production lines stays the same; in other words, they depend on the number of production lines in a mill.

7.4.2. Energy production and supply

As a starting point for optimizing the energy supply the following must be known:

(1) The net consumption of different types of energy.
(2) The burnable fuel that the integrate offers as by-products without any other use.
(3) The prices and availability of different additional fuels to be bought outside.
(4) The prices and availability of electricity.

The optimal structure of internal production and buying are determined by minimizing the cash flow that goes out of the integrate for buying fuels and energy. Minimizing this cost establishes the internal boiler capacities, the self-electricity production capacity, and the purchased fuels.

Thus is determined the size and structure of the power plant, turbogenerators, and the investment costs.

The energy balance must be examined not only for the design conditions, but also for exceptional circumstances, such as during low-capacity production, during technical shut-down conditions, and during interruption in specific fuel supplies.

7.4.3. Wood supply pattern

Let us consider the cutting area as the smallest unit from which, by buying, harvesting, and transportation to the mill, the wood supply is satisfied. The price is affected by the demand, but competition for the wood raises the price. This self-caused rise of prices is interesting. In some areas, where there is no major demand, the price of wood may be very tempting, but after start-up of an integrated plant the prices increase. Therefore, it is necessary to control enough wood supply before building new plants, which can be done by buying forest land and/or leasing logging rights.

The optimal wood supply pattern is determined as the maximum of the following expression:

$$\sum_{i,r,s,q} M_{i,r,s,q}\left(C^0_{r,s,q} - C_{i,r,s}\right) \tag{7.1}$$

In the expression $M_{i,r,s,q}$ is the flow of wood of (r,s)-quality from cutting area i for product q, $C^0_{r,s,q}$ is the limit cost enabled by product q for wood of (r,s)-quality, $C_{i,r,s}$ is the mill cost of wood of (r,s)-quality from cutting area i, i is the number of the cutting area, r is the number of the wood sort, s is the number of the quality class of the wood, and q is product number. The limitations are determined by the trees present in a cutting area and by the total wood demand for the planned production.

7.4.4. Limitations

In specifying the optimum structure of the integrated plant the following limitations have to be taken into account:

(1) The return on the invested capital must at least equal a given limit value.

(2) The magnitude of the investment may not exceed a given capital limit.

These two restrictions, in addition to the limitations defined earlier, are enough to specify an optimum integrated plant configuration.

7.4.5. Optimum configuration for an integrated forest products plant

The optimum configuration sought is a static situation that accounts for, among others factors, the maximum mill capacities. In practice the situation does not stay static, since manufacturing and other circumstances change. Alternative situations can be expressed in the form of multidimensional probability distributions. The optimal integrated plant planned today may thus no longer be optimal after some years, but this problem can be studied by simulating the situation year by year into the future, using the end situation of one year as the starting point for the next. Simulation is performed by introducing the expected changes to the external factors. In this way the behavior of the planned "optimum complex" can be simulated by "what if?" techniques.

7.5. Advantages of an Integrated Forest Products Plant: Technical Example

7.5.1. Starting points

In order to illustrate the potential advantages of the integration approach a hypothetical, integrated plant is postulated, consisting of the following:

(1) Pulp mill to produce bleached kraft pulp (160 000 ton/year), 30% of which is hardwood and 70% softwood.
(2) Fine paper mill to produce printing and writing papers (120 000 tons/year), which consist of 40% hardwood pulp, 46% softwood pulp, and 14% fillers.
(3) LWC mill to produce coated, wood-consisting printing papers (180 000 tons/year). These consist approximately of 12% fillers for coating, 30% bleached hardwood pulp, and 58% groundwood pulp.
(4) Groundwood mill with a yearly capacity of 120 000 tons.
(5) Sawmill to produce sawn goods (200 000 m^3/year).

(6) Power plant to produce heat for the total consumption of the integrate, about 3400 MJ/year of low-pressure steam and 4350 TJ/year of high-pressure steam (about 100 bar).

(7) Back-pressure turbine plant to produce electricity (225–250 GWh/year) and high-pressure steam (153 t/h). The design capacity of the turbine plant is 40 MW.

(8) Wood-handling plant with a design capacity for 2 000 000 m^3/year and a yearly consumption of wood of 1 600 000 m^3/year.

The radius of the wood supply area is about 70 km, the size of the supply area is 1 500 000 ha, and half of the supply is from owned forests. The yearly growth of the area is sufficient to provide both soft- and hardwood consumptions of the integrated plant, which consumes about one third of the area.

Figure 7.8 shows the material flows of wood, fibers, and fillers and the energy flows are shown in *Figure 7.9.*

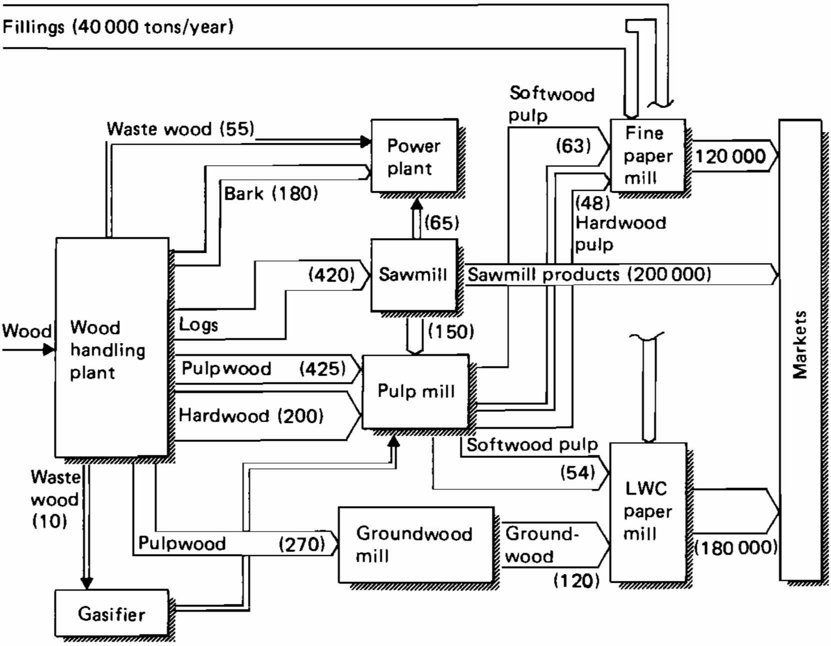


Figure 7.8 Material flow for the hypothetical integrated forest industry unit (wood, m^3/year; fibers, m^3/year; fillers, tons/year or 10^3 tons/year).

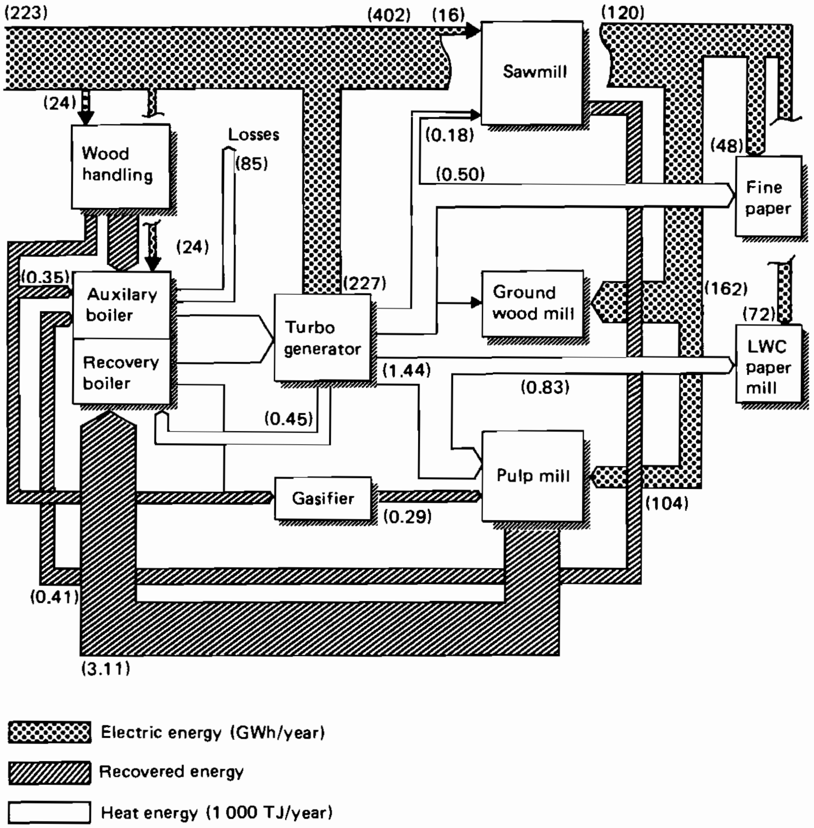


Figure 7.9 Material flow of the hypothetical integrated forest industry unit.

7.5.2. Material flows

Raw material is brought to the integrated plant as whole trees or stems and is directed from the wood-handling plant to different mills of the plant. Thin wood and branches are chipped and burned with bark and fine particles. Part of the waste wood, which goes for burning, is dried with stack gases and changed into generator gas for regenerating lime at the kraft pulp mill.

The barked logs are directed to the sawmill, those of poorer quality can be separated for the pulp- or ground-wood mill. All the waste wood produced in the sawmill is chipped and the chips are, after separation of the fines, consumed in the kraft pulp mill. The main raw material for the kraft pulp mill is the thinner and poorer quality wood, which comes direct from the wood-handling plant and of which about one half is hardwood. Softwood and hardwood pulp are produced periodically.

Raw material for a groundwood mill is the less resinous softwood cut into a fixed length (1–1.5 m), the humidity of which is maintained, during storing at the mill, as high and as uniform as possible. The whole production of the groundwood mill is consumed at the LWC paper mill.

The fine paper mill consumes the main part of the kraft pulp mill production; in other words, all the hardwood pulp and almost half of the softwood pulp. In addition, about 15% fillers, such as kaolin and magnesium carbonate, are needed. The product is printing and writing papers, suitable, for example, for continuous forms.

7.5.3. Energy

The waste liquor of a pulp mill (black liquor) produces the main share of the heat energy that the pulp mill needs. The rest of the consumption can be produced from the wastes of wood material supply and handling, first of all as bark and sawdust. The wood that is removed from forest during the thinning process is a remarkable energy source and is also utilized. The requirement of heat energy is altogether about 4500 TJ/year and, to satisfy this, the available wood-origin fuels supply the following: waste liquor, 62%; bark, sawdust, and small particles from assorting the chips, 31%; and branch- and thin-wood chips, etc., 7%. Of these, the first are wastes produced in the normal raw-material handling processes of a forest products plant, and they do not, as a rule, have any other usage but for energy production. The chemicals of the waste liquor are, of course, a different thing, but recycling of these can be achieved also without utilizing the heat energy, as happens nowadays in some plants. The branch- and thin-wood chips, which produce 7% of fuel consumption, cannot be considered as part of the normal wood supply, but they are easily included in it. Heat energy production in this kind of plant does not require fossil fuels.

Steam production, corresponding to the total consumption of the integrated plant, can produce 50% of the electricity demand of the mill using the turbine back-pressure method, that is, about 32–34 MW. Because condenser power from wood fuel is usually uneconomic, it is better to buy the extra consumption, about 30 MW, from outside sources. The short, periodic peak power demands can be smoothed by drawing extra energy from the back pressure turbine with an extra condenser.

7.5.4. An estimate of the advantages of the integrated plant

The net mill-invoicing of this integrated plant is about US\$ 170 × 10^6 and the investment costs more than US\$ 400 × 10^6. These are very rough estimates based on 1984 cost levels in Northern Countries. The calculation is made using the unit costs and prices in *Table 7.3.*

Table 7.3.

	Sawn goods	*Kraft pulp*	*Fine paper*	*LWC*	*Total*
Production (10^3 tons or 10^3 m^3)	200	160	120	180	
Investment costs (US\$/ton or m^3)	100	600	850	1 100	
Net mill price (US\$/ton or m^3)	130	–	500	475	
Investment costs (10^6 US\$)	20	96	102	198	416
Net mill invoicing (10^6 US\$/year)	26	–	60	86	172

Advantages of the integrated plant are fully appreciated only in a very detailed technical–economical simulation. The following are a few of the savings of greatest importance:

(1) Wood supply to integrated plant: 3 US\$/m^3 wood.
(2) Chip transport costs: 7 US\$/m^3 chip.
(3) Improved quality and yield by the sawing of sorted logs: 5 US\$/m^3 sawn goods.
(4) Better utilization of sawmill bark and sawdust: 10 US\$/m^3.
(5) Drying, transport, and pulping costs of kraft pulp: 25 US\$/ton pulp.
(6) Pulp receipt costs in fine paper: 8 US\$/ton paper.
(7) Utilization of excess energy from kraft pulping: 10 US\$/ton pulp.

These savings in variable costs give the integrated plant altogether a total savings of US\$ 14 × 10^6 per annum. The given example values for savings are, of course, not unique. Each varies within very wide limits from case to case. However, these values refer to some typical situations that have arisen in practice.

The scale effect influences the following factors of the fixed cost:

(1) Power production: capacity costs and other fixed costs.
(2) Wood handling: capacity costs and other fixed costs.
(3) Overhead costs of the integrate.

The fixed costs savings are of the order of US$ 10 × 10^6 per annum. Thus, in the forest products industry the advantages of integration compared with totally unintegrated production are, according to this example, about 14% of the turnover.

7.6. Operational Control of an Integrated Plant

An integrated forest industry has large potential advantages in comparison with single-product mills. The utilization of these advantages requires, however, a very high standard and good reliability of operational control.

7.6.1. Exceptional situations

The heavy forest industry is, as a rule, very restricted by previous, fixed decisions. This is seen very clearly in an integrated plant, where different lines are structurally and optimally proportioned to each other. The limitations of the lines that make up an integrated plant can become a problem unless plans have been prepared to take care of unusual situations. For example, if the pulp mill is dependent on chips from the sawmill and the market situation of the sawmill weakens, then:

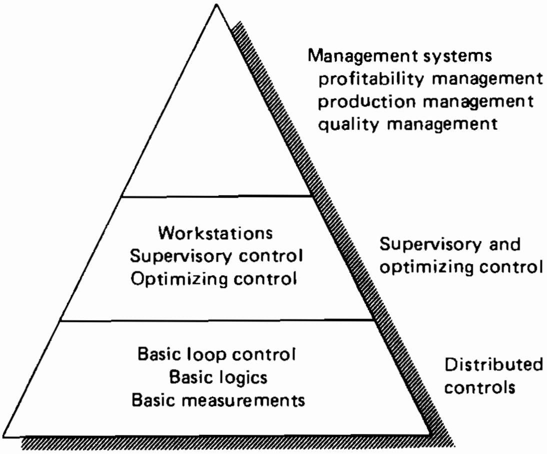
(1) The sawmill must be used partly as a chipping plant, taking only the best part of wood for sawn goods.
(2) There must be extra chipping capacity; for example, field chippers.
(3) The sawmill will increase the level of the product stock.
(4) Chips must be bought from outside, which may be difficult because the situation is similar everywhere else.

However, by planning and being ready for possible unusual situations in advance, these difficulties can be handled by a combination of actions. Such unusual situations are worth simulating in the integrated plant model. How much investment is justified to take care of the unusual situations depends on the extent of their impact and the probability of their occurrence.

7.6.2. Planning and control

Figure 7.10 illustrates the control pyramid for a single mill, by comparing the control operations and their analogues at, for example, the regulation, supervisory, and management levels. Note especially that, at each level, the control and the target or plan are linked.

The operational plan and follow-up of the activities of an integrated plant must be coordinated above the individual lines; the same applies for production planning (*Figure 7.11*). Compatible personnel programs, for



	(1) *Managerial control*	(2) *Supervisory and optimizing control*	(3) *Distributed instrumental control*
Type of control	Managerial	Supervisory	Automatic
Time span	Days, months	Minutes, hours	Seconds, minutes
Type of data	Cumulative data, financial data	Derived data	Sincle measurements
Entity to be controlled	Organizational unit	Operational unit	Sincle loop
Target for control	Plan	Operational target	Set point

Figure 7.10 Control pyramid for a single mill.

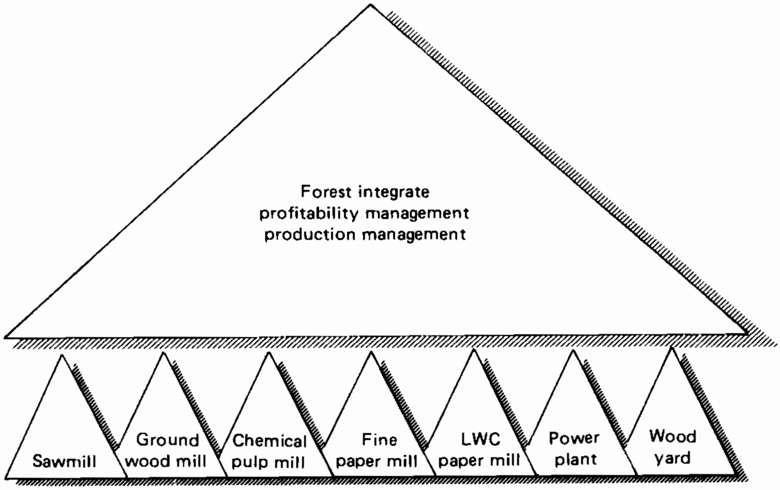


Figure 7.11 Planning and control pyramids for a forest integrate.

example training and wages, must be adopted by all the manufacturing groups in the complex. Setting the transfer prices to a correct and motivational level is also important in the integrated operation.

All this implies that the integrated plant must have a common management, who plans and takes care of the policies and development directions of the whole plant. Within these common policies and development directions the mill managers each have the responsibility to take care of their individual mills.

Plants that belong to an integrated operation cannot act as independently as separate plants. It can also be shown that in the integrated plant it is necessary to pay more attention to planning than is necessary in a single-product mills in order to maximize the potential advantages of integration. In addition, policy guidelines must be more clearly set forth.

7.7. Integration as a Development Factor

7.7.1. The advantages of integration

The synergistic operational possibilities between the separate plants of a multiproduct integrated plant provide a much better competitive capacity than when production occurs in separate plants. Among the advantages of integration are:

(1) Integration creates possibilities for raising efficiency in supplying, harvesting, and transporting wood. Wood control for optimal usage thus becomes possible.
(2) Intermediate products (for example, pulp for paper) can be moved to the next process with little cost and without preparing them for transportation (i.e., without drying).
(3) The recovered energy can be more efficiently utilized and thereby the overall use of energy can be decreased.
(4) Wood fractions suitable for energy production can be utilized. An energy independent integrated plant can be planned.
(5) It is known that the mill must be large enough to be profitable. This scale effect is achievable with integration. The volume of wood supply grows, wood handling is common, and so is energy production. Thus, the total investment costs are smaller in an integrated plant than the sum of equivalent, separate plants.
(6) In an integrated plant the quality of end-products can be optimized by vertical integration. For example, pulp can be cooked to suit requirements for the plant's own paper grades. This enables higher quality with minimum costs.
(7) Integration reduces water consumption, because water recovered from one plant can be used in another.

7.7.2. Synergy and integration

An optimally integrated plant is, by nature, multiproduct integrated. Thus, the idea of synergy is already utilized in several forms. Common raw-material supplies, harvesting, and handling are used for the separate plants and products. Know-how of wood and its properties is commonly shared and the similarity of separate production processes is helpful. On the marketing side, however, there is less synergy, and separate marketing efforts are probably required for optimal results.

Growth is necessary for a company's development, but there are two different strategies to choose between: growth based on product synergy and growth based on increasing production volume. Each strategy has already been used in Northern Countries and has led to a diversification of companies. From forest industry experience has grown worldwide planning activity and engineering works that serve world markets. Also, the development and sales of control systems by the electronics industry have developed from the experience of the forest industry.

7.7.3. Dynamics and integration

The situation does not remain constant for a long time. Even in a controlled environment the balance is dynamic, with some products declining and new ones being developed. The time factor must therefore be taken into account, as what is optimum today is not necessarily so tomorrow. Thus:

(1) The changes and pressures for changes to be expected must be logically estimated and their effects weighed. So, at the company level it is necessary to be prepared and to have ready plans for possible changes in the future.
(2) At the national level the competitive structure of the forest industry must be understood.
(3) With planning control in this fashion it is possible to stay one step ahead of the competition.

CHAPTER 8

Technological Development in Mechanical Wood Processing

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Mechanical wood processing is passing through a metamorphosis that began with the establishment of large production complexes some 30 years ago and that is likely to continue into the next century. From an activity undertaken essentially by small- to medium-sized sawmills in country areas and by master carpenters and other craftsmen in villages and towns, it is evolving toward an increasingly sophisticated industry capable of converting a versatile and renewable resource into competitive consumer products.

In this evolution, some of the attributes that have contributed to the success of wood during the long tradition of its use are no longer advantageous in today's industrial environment. While the craftsman's skill will always be in demand for refined, high-quality articles, such as beautiful furniture for which high cost can be accepted and may even be an asset, the large-scale use of timber in building and utility products calls for highly productive manufacturing processes. Guaranteed performance, quality assurance, and adaptability to market conditions are indispensable if wood is to maintain and increase its share among modern materials.

In this chapter, we assert that the timber industries can meet the challenge of technological competition for consumer preferences. Success in this endeavor is not, however, a foregone conclusion. It is a function of choices and decisions made now and in the years to come, not only by the timber industry itself, but also by those responsible for planning the future of forests, the source of the raw material.

In this connection, it must be clearly understood that the very act of outlining perspectives and forecasting developments may give rise to feedback that influences the directions this development may take. A forecast made today may affect an investment decision for an industrial facility that may come onstream in three to five years and still be operating in 20 years' time.

In the following sections, we endeavor to identify trends that are recognizable today and that, in our opinion, may continue to shape industrial development over the next 20 or 30 years. Our approach is inductive rather than analytical, and does not make use of any specific model or scenario. This is not to deny the importance of such scenarios, which form the basis for simulating the consequences of different options of development and thus provide a valuable tool for decision making. This aspect is dealt with in other chapters of this book.

Similarly, forecasts of production and consumption of timber and its products are the subject of other contributions. To indicate orders of magnitude, in *Table 8.1* we summarize FAO (1985) figures on the production of various timber commodities. Note that production figures remained fairly static from 1972 to 1983, except for some significant increases in the developing countries. These include a 27% increase in fuelwood, but also a 72% increase in sawnwood production and a 90% increase in the production of wood-based panels. However, fuelwood remains the destination of the overwhelming part (82%) of the total roundwood production in developing countries.

Table 8.1 Production of wood and wood products (FAO, 1985).[a]

	Total roundwood (10^6 m^3) (*rd*)		*Industrial roundwood* (10^6 m^3) (*rd*)	
Region	*1972*	*1983*	*1972*	*1983*
World	2 532	3 042	1 271	1 409
Europe	320	342	260	287
North and Central America	498	633	447	483
Japan	45	33	43	32
All developed countries	1 241	1 356	1 066	1 101
All developing countries	1 290	1 686	205	309
	Sawnwood and sleepers (10^6 m^3) (*s*)		*Wood-based panels* (10^6 m^3) (*p*)	
Region	*1972*	*1983*	*1972*	*1983*
World	431	451	87	104
Europe	86	87	27	32
North and Central America	126	129	35	34
Japan	43	30	9.2	8.8
All developed countries	377	358	79	87
All developing countries	54	93	8.6	16.3

[a] The difference between total and industrial roundwood is fuelwood; *rd* – log volume; *s* – sawn volume; *p* – volume of panels produced.

It is not our purpose, either, to discuss the trade flows of timber and its products, but it is of interest to note that timber occupies the fifth place among all commodities traded on a world basis, being preceded only by oil and oil derivatives, vehicles, and machine tools. The total volume in 1980 was 200×10^6 m^3, at a value of 60×10^9\$ (US) [Lemaignen, President of Association Technique Internationale des Bois Tropicaux (ATIBT), personal communication].

8.1. The Timber Industry and the First Industrial Revolution

Most of the conversion processes and wood products in use today have been known for thousands of years. Sawn and hewn beams and planks were used for building at least 5000 years ago, veneered and inlaid furniture was produced by the Egyptians in the second millennium BC, and paper has been in use in China since before the start of our era.

The first innovation in recent times came with the introduction of, first, water and, second, the steam engine to drive "mills" with mechanically powered saws, which replaced the ancient pit sawing and opened the way to larger production units.

In the nineteenth century, the progress in machine-tool manufacture enabled, for instance, invention of the veneer peeler lathe and of the fourdrinier machine, which supplied the means for industrial production of plywood and paper.

These developments were, however, no more than refinements of ancient techniques. The basis for radically new products was created by the surge of polymer chemistry in the first half of the twentieth century and, particularly, by the discovery of a number of synthetic resins, such as urea- and phenol-formaldehyde, capable of bonding wood surfaces together with greater strength and water resistance than the older adhesives, such as animal glues and casein. These discoveries made it possible to develop particle board and other types of reconstituted wood, which have seen such a spectacular growth during the last 40 years.

Developments in timber technology do not occur as isolated events, but are impelled by changes in the general technological and social environment and by the supply situation of raw material. The first impetus is provided, as we have seen, by advances in seemingly unrelated areas, such as mechanical engineering and chemistry. A second impetus may be traced to the changing character of the raw material source, the forest. Up to some 100 years ago (and still today in many tropical countries), timber was derived from primary or naturally grown secondary forests consisting of trees of a wide variety of forms and growth habits, and in many cases of large size. This, combined with the hard labor necessary for sawing trees into elements of small dimensions, encouraged a relatively wasteful use of the raw material with massive beams, thick floors, and so on. The gradual disappearance of these forests, and the increase in man-made plantation forests and silvicultural techniques to produce large numbers of trees of relatively uniform size and properties, provided opportunities for more economical, industrialized, mechanical conversions, which were not practicable with the former, naturally grown material.

A third impetus for development may be termed "user requirements" and includes technological and economic factors. Technological aspects, such as the importance of grain direction, drying, and jointing, must have been recognized from the earliest times by cabinet makers, carpenters, and wheelwrights. Wood preservation is mentioned in the Bible in connection with the construction of Noah's ark. There is no record of the systematic measurement of strength properties before the nineteenth century, but it is clear from the work of shipwrights, cartwrights, coopers, and other tradesmen that they had a good understanding of the strength of wood (Duhamel du Monceau, 1758, 1764, 1767). The increasing demands for guaranteed performance, reliability, and durability promoted the establishment of wood technology laboratories, whose work was made possible by the wide range of testing machines, instruments, and experimental methods that have appeared during the last 100 years (for details, see *History of Wood Science* by Kisser *et al.*, 1967). In addition, the need for wood to compete increasingly with new materials, such as plastics, aluminum, and the more recent composites, led to greater emphasis on economic use of the raw material and on lowering production costs.

Since the beginning of the twentieth century, the development of standards for the testing of wood properties and for the performance of wood products has made a most important contribution to the rational use, competitiveness, and reliability of timber, particularly in building and construction. It is fascinating to trace the work of pioneers, such as Monin (1931) in France, Graf in Germany, Ylinen in Finland, Fernow and Hatt in the US (see Tiemann, 1942), and many others, which led to the establishment of the comprehensive standards in the Norme française (NF), Deutsche Industrie Norm (DIN), American Society for Testing Materials (ASTM), and other national systems. In more recent times, the International Standard Organization (ISO) and regional bodies have been endeavoring to produce uniform specifications. Important contributions in specific areas were made by industry associations, such as the British and American Wood Preservers' Associations (BWPA, AWPA), the International Technical Association for Tropical Timbers (known by the initials of its French name: ATIBT), and many more. The practical application of many standards is facilitated by manuals issued by timber development and promotion associations, by uniform building regulations, the French *Documents Techniques Unifiés* (DTU), and the like.

This work is never ending. Standards and specifications must be constantly brought up to date and new ones prepared in line with progress in wood science and manufacturing technologies.

The present state-of-the-art is described in many textbooks, one of the most comprehensive being the encyclopedic publications of Kollmann and Côte (1968) and of Kollmann *et al.* (1975). Stamm (1964) presented a basic treatise on wood and cellulose science from the physical chemist's point of view. More recently, an excellent account of the properties of wood seen as a natural polymer, and of its interaction with various chemical substances, was edited by Rowell (1984).

A great number of manuals and technical books deal with the technology of wood transformation and utilization, such as the wood handbook of the USDA Forest Service (1974), the *Holztechnologisches Handbuch* of Vorreiter (1949), the *Pense Précis Bois* edited by Bailly *et al.* (1984), the *Manual* of Tuset and Duran (1979), and the two volumes by Krischer *et al.* (1978), or with some important species, such as Koch (1972), Hillis and Brown (1978), Plumptre (1984), and Bamber and Burley (1983), to cite but a few examples [1].

Today, the timber industry is still in the process of catching up with the recent developments outlined above. In some areas, this implies the setting up of large, highly productive manufacturing units, but in the majority of cases it is still a matter of gradual improvements in the efficiency, productivity, and quality of small and medium-sized companies. At the same time, both large and small companies are now confronted with the challenge of the second industrial revolution, which requires the rapid adaptation to, and introduction of, automatic production control and robotization, regulated and supervised by microprocessors and computers.

8.2. The Challenge of Automation

One of the implied postulates of our discussion so far is that technological developments in wood processing are conditioned by advances in seemingly unrelated but basic technologies. The present boom in information techniques, both in hardware and software, is no exception. Once its particular features have been understood, wood offers a particularly wide range of applications for automatic sensing, process control, and production management.

8.2.1. Load-bearing uses

The biological nature of wood is responsible, on the one hand, for the presence of "singularities" [2], which must be recognized and allowed for or possibly eliminated, and, on the other, for a statistical distribution of strength properties, which entails the necessity of stress grading [3] for load-bearing uses. A variety of sensors, gauges, and other testing devices may be applied to measure these properties.

Once singularities and defects have been pinpointed and stress grades determined, the piece in question may be further processed to obtain the greatest recovery in terms of volume or value of the end product, and the production must be sorted to direct each piece to the appropriate destination.

It is obvious that all these operations lend themselves *par excellence* to automation and computerization, either by fully automated procedures or by a combination of operator and automatic control. It is not our purpose to discuss the many devices now under development (some are already in operation), but we briefly return to this point in Section 8.4, and further details may be found in the literature (e.g., Lombard *et al.*, 1982).

8.2.2. Furniture and decorative uses

Automation also has a role in the production of high-class articles made of wood, such as quality furniture for which the individual and unique character of each piece may be at a premium. Traditional methods based on the production chain derived their profitability from the scale factor of large series, making them highly suitable for mass-produced articles, but uneconomical for those intended for the discerning customer. Computerized control enables, after the main production line has been set up, the introduction of small series with individualized features without requiring time-consuming retooling.

Very recently, computer assistance has been taken a step further by the introduction of CAD (Computer-Assisted Design), CAM (Computer-Assisted Manufacture), and similar processes. There are some who believe that the computer will eventually take over the creative act and conceive entirely new forms, new assemblies, and new arrangements in space. Although, undoubtedly, considerable progress will be made in this direction during the next 20 or 30 years, we think that the creative spark of true originality will continue to be provided by the human brain for a long time to come.

The timber industry faces the challenge today of having to procure not only the transition from the artisan's workshop or small family enterprise to a highly productive industrial undertaking [4] but also, at the same time, of having to introduce modern, electronic production aids.

In the following sections, we endeavor to trace present developments in the context of the motivating causes discussed above and to extrapolate them into the future.

8.3. Orientations Today

As a result of the metamorphosis outlined in the preceding discussion, the timber industry covers today a very wide spectrum of technological levels. If we leave aside pulp, paper, and other fiber-based products, which are dealt with in Chapter 9, timber services essentially two markets (Kauman, 1980):

(1) Building, which requires an engineered product with specified and guaranteed properties and performance.
(2) Furniture and other decorative uses, where aesthetic values may be of primary importance, with strength and performance being taken for granted.

An important aspect of all applications is the durability of the product, which should correspond at least to the service life expected of similar articles made from other materials, with as little maintenance as possible. Let us review some recent, technological developments conducive to the achievement of these aims.

8.3.1. Sawmilling

The trend in sawmilling for a number of years has been toward bandsaws, which are capable of higher production rates, greater precision, and greater economy of raw material because of the thinner kerf, although recent developments in thin, stabilized, circular saws may provide an alternative for certain applications. Gangsaws with alternative movement remain important for the accurate sawing of uniform, small- to medium-sized logs, such as are produced in many pine plantations. For the sawing of large logs, irregular tropical trees, and trunks with appreciable growth stresses, a large bandsaw (up to 2 m), with a versatile carriage that permits frequent turning of the logs, is likely to remain the best tool for a long time.

The use of laser beams or high-speed liquid jets for cutting or machining is reported from time to time in the literature and is being applied in some plants for trimming (laser) or debarking (water jets). Similarly, radically new "stationary saws" have been proposed. We believe, however, that the sawing machine using a moving, serrated blade or disc will remain the main tool for primary cutting for at least 20 or 30 years. Advances are likely in better tensioning, better aids to stable running, and increases in wear resistance, advances to be brought about more by progress in metallurgical technology than by research on wood.

Notable advances were made during the last 20 years in adapting sawing operations to log characteristics to improve yield and productivity, particularly for plantation-grown softwoods. One of the first developments was the "Best Opening Face" program introduced by the USDA Forest Products Laboratory (Madison). This was followed up by engineers in Finland, Sweden, the FRG, and other parts of the world, as well as in North America. Today, many systems are available based on automatic scanning of the logs, cants, and boards and on the computerized control of processing to harmonize tolerances, knots, wane, and other features with market specifications. The same applies to material handling in the mill, to sorting, and also to grading, which are discussed in Section 8.4. This is an area of rapidly expanding technology.

Much know-how has also been accumulated on plant layout, material flow, and balancing of sequential operations in sawmills and other conversion plants, and the work in Australia (by Page of the Commonwealth Scientific and Industrial Research Organization: CSIRO), Belgium (by Antoine of the University of Louvain) and France (by Chardin of Centre Technique Forestier Tropical: CTFT, Paris) on the sawing of tropical wood is important. Application of this know-how in existing plants by the French Centre Technique du Bois et de l'Ameublement (CTBA, Paris) has recently resulted in increases in recovery and in productivity of the order of 3% and it does not seem unreasonable to predict that gains of up to at least 10% are possible in some companies, without additional investment. The figure may be considerably higher for less developed countries.

The most significant progress will undoubtedly be observed in improved handling of the sawlogs and sawn products, such as with the overhead carriages now being introduced more and more into large production units, in better layout of the mills, and in a rapid increase in electronic aids for sizing, detection of singularities, sorting for quality, strength, and dimensions, and the general control of production. A number of such aids already exist and many more are on the drawing board or under test in laboratories.

8.3.2. Drying or seasoning

The drying or seasoning process is a key link in the chain between tree and finished product. Since the first introduction of forced circulation kilns around the turn of the century, of Tiemann's superheated steam kilns in about 1915 to 1920, and the more general introduction of drying of sawn timber above 100°C in Germany after World War II, some significant strides have been made. It should be emphasized, however, that these improvements consist more in the perfection of known methods than in the development of radically new processes.

Better understanding of kiln thermodynamics and water transport in wood has led, during the last five years, to the installation in Australia of a considerable number of drying chambers for radiata pine. Here, for the first time, large quantities of timber are routinely dried at 120 to 130°C from the green condition (Christensen and Northway, 1982). (Previous high-temperature drying, particularly in the FRG, was more usually from an initial air-dry condition, although some drying from the green was carried out.) The higher speed and greater heat economy of this method makes it likely that it will be adopted for the drying of plantation-grown softwoods in other parts of the world. It has been shown, for instance, to be perfectly suitable for North American pines (*P. elliotii*, *taeda*, etc.) (Koch, 1984), but is not yet used industrially for these species to any extent (Koch, personal communication).

The next generation of drying kilns, operating at about 180°C, was first developed in Australia and has been further advanced in a French laboratory (Basilico *et al.*, 1982). It seems quite possible that these may be ready for introduction into industry in five to ten years' time, reducing drying times further.

Although dielectric [5] drying would seem *a priori* to be an eminently suitable method, since it concentrates heat production in the regions of highest moisture content, in practice it seems to us unlikely that it will be used for sawn timber of 27 mm or greater thickness in the short- to medium-term future. The problem is proper control of the field intensity. High-frequency drying was first tried by Tiemann in the 1920s and has found little application, other than for the polymerization of adhesives, but microwave drying, tested more recently, could have some possibilities.

Low-temperature methods (dehumidification drying), the use of heat pumps, and, of course, improved methods of air drying will very probably gain further importance, but we believe that drying under vacuum or pressure will remain confined to some very specialized applications.

Solar energy drying kilns have been experimented with in many countries (France, Japan, the US, Puerto Rico, Fiji, Brazil, the UK, etc), but it seems unlikely that they will prove economical for operations other than on a fairly small scale.

From an operational point of view, proponents of the method of through-and-through sawing and edging after drying, used widely in Europe and South America for hardwoods (French: *sciage en plots*), have been arguing for many years with those advocating cutting to width prior to drying. There is now a trend in North America ("saw-dry and rip") to use the former method. Drying of unedged flitches is said to result in less deformation, but is detrimental to efficient air circulation in kilns.

8.3.3. Preservation and biotechnology

Preservation is an indispensable technique for all applications in which decay-susceptible woods are to be used in situations that involve a risk of fungal attack or where there is a danger of attack by insects. Although reliable methods are available for the application of insecticides and for the impregnation of readily permeable woods (such as the sapwood of pines) with fungicides, problems persist with impermeable timbers (such as the heartwood of spruce and many tropical species), which are not readily penetrated by preservative solutions even with pressure–vacuum treatments.

Other problems are looming in relation to the pesticides themselves and to the solvents used for the application to wood, many of which are increasingly coming under attack from environmental legislation. Although, in fact, the risk of contamination from treated wood in normal use is practically nonexistent, the biocidal properties of substances such as pentachlorophenol or copper–chrome–arsenic salts are attracting exaggerated attention from the press and legislators, whereas other, much more widespread and potentially dangerous sources of pollution are often neglected (domestic heating and motor vehicle exhaust gases, which appear to be, in large part, responsible for the present dieback of forests in Europe).

In view of these problems, considerable development will be required in the next decade or two to find narrow-spectrum pesticides whose action is confined to the organism to be eliminated, and to devise methods that give improved penetration of fungicides into the wood, so that the whole volume susceptible to fungal attack may be impregnated. Such development is, unfortunately, not simply a matter of technology but requires, in the first place, better understanding of the interaction of wood with complex solutions, of the metabolism of fungi, and of mechanisms that govern the fixation of the pesticides in the wood. This is an area in which a considerable research effort will be required, but in which one may be hopeful that useful results can be obtained in the not too-distant future. The interaction of preservatives with wood is considered by Nicholas and Preston in Rowell (1984).

A great deal of research has been published in recent years on the application of biotechnologies to wood, particularly for biological decomposition. This subject is marginal to our discussion, but details may be found in the relevant chapter by Kent and Cowling in Rowell (1984).

8.3.4. Surface finishes

Another area under intense development is the protection of wood surfaces against deterioration when exposed to the weather and against discoloration, staining, and (sometimes) abrasion in indoor uses (furniture, flooring, paneling).

To bring out the natural beauty of wood, which is an important marketing asset, it is desirable to use transparent surface finishes. Unfortunately, no such finish is known at present that will last more than one to two years in outdoor exposure without maintenance, although some with a potential life of four to five years are said to be under test. The present consensus is that pigmented stains (French: *lasures*, German: *Lasuren*) are the best solution available, because they are easy to maintain and renew.

Clear finishes may last longer under protected conditions inside a house, but little can be done about changes in the natural colors of decorative woods. On the other hand, a good, modern paint system may last from six to ten years when exposed to the weather, but the natural figure of the wood is hidden.

On the basis of current knowledge, there seems little chance of improving the performance of surface finishes, which ideally should last as long as the life of the structure or article. Although it is always possible that a commercial paint manufacturer may empirically find a system having the required properties, it seems more likely that the answer will eventually come through a better understanding of the physical chemistry of wood surfaces and their interactions with the finishes. Intensive research on this subject is going on in France, the UK, Switzerland, and the US, as well as a number of other countries, but it seems that industrially useful results are still a number of years away. (For a discussion of recent progress, see the chapter by Feist and Hon in Rowell, 1984.)

8.3.5. Machining

Up to now, we have mainly dealt with the production and utilization of sawn timber in the form of boards, beams, framing, and so on. Another important area in this conversion is *machining* and mechanical surface dressing.

Presently available four-siders, moulders, planers, sanders, and other machines have reached a fairly high degree of perfection, with immediate progress dependent more on machine design than on an understanding of wood, although some defects, for instance grain lifting, cannot yet be perfectly handled. There is intense competition between woodworking machinery manufacturers, the leaders being the US, the FRG, and Italy. It will be interesting to see how much of this market may be conquered by the East Asian industrial nations.

8.3.6. Reconstituted wood

The *reconstitution* of *sawnwood* into laminated beams, wide edge-glued panels, laminated veneer lumber (LVL), microlam, lamibois, and other similar products is an area in which spectacular progress has been made during the last few decades. The breakthrough of these products was made possible by the development of high-performance adhesives, already mentioned, particularly the resorcinols. These provide entirely new possibilities for the imaginative designer and architect and, just as important, permit small trees containing numerous singularities to be used in the manufacture of large cross-section members, long lengths, and curvilinear beams, almost impossible to achieve by conventional methods. The elimination of singularities can result in significant increases in quality and strength, for instance by finger jointing, and is made possible by the availability of high-precision profile cutters.

The development of better engineering design and construction methods goes hand in hand with improvements in manufacturing processes to kindle ever-increasing acceptance and use of this type of product. Some interesting recent developments, which may point the way to future progress, include "Circular Slicing with Constant Radius", a method for producing veneer slats up to 12 mm thickness without peeler checks, suitable for lamination, which was patented by a French team (Fondronnier and Jaudon, 1978) and "Scrimber", a new method of reconstitution by the rending of stems of juvenile wood and reconsolidation of the resultant strand mass, proposed in Australia (Coleman, 1981).

8.3.7. Mechanical joints

The contribution of better assembly methods is mentioned here in passing, particularly the nail plates developed for joining elements of roof trusses by largely automated methods, and a large number of different metal brackets for the easy joining of various parts of timber frames in houses and larger structures.

8.3.8. Adhesives

However, the greatest contribution to the assembly of wood elements is undoubtedly that of the synthetic adhesives, already mentioned. These have today reached a high degree of performance, but are still fairly expensive constituents of the finished article and their application is amenable to various improvements in relation to assembly and curing times, easier application, and suitability for a wider range of densities. The problem of gluing end grain is still largely unsolved and gluing surfaces not strictly parallel to the grain also still presents some difficulties. Better glues for rough-sawn surfaces are desirable, although a number of gap-filling or expanding glues already give reasonable results. By eliminating the need for special dressing, they can lead to significant savings of wood material (Elbez and de Leeuw, 1981).

Progress in this area may be expected from both empirical experimentation and advances in fundamental chemistry. The polymers on which modern adhesives are based are quite well known, but their interaction with the wood surface (wetting, bonding) needs further elucidation. New formulations are being tested by cooperation between glue manufacturers and wood technology laboratories. Developments over the next 10 to 20 years are likely to result in better performances under a greater range of exposure conditions (temperature, weather) and in easier application and curing, but it seems unlikely that any completely new product or technology will arise within this time span. (For further details see the chapter by Subramanian in Rowell, 1984.)

8.3.9. Wood–resin combinations, compressed wood

We are skeptical, also, in both the short and medium term, about products derived from wood by impregnation with various resins in monomer form, which are then polymerized *in situ* through catalyzation by nuclear radiation or by chemical means, and about products manufactured by thermoplastic treatments of natural wood. This is not to deny the technical feasibility of such products, for which many patents have been taken out over the last 40 years, but rather to doubt their ability to conquer other than very specialized markets. In general, the large quantity of resin required, and/or the severe conditions of temperature and pressure used in the process, while bringing about an improvement in some properties, such as hardness, often lead to deterioration in others, such as bending or impact strength, and to higher density. They are certainly durable, as is demonstrated by the floor of the public areas in Helsinki airport made from resin-impregnated wood and still in good condition after some 30 years' service. (For a discussion of wood–polymer materials, see the chapter by Meyer in Rowell, 1984.)

8.3.10. Wood-based panels

We now come to wood-based panel products and, in particular, plywood and particle board. We have already stated our opinion that particle board in its various forms is the only radically new wood product to have appeared in modern times. Both of these products have benefited and, indeed, were made possible by the development of modern synthetic adhesives alluded to above, although plywood was made earlier with animal and casein glues.

It would take us outside the scope of this chapter to discuss in detail the many forms of particle board developed during the last 30 years and the complex machinery used in its manufacture. An abundant literature exists on the subject (see, for instance, Kollmann *et al.*, 1975, for a general description and Anon, 1984, for recent new plant installations). Suffice it to say that the technological development of this material is far from complete and that new forms may yet see the light.

One of the virtues of particle board is, of course, that it provides a very profitable use of thinnings, offcuts, and other residue material. However, it must compete with the use of these materials in pulp manufacture and, more recently in the developed countries, as firewood for domestic use.

The main use of particle board in the past has been for furniture parts, shelving, and other utility applications. Veneering has enabled its use as a core material for many purposes where an attractive wood surface is desired and a number of resin and paper overlays have been developed. The main growth area at present appears to be in structural applications, made possible by the development of better chippers and other types of mills that enable the production of particles as wafers, strands of fibers, and other forms, thus giving rise to materials such as waferboard, oriented strandboard (OSB), and so on (Maloney, 1984). These combine some of the virtues of solid wood (greater strength in one direction) with those of conventional particle board (uniformity) and it may be safely predicted that new types of better performance will appear in the next ten years. A breakthrough might be achieved if these could be combined with new, cheaper expanding glues to give an overall lower density.

8.3.11. Other wood uses

Wood has numerous other applications, some of which are, however, dwindling. Poles for telecommunications and electricity transmission are being increasingly replaced by microwave circuits and underground cables, and a large proportion of wooden railway sleepers are gradually being replaced by concrete. Similarly, mine pitprops are increasingly nonwood (except in the Republic of South Africa, where mining timber accounts for about 50% of total timber use), scaffolding in industrialized countries is now generally made of steel, and many domestic appliances are now plastic, from toothpicks to toilet seats. In other applications wood is maintaining its market; for instance, fencing in rural and suburban environments (in countries where wood is traditionally used for this purpose), small jetties and marine pilings, pallets, fruit boxes and some other packaging materials, as well as musical instruments, but this is no reason for complacency, as new materials may rapidly conquer these markets if offered with equivalent properties at competitive prices.

Some markets have been more or less irretrievably lost, for instance wooden boats, but new uses are appearing, such as acoustic barriers along freeways, which should be given more attention. We have not mentioned the use of wood for the production of energy or chemicals, not only because these subjects are outside our present topic, but also because we believe that these applications are unlikely to give rise to major industries in the medium-term future, except in some local contexts.

8.4. The Contribution of Technology to Marketing

There are many facets to the successful marketing of a material or product. Technology, though rarely a selling point appealing directly to the end user, may make an indispensable contribution to the achievement of properties the end user desires. Among these, as far as timber and wood products are concerned, reliability and adequate, maintenance-free service life, including the conservation of the aesthetic aspect, are probably the most important ones. It is our belief that the greatest contribution of technology to the marketing of wood during the next two or three decades will be in these areas.

Reliability of performance over long time spans is required, particularly of timber in structural uses. It may be achieved through a proper understanding and control of the static strength properties and of the behavior of timber under long-term loading.

8.4.1. Stress grading

The first aspect, determination and control of static-strength properties, is a function of stress grading, i.e., assigning a guaranteed structural strength to each individual piece of timber (already mentioned in Section 8.2). Various techniques are already being used for this purpose and others are under development. They fall basically into three classes:

(1) Visual stress grading by assigning strength values according to an assessment, by a trained operator, of the presence and distribution of singularities.
(2) Mechanical grading by machines that measure the modulus of elasticity in bending and assign strength values based on the statistical correlation between modulus of elasticity and modulus of rupture (Fewell, 1982).
(3) Grading by machines that determine the presence and distribution of singularities and defects by electromagnetic means (laser, gamma-rays, microwaves) and assign strength values based on the statistical correlation between these singularities and the modulus of rupture.

In addition, we must mention proof-loading machines, which operate by applying a load corresponding to more than twice the design stress in bending. Pieces that fall short of the required strength break in the machine and the remainder are deemed acceptable.

Moisture content control is, of course, essential for stress grading to be meaningful. Some continuous moisture testing and alarm devices exist, based on the measurement of either capacity or dielectric parameters by means of microwaves. However, these methods require an independent knowledge of the basic density of the material. Promising developments for the simultaneous, independent measurement of density and moisture content on a continuous, production line basis are in progress, using a combination of gamma radiation and microwaves.

All strength-grading methods must take into account that wood is a biological material whose properties are distributed according to a probability function, usually a Gaussian distribution. It is therefore necessary to measure each individual piece and label it according to its stress grade. This is being done at present with radiata pine in Australia (RPAA, 1981) and we have no doubt that similar methods will be widely used for many species within 20 years. Before they can be applied it is, of course, necessary to undertake a great amount of laboratory testing of the timber concerned in order to establish the statistical correlations. It is clear, from an analysis of information found in the literature, that the whole field is in rapid development and considerable innovation may be expected in the medium term.

The result of this development will be to offer to the builder an engineered material with guaranteed strength properties and dimensions that is fully competitive, from a technological point of view, with steel, concrete, and other alternatives.

The remarks made above with regard to solid timber apply, *mutatis mutandis*, to wood-based panel products, reconstituted wood, and other derived materials. Prediction of strength properties for these more uniform materials is somewhat easier than for solid wood and stress grading on a continuous, production-line basis is still in its infancy. Increasing structural use of panels, such as various types of particle board, will probably stimulate the development of new methods applicable to this type of material.

Another area where considerable development may be expected is in the performance testing of joints between timber elements, including the effect of various metal and plastic connectors.

8.4.2. Conservation of properties

A second important aspect of performance guarantee is the conservation of properties during the normal service life of the product. This involves, on the one hand, structural stability and, on the other, the absence of biological decay or chemical alteration of the wood material.

Wood is a viscoelastic and viscoplastic material and may deform slowly by creep under long-term loads, such as those existing in structures. This may often be observed in old farmhouses, barns, and similar buildings, where the originally straight, horizontal beams have bent and sagged under the weight of the superstructure. The deformation is enhanced if the moisture content of the wood fluctuates, as it normally does in service due to its hygroscopicity.

The accepted design procedure for long-term loading is the introduction of an empirical factor that increases the cross section of the elements concerned. This is wasteful in terms of material and space. At present, our fundamental understanding of the rheological behavior of wood is grossly inadequate; and it is unlikely that better practical methods for the control of creep will be found until this behavior has been elucidated. Intensive research in this area is under way, particularly in the US, Canada, France, the Netherlands, Denmark, the FRG, and Japan. It is based on earlier, significant results obtained in the UK and Australia, which, however, fell short of practical application.

The absence of biological decay may be ensured by the application of the appropriate preservation to protect the wood against fungi and insects. A great deal can be achieved, even without preservation, by rigid attention to correct site practices, to building methods that ensure proper ventilation, and to careful building hygiene after completion [6]. In each case, it is important to assess the precise risks to which the structure may be exposed in service and to prescribe preservation treatments according to these risks and the nature of the timber used. As already stated, significant progress may be expected in this area during the next 20 years.

Progress may also be expected, but is less certain, in the better performance of surface finishes (particularly transparent stains, varnishes, and similar products) to protect the surface of wood in outdoor and indoor use. This is another subject where the scientific knowledge at present available is grossly insufficient.

It seems to us, in resumé, that progress is well under way to offer the consumer of the early twenty-first century timber and wood products that are of guaranteed dimensions, moisture content, and strength, as well as having a guaranteed service life.

8.4.3. Other contributions

The two topics discussed in this section do not exhaust the possibilities of contributions by technology to better processing and marketing. Returning to our discussion of orientations today, in Section 8.2, we may confidently expect that the widespread introduction of automation, of more productive machines, and of better plant design may result in increases in productivity that we conservatively estimate to be capable of attaining an average of 20% over the next 20 or 30 years. The contribution of better organization and management of production can also be very important and frequently permits impressive gains in productivity or raw material recovery without significant new investment. Another aspect that contributes to greater economic return is the efficient and profitable use of residues. These factors, by reducing production costs and increasing quality and reliability, make a basic contribution to the competitivity of the final product.

8.5. Wood Processing in Developing Countries

Orientations should be seen from a worldwide perspective, thus avoiding any ethnocentric or society-centered approach. We are not in favor of partitioning the world into "North" and "South", "Developed" and "Developing", but there is no doubt that the situation in the so-called developing countries requires some special consideration.

The following basic facts should be remembered:

(1) Most of the developing countries are located in tropical or subtropical regions.
(2) Developing countries own about half of the world's closed forest areas and harvest a little over half of the world's total timber crop, but only 19% of this harvest is for industrial purposes, the rest being for firewood. By comparison, in Europe and North America, 89% of the harvest is used for industrial purposes (1980 figures).

Most of the natural forests in developing countries are hardwoods and few have received silvicultural treatment. The timbers derived from them present special conversion problems, often not fully understood by machinery manufacturers and timber experts whose experience is limited to developed regions of the Northern Hemisphere. The problems include the irregular form and large size of many trees, hollow centers or other forms of decay, growth stresses, brittle heart, and overmature wood, to name but some of the most important. Their conversion calls for versatile sawmills with simple, robust equipment that permits frequent turning of the log during sawing (Page, 1972). Specially adapted procedures are often necessary to dry such timbers, which may be prone to splitting and collapse or to changes of their natural colors.

These technical problems, combined with the frequent lack of technical infrastructure and skilled personnel, make it imperative to use the appropriate equipment and technology. Sophisticated control mechanisms, advanced automation and equipment requiring special maintenance should not be advocated in most cases.

Improvements in the technology of mechanical wood processing in these countries should start by endeavoring to obtain the best from the existing equipment and labor force. Practical advice by technically competent persons familiar with the social and industrial environment can often go a long way toward increasing productivity and quality, even in a primitive conversion plant. Investment in new equipment must not be recommended for its own sake, but only if it is proved that such equipment will be able to operate within the context of available skills and technical support facilities and so avoid a further profitless increase of the already intolerable debt burden of many developing countries.

Another important point is that many developing countries have their own forest products laboratory with highly trained personnel familiar with local problems. Unfortunately, government and industry executives in these countries often give more credence to the pronouncements of visiting foreign experts than to the opinions of their own competent countrymen. We strongly believe that many technological problems of forest industries in developing countries could be solved if their own national laboratories and staff were properly supported and given an opportunity to apply their knowledge.

Apart from its technical function of efficiently converting a natural resource into marketable products for export or domestic use, the timber industry also fulfills a social function in providing employment in rural areas, in producing building materials for local dwellings and furnishings, and in generating some export income. The utilization of timber must be compatible with the conservation of the forest resource by paying attention to correct land use, such as a sustained yield management either in the natural forest or by the establishment of ecologically appropriate plantations, and by avoiding unauthorized clearing. A full discussion of this aspect is outside our present topic, but attention should be drawn to the threatening decrease in tropical forest areas, which is due more to indiscriminate displacement of whole populations into forest areas to establish subsistence agriculture and to clear-cut for grazing, with the sole purpose of producing cheap meat for developed countries, than to logging for timber utilization (Zerbe *et al.*, 1980).

8.6. The More Distant Future

In the preceding sections we have endeavored to show that technological developments in mechanical wood processing are provoked, *inter alia*, by:

(1) Developments in general engineering science, chemistry, and other areas.
(2) The changing character of the forests.
(3) Market trends and user requirements.

There is no reason to suppose that these mechanisms will change during the next century.

8.6.1. Effects of developments in engineering sciences

The most outstanding general development at present is the growth of information science and its applications to computers, automation, robotized manufacture, and process control, the effects of which will probably not make their full impact on the timber industry until the early 2000s. Another important area of rapid advance is the progress in polymer chemistry, leading to new possibilities for the combination of natural and synthetic materials and to new possibilities for the use of the remarkable molecules produced by photosynthesis.

A more uncertain development is the production of abundant energy by using hydrogen fuel or by controlled nuclear fusion; it remains to be seen whether these technologies could be adapted economically to common use and to environmental constraints.

It is hazardous to conjecture what influence these developments might have on timber conversion, but some possible orientations may be discerned:

(1) Greatly improved quality assurance in timber products by automatic sensing of properties, sorting, and processing.
(2) Dimensional stabilization of wood and reduction in viscoplastic deformations under long-term load by the combination of wood with new polymers or by selective reinforcement of the wood structure.
(3) Progress in reconstituting wood by adhesives, using components ranging from small particles to boards and planks.
(4) Use of the outstanding mechanical properties of cellulose in new composite materials.

This is not an exhaustive list, but points to some directions that we consider promising.

8.6.2. Influence of changes in forest resources

As regards the resource, the next 100 years are likely to see the very widespread disappearance of primary forests, apart from, hopefully, large bioreserves and national parks. By 2100, timber for utilization will be derived to a great extent from fast-growing plantations and from managed secondary forests. This will open the way to the rationalization of plantation and harvesting by increasing the introduction of automated and robotized methods, and so produce stems of uniform size and density, which lend themselves to further streamlining of the conversion processes.

Naturally, grown wood from unmanaged trees will be at a premium price for artistic and luxury applications.

This scenario, though it may seem alarming, actually represents the optimistic view in postulating that an extensive forest cover will be maintained. The pessimistic view is the almost complete disappearance of forests as a result of demographic growth, which will double the population of the developing countries in the next 25 years and may quadruple it by 2050. This could lead to even more extensive agricultural settlement schemes on unsuitable soils, further deforestation for grazing and to accommodate the urban sprawl, and even more widespread destruction of marginal forests for firewood. The recent serious increase in dieback and pathogenic deterioration of many forests, especially in industrialized regions, is another danger, which if unchecked, could invalidate any forecasts of future developments in the timber industries.

8.6.3. Influence of market trends

Taking the optimistic hypothesis that there will be no catastrophic changes, either man-made or through ecological deterioration, we may conjecture some of the alternative paths that the technological development of timber conversion may take.

We believe that two trends may be postulated:

(1) As far as the demographic explosion and urban sprawl will permit, human beings in most places will prefer individualized dwellings to large blocks of communal flats. Timber may be a preferred building material for single houses for one or a few families if it can meet consumer expectations as regards cost and reliability. In regions where timber is not at present readily accepted for housing, sociological and marketing research should be encouraged to identify relevant promotional techniques.

(2) In the industrialized countries and in the increasingly crowded environment of the next century, many people will wish to surround themselves with "natural" rather than synthetic or artificial materials, and wood may be a first choice for furniture, interior decoration, and articles of utilitarian or cultural use, if ways are found to enhance and conserve its natural beauty by appropriate surface treatments, dimensional stabilization, and new conceptions of form.

The ability of wood to be worked with simple tools by the handyman will undoubtedly be another asset in industrialized countries, where the citizen lives in an increasingly artificial environment and does work of a more and more sedentary nature and so will long to express him- or her-self by creative activities with his or her hands, as is already observed in some of the OECD countries.

8.7. Conclusion

In tracing the technological developments of mechanical wood conversion we have seen that this activity, like most others, cannot be considered in isolation, but must be seen in the context of technical, economic, and social development generally. At present, the timber industry seems to us, by and large, to be meeting with some success the challenge of converting from the crafts to the industrial era. The very nature of wood, with its many different species, its probabilistic distribution of properties, its remarkable strength-to-weight ratio due to its anisotropic structure, and the possibility it offers of an almost infinite range of aesthetic presentations, make it eminently suitable for the application of information science to its processing. It is thus well placed to weather with profit the further transition to the computer age.

The mechanical conversion of wood also has, however, a social function that seems likely to remain important for a long time. Its ability to be processed in small and medium-sized industries provides possibilities for the employment of relatively unskilled labor in rural areas and, with simple technology, of producing building materials for simple dwellings. Unless the world situation changes very much for the better, this will remain an important feature.

The forest and the wood and wood products derived from it have a deep emotional significance for most people. The many movements of conservationism and trends to return to a more "natural" life, at present observed in industrialized countries, are an expression, still somewhat confused, of these emotions. We believe that they will contribute, in a more mature form, to the maintenance of the world's forest areas and encourage the utilization of the "natural" material "wood" in all its forms, derived from these forests with due regard to ecology and to the environment.

However, the various trends examined in this chapter and the conjectures put forward must be clearly understood to represent no more than the opportunities for development that exist today. They are not "forecasts" in the sense of events that will inevitably arise from the causes we can identify at this moment. Future developments are not uniquely predetermined. They may proceed in a number of different directions; which in particular depends on decisions we take and choices we make now.

One thing is certain: the major conversion plants we plan and build today will normally still be operating in 20 years and the forests we plant and manage today will provide the timber to be used 20, 50, or even 100 years from now. Conversely, the forests we destroy today will not produce timber (nor remain as bioreserves) in the future.

The future is thus not something to be passively expected, but something we help to shape and determine by the decisions we make and the actions we undertake today. It is well to remember that our good or bad choices may affect, for better or worse, the well-being of a large proportion of members of the human family for a long time to come and that our responsibility is very much engaged.

Notes

[1] For reviews of current developments see the many specialized technical journals, such as the *Forest Products Journal*, *Wood Science*, *Wood Science and Technology*, *Holz als Roh- und Werkstoff*, *Holzforschung*, *Mokuzai Gakkaishi*, and other Japanese journals. See also the series issued by the forest products laboratories in Madison, WI, US; Princes Risborough and TRADA, UK; the Centre Technique du Bois et de l'Ameublement and the Centre Technique Forestier Tropical in Paris; the German institutes at Hamburg, Munich, Braunschweig, and Stuttgart; Japanese laboratories in Tsukuba, Kyoto, Nagoya, Sapporo, and Asahigawa; institutions in India (Dehra Dun, Bangalore), Malaysia (Kepong), the Philippines (Los Baños), Brazil (São Paulo, Brasilia, Manaus, Curitiba), Argentina (Buenos Aires, Santiago del Estero), Chile (Santiago, Concepción, Valdivia), Mexico (Mexico, Xalapa), Australia (CSIRO, NSW For. Comm.), New Zealand (Rotorua), South Africa (CSIR), and many more.

[2] We define "singularities" as natural irregularities of the wood structure, such as knots, resin or gum pockets, and grain deviations. "Defects" are man-made, for instance, wane, seasoning checks, and distortion induced by incorrect processing.

[3] "Stress-grading" is the grading or classification of individual structural elements (boards, beams, etc.) into strength classes by visual inspection or special machines (see Section 8.4.1).

[4] This is an ongoing process, already well under way or achieved in a number of companies, but still in the making in very many places.

[5] Dielectric drying, also known as high-frequency drying and microwave drying, is a method of transferring heat directly to the water molecules inside the wood by a rapidly alternating electric field. To achieve this, the drying chamber contains suitable electrodes between which the timber remains for the time necessary to remove the moisture.

[6] Wood-destroying fungi do not attack wood below a moisture content of 20%, a condition that may be maintained in normal buildings by proper attention to the points mentioned.

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CHAPTER 9

Technological Developments in the Pulp and Paper Industry

K. Ebeling

The global consumption of paper and board was slightly over 190 × 10^6 ton in 1985 (Anon, 1985d). Of this figure, about 45% comprised various board grades and about 55% various paper grades. Typical grades of the paper sector are:

(1) Printing and writing: 49 × 10^6 ton/year (Graff, 1984b).
(2) Newsprint: 28 × 10^6 ton/year (Graff, 1984a).
(3) Soft tissue paper: 11 × 10^6 ton/year (Anon, 1985c).
(4) Sack paper: 6 × 10^6 ton/year (Malmipohja, 1985).

Linerboard (kraftliner and other liners; $< 30 \times 10^6$ ton/year) and corrugating medium (fluting; *ca* 15 × 10^6 ton/year, a figure that also includes all products based on recycled fiber) form the largest board grades, followed by various folding boxboards and liquid packaging boards.

Excluding some coated paper grades and uncoated free sheets, there seems to be an overcapacity for several years to come in most paper and board grades.

In *Table 9.1* we outline roughly the allocation between the various raw materials used to produce 190 × 10^6 ton of pulp and paper in 1985 (Terãs, 1985). For most pulp grades there exists an overcapacity that will continue for years to come (Põyry, 1985; Gundersby, 1985).

Besides the production of papermaking pulp grades from wood fibers, wood pulp fibers are used also for the manufacture of fluff products (*ca* 10^6 ton/year) and of dissolving pulps (*ca* 4 × 10^6 ton/year). About 30 × 10^6 ton/year of the paper grade pulps form the so-called market pulp lot that is

Table 9.1 Rough estimates for the relative shares of various papermaking raw materials in the 1985 global output of paper and board.

Raw material	*Share* (%)
Chemicals, fillers, synthetic fibers	7
Recycled fiber	22[a]
Mechanical pulps (mainly softwoods)	16
Semichemical pulps (mainly hardwoods)	4
Chemical pulp, softwood	32
Chemical pulp, hardwood	13
Pulps from nonwoody plants[b]	6
Total	100

[a] Share is larger if it is based on the amount collected.
[b] Including bagasse, kenaf, bamboo, reed, etc.

transferred from one country to another before being manufactured into paper.

Mechanical pulp (*ca* 30×10^6 ton/year) is mainly used in the manufacture of:

(1) Newsprint papers (the relative share of mechanical pulp in the furnish varies from 80 to 100%).
(2) Wood-containing printing and writing papers [the largest grades being supercalendered magazine paper (SC paper); *ca* 3×10^6 ton/year] and low-weight coated paper (LWC paper; *ca* 5×10^6 ton/year), in which the share of mechanical pulp varies from 30 to 60%.
(3) Folding carton boards (relative share of mechanical pulp around 30 to 50%).

Mechanical pulp is used in these products because of its opacity (nontransparency), ink absorptivity, resilience, and/or stiffness.

Semichemical pulp is mainly used in the manufacture of corrugating medium (fluting), because of its very good in-plane compression and crushing properties.

Recycled fiber (i.e., wastepaper as such or deinked [1]) is used mainly in packaging papers and boards, but also in sanitary, creped papers, in newsprint, and in other printing papers.

Pulps from nonwoody plants (bagasse, straws, bamboo, and, in the future perhaps, kenaf) have locally significant roles as papermaking raw material. More exotic nonwoody fibers (sisal, abaca, hemp, cotton, linters) also form important grades of market pulp used in the manufacture of certain special papers (porous papers, security papers, and electrical insulation papers). The rest of the fibrous raw material for global paper and board production comprises chemical pulp, mainly softwood chemical pulp, about half of which is of bleached quality. Softwood chemical pulp is used for its strength properties as a reinforcement fiber in almost all paper and board grades. Hardwood chemical pulp (mainly bleached) is used for its less expensive price and for its good surface and formation (even areal distribution of mass) properties.

9.1. Special Features of the Pulp and Paper Industry

The pulp and paper industry is an example of the so-called process industry. Besides having typical features of the process industry, the pulp and paper industry has also special features of its own, which are outlined here according to three subgroupings:

(1) Reasons for very large production facilities:
   (i) New capacity is very capital intensive; thus a large mill is built in order to benefit from the economies of large scale and operated in continuous shifts (three) in order to minimize the capital costs per unit of production.
   (ii) Environmental protection and energy conservation measures, plus automation costs, are proportionately less expensive (up to a certain limit) the bigger the mill.

(2) Reasons for manufacturing costs and selling price being the key competitive elements of the industry:
   (i) Relatively old basic technology, which is available to all (mature industry).
   (ii) Well established and slowly growing markets.
   (iii) Similar products of competing producers are easily interchangeable and there seems to be very little product loyalty.
   (iv) Cyclic trends of overcapacity and tight supply.
   (v) In many cases, products are actually (or have been) commodities and are not final consumer products.
   (vi) Adjustment between capacity and demand is quite limited.
   (vii) Most products have worldwide markets and the exchange rates of currency overshadow the operating rates.

(3) Reasons for a short-term R&D practice and for optimization and modernization of the present production processes (an evolutionary

development of cost effectiveness) instead of innovative, new product/new process development (revolutionary approach):

(i) The financial performance of the global pulp and paper industry has deteriorated over the last ten years (Salonen, 1984), and no quick recovery is foreseen.

(ii) Capital risks involved in totally new manufacturing processes are gigantic and the road from a new idea through preliminary laboratory tests, to bench scale, pilot scale, and prototype operations, to an established and proved new process is long (5–10 years) and costly. Therefore, pulp and paper companies favor investments in well-proved manufacturing methods and equipment.

(iii) Much of the new process and equipment development work is conducted outside the pulp and paper industry by the equipment manufacturers themselves.

(iv) The previously described capital intensiveness and large manufacturing facilities induced by it favor the "quantity beats quality" philosophy in many products of the pulp and paper industry.

(v) More and more of paper and board production occurs in integrated operations that balance the business cycles of market pulp to utilize the excess of energy in modern pulp mills and to avoid the intermittent drying costs of pulp. Such integrated manufacturing facilities are less flexible in terms of their production programs.

9.2. Preliminary Assumptions Concerning Technological Development in the Pulp and Paper Industry

The special features of the pulp and paper industry outlined in the previous section do have an effect on the expected technological development of the industry. Because of the prevailing overcapacity, of slow growth in many pulp and paper grades, and of a generally weak, long-term financial performance, the pulp and paper industry favors bottleneck clearance and modernization investments in existing mills over investments in totally new greenfield mills in order to become cost effective or generate "new" capacity or replace outdated, low-profit capacity [2]. In such modernizations paper machines of medium age — manufacturing bulk grades — will be converted for higher value grades or some new specialty grades. Temporary mismatch of exchange rates for foreign currency may cause periods during which new capacity investment in a particular country is very advantageous.

It is believed that the general consumption pattern for paper and board will prevail during the next ten years (see pp 224–226) and the amount of paper and board consumed annually will grow, albeit slowly (Gundersby, 1985). In other words, it is assumed that there will be no large economic or energy crisis and that the role of plastics in packaging will not expand very much above that of paper and board. It is also assumed that the new electronic communication media will not affect paper consumption very significantly during the next ten years [3]. There will be no large-scale competitive business for wood besides the conventional forest industry and no ecocatastrophe or man-made restrictions (i.e., acid rain) will affect the availability of wood.

Since the cost of wood is one of the most significant manufacturing costs of pulp and paper production and since new wood fiber supplies are restricted in many industrialized areas of the globe, pulp and paper companies will favor such measures in their technical development programs that decrease the cost of wood (pulp mills) or the cost of expensive, chemical pulp fiber (paper mills) in addition to decreasing the demand for primary energy (Wrist, 1982).

In other words, the next ten years of pulp- and paper-making industry are foreseen as "more of the same" years, without revolutionary changes in products or production technologies. However, some paper grades will grow above the average global rate for pulp and paper (coated, high-value printing papers and papers destined for computer-related business), some will grow much less (newsprint), or even decline somewhat (sackpaper), depending on their position in the product lifecycle. The R&D philosophy of the industry will center around methods to decrease the manufacturing costs and to provide inexpensively better properties to paper and board.

9.3. Technological Developments in the Pulp and Paper Industry

Here technological developments that are most likely to take place during the next ten years are reviewed. The developments in the pulp industry (papermaking fiber) and in the paper and board industry are treated separately. The developments in the process control technology of the pulp and paper industry are also treated separately.

9.3.1. Technical developments in the pulp industry

This subsection is divided into developments in the manufacture of mechanical pulp, of chemical pulp, and of recycled fibers.

Mechanical pulp manufacture

The share of mechanical pulp will increase in many paper and board grades, largely for the following reasons:

(1) The yield of fibers is much higher (> 90%) in comparison with chemical pulps (*ca* 50%). When available pulpwood — and especially available softwood — is a limiting factor in the expansion of pulping capacity and/or when the price of pulpwood is relatively high, the production of mechanical pulp is preferred to that of chemical pulp.
(2) The greenfield chemical pulp mill will require more than twice the investment cost per ton of annual capacity in comparison with an integrated mechanical pulp mill, assuming that electrical energy is available in plenty.
(3) New mechanical pulp capacity can be added in considerably smaller units than new chemical pulp capacity.
(4) The environmental impact of the pure mechanical pulp mill is considerably less than that of the chemical pulp mill and thus the required, external environmental protection measures are simpler and less expensive.
(5) The papermaking properties of new mechanical pulp grades are quite good and make it possible in many cases to decrease the role of more expensive bleached or semibleached softwood kraft pulp or to decrease the basis weight of the paper.

One of the drawbacks of mechanical pulp manufacture is its large electrical energy expenditure [4]. *Figure 9.1* depicts, for newsprint type furnish, the relationship between tear strength (a simplified runnability parameter of mechanical pulp) and scattering coefficient (measure of opacity, i.e., nontransparency or a simplified printability parameter of mechanical pulp) and energy expenditure for the common mechanical pulping processes. The values shown are based on results obtained with Scandinavian spruce. When thicker-walled fibers, i.e., fibers from softwoods growing in the warmer areas, are used considerably higher (up to 50%) energy expenditure may be needed.

It is clear from *Figure 9.1* that stronger mechanical pulp means more expenditure of energy. *Figure 9.1* also shows why conventional

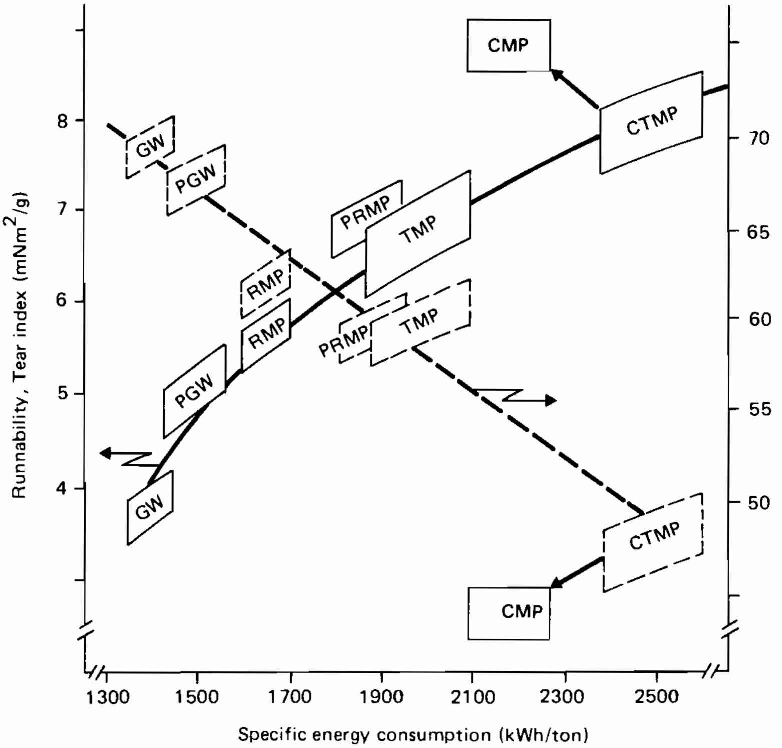

Figure 9.1 Energy expenditure in various mechanical pulping processes for Scandinavian spruce versus runnability and printability of corresponding pulps (100 Csf) (Sundholm, 1985).

groundwood (GW) is losing its share of mechanical pulp manufacture. Out of the new mechanical pulp capacity about 70% is predicted to be thermomechanical pulp (TMP) (Anon, 1984).

Although TMP has a very high external electrical energy expenditure, with today's energy and wood prices it is, in many cases, the least expensive furnish for standard newsprint. This is because it is so strong that it does not require (usually) any semibleached softwood pulp for reinforcement, as do the other grades of mechanical pulp. Besides, the modern TMP manufacturing process with atmospheric presteaming of the wood chips and high refining pressure enables recovery of part of the electrical energy as clean steam at 4.0–4.5 bar for use in paper drying. This type of "recovery boiler" enables the heat equivalent of approximately 65% of electrical energy supplied to refiners, corresponding to about 20% of power costs, to be recovered for paper drying. About 25% of the TMP systems installed are already equipped with such heat exchange systems.

Other features, in addition to strength, that also favor TMP over conventional groundwood are its low labor requirements and suitability for automated and controlled operation. Thus, it is predicted that simultaneously with new TMP installations the GW capacity will diminish, reaching 50% of its 1980 value in the early 1990s.

Where wood prices and energy prices are relatively high and where good quality softwood pulpwood is available, the paper companies that produce printing papers of higher value than standard newsprint [5] may prefer pressurized groundwood (PGW) over 100% TMP. The PGW furnish provides better opacity (nontransparency) and surface smoothness to the paper and simultaneously allows the reduction of the basis weight of the sheet, so saving on manufacturing costs. It is also quite possible that grades of printing and writing papers that involve the excessive use of wet-end chemicals and fillers may not tolerate a very high share of TMP in the furnish, because of the interaction of TMP solids, dissolved in the white water, with the retention and other functions of added chemicals.

The technical developments in pure mechanical pulping might lead to a situation where — under specific external conditions (wood price and availability of good pulpwood, energy price, paper grades to be manufactured) — the opacifying part of the furnish is produced with pressurized (or modernized conventional) groundwood and the strength component of the furnish is produced with the TMP process. It is also clear that the manufacturers of TMP equipment will try to develop methods that reduce the electrical energy expenditure and provide more opacity and smoothness to the pulp obtained, without a simultaneous loss of strength. Apparently, the geometry and dimensions of the refiner plates have a key role in this development and there will probably be a move toward finer plate patterns with a microscale surface roughness. It is predicted that the TMP process of the 1990s will consume — on average — about 15 to 20% less energy than today's processes.

By chemically treated mechanical pulps we mean refiner-manufactured mechanical pulps that have been given a chemical treatment (a) prior to refining (i.e., in chip form), (b) in between the stages of refining, or (c) after refining. The chemical treatment can be mild or heavy. Today the chemical treatment of chips prior to refining predominates. If the refiner is pressurized the method of pulp manufacture is called CTMP (chemithermomechanical pulping); if the refiner is discharged directly to the atmosphere, the manufacturing method is called CMP (chemimechanical pulping). Most operating systems are of the CMP type. Annual world capacity of CMP and CTMP pulps is about 4.5×10^6 ton, of which almost 0.6×10^6 ton is hardwood pulp. The chemical pretreatment of hardwood chips is a prerequisite for a successful defibration of the hardwood structure.

As softwood chips are treated with chemicals prior to defibration, the resultant pulp (CMP/CTMP) shows good strength properties, but simultaneously the opacity (nontransparency) is greatly reduced. A light chemical treatment may even increase the energy requirements (*Figure 9.1*).

Heavier chemical treatment of softwood chips yields pulps with strength values that approach those of chemical pulps, but simultaneously the opacity is reduced by 70%. Such pulps are much used in Canadian newsprint mills to replace the lower yield chemical reinforcement pulps, which have — in many cases — been produced without proper internal and external pollution control measures. Because of the very low opacity of such CMP pulps, the addition to a newsprint furnish has been limited to a maximum of 40%.

It is expected that such a trend will continue in Canada, but elsewhere — because of the low opacity of CMP/CTMP, of stricter environmental restrictions, and of different manufacturing processes for chemical pulping — the use of CMP/CTMP softwood fibers will be restricted to special, very high filler-content printing papers and to applications in soft tissue papers, fluff products, and special board grades, such as food board and liquid packaging boards (Fineman, 1985). *Figure 9.2* shows how the special properties of CMP/CTMP compare with similar properties of other pulps.

It is predicted that CMP/CTMP processes will find applications in the treatment of the rejects of mechanical pulping systems and in the treatment of part of the long fiber fractions, to render these materials more suitable for high quality paper manufacture. Examples of such procedures are the Opco process (Barnet, 1985) and the CTLF/CTMP (chemically treated long fiber fraction) process (Joyce and Mackie, 1985).

Because the nonintegrated-market CMP/CTMP mills are about as expensive to build per ton of capacity as is a greenfield, bleached kraft mill, the CTMP and CMP installations will occur mainly in integrated operations (Gundersby, 1985; Aurell, 1985). The manufacturing costs for market CTMP paper grade pulp are also high because of the very high bleaching costs. Hardwood aspen CTMP, in addition to fluff grades, might become exceptions to the integrated installation line. The overall capacity of CMP/CTMP installations should be around 9 × 10^6 ton in the year 2000, i.e., it should double its capacity in 10 to 15 years (Croon, 1984).

The CMP/CTMP technology will make it possible to obtain better papermaking fibers from certain nonwoody plants (bagasse and bamboo, for instance) as well as from hardwoods. Thus, it is predicted that CMP/CTMP will "open up" some papermaking possibilities in the Third

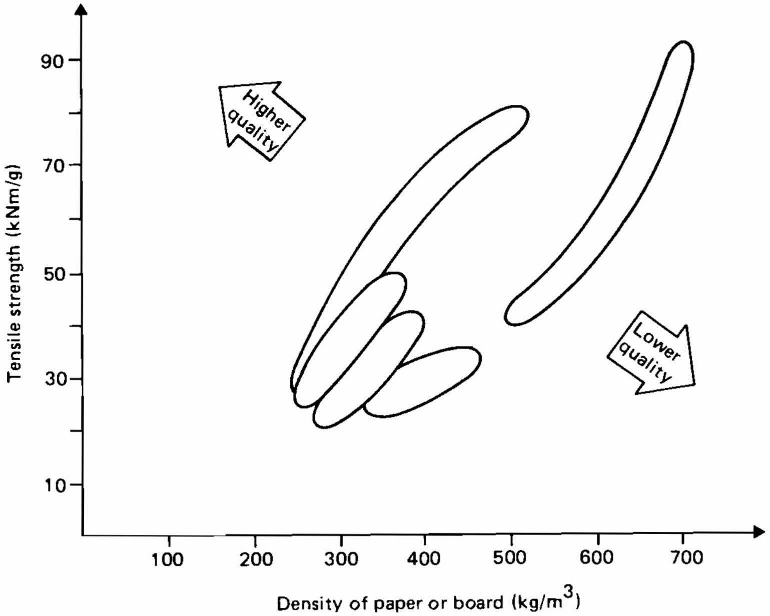

Figure 9.2 Strength versus density spectrum of various pulps from the viewpoint of printing and packaging paper (Croon, 1984).

World (Ryrberg *et al.*, 1983). These methods will, however, require appropriate pollution control measures (Gullichsen, 1985).

In *Table 9.2* we summarize the interrelationships in the "development of popularity" between the selected methods of manufacturing for mechanical pulps.

Chemical pulp manufacture and bleaching

Pulping processes. The process development in chemical pulping will be geared to decreasing the manufacturing costs and increasing the capacity of already existing mills in order to meet the required quantities of softwood kraft pulp because of the following three factors:

(1) Technological advancements in the manufacture of mechanical pulps and recycled fibers.
(2) The lower manufacturing costs of these pulps.

Table 9.2 Effect of selected factors that determine the popularity of various manu-

Process	*Wood (cost/quality/ availability)*	*Capital*	*Labor*
GW (grinding)			Old labor and maintenance intensive capacity will be phased out
PGW (pressurized grinding)	High wood prices, together with availability of good quality softwood roundwood		
TMP (thermomechanical pulping)	Wood in chip form available in plenty	Energy recovery systems add investment costs; thick-walled fibers may require more phases of equipment	Can be automated effectively
CMP (chemimechanical pulping)	Certain hardwood species can easily be processed		
CTMP (chemithermomechanical pulping)	Besides softwood, hardwood and non-woody plants can also be processed	Nonintegrated, fully bleached qualities are expensive to invest and to manufacture	

[a] Can be applied also to modify properties of coarse fiber fraction or rejects fraction to

(3) Overcapacity of chemical pulp production (the low demand of this pulp grade stems from its high price and technological advancements in papermaking, which have made it possible to reduce the basis weight of many papers or to process paper webs with lower strength).

A thorough review of current technical developments in chemical pulping is given by Kleppe (1986).

In installing new capacity for chemical pulp the continuous kraft pulping process will prevail. In order to relieve the very high and continuously rising capital demand of new kraft pulp mills [6], some modifications facturing processes for mechanical pulp.

Energy	*Other manufacturing costs*	*Special properties of end product*
High energy prices favor this alternative		Best for lower basis weights and smooth, high-quality surface
Energy recovery systems add investment costs; thick-walled fibers may require more energy	Makes possible large reductions of chemical pulp in the furnish	Because of its tendency to produce coarse fibers, the process has been best suited to newsprint and less demanding papers
		For manufacture of "replacement pulp" for chemical pulp[a]
		Integrated production to certain high filler content printing and writing papers and to certain packaging boards plus fluff

enhance papermaking properties to TMP.

might be developed in the recovery part of the kraft process. However, these will mainly be for hardwood pulping cases, where wood is available at a relatively low price. Since many of the new processes are in the early stages of pilot or prototype testing (Hough, 1985), it will be five to ten years before such process modifications can be of significance, if proved to be economically and technically feasible.

The neutral sulfite anthraquinone (NS–AQ) pulping of softwoods might gain some limited popularity as a reinforcement pulp in integrated mills, because of a better yield from the wood and of less demanding bleaching operations.

Prolonged cooking using a modified alkali profile, advanced use of anthraquinone and polysulfide addition, and oxygen delignification before actual bleaching are possible techniques that will allow a kraft pulp mill to cook softwood to a 20% lower residual lignin content, while maintaining a higher yield and hemicellulose content in comparison with today's method (Joyce and Mackie, 1985; Kleppe and Storebraten, 1985). Thus the bleaching process will be simpler and less expensive than that of today's technology. Although these developments will improve the overall economy of a new softwood kraft pulp mill, the market price of kraft pulp has to increase quite dramatically to allow such new mills to materialize (Grant, 1985a). The effect of such technical measures on "full-scale" yield and on pulp quality is still open to question.

Although some interesting and promising laboratory and pilot scale experiments are in progress (Lora and Aziz, 1985; Edel and Feckl, 1985), it is believed that the totally new pulping methods based on pulping with alcohol, amines, phenols, or formic acids, as well as biopulping, will not progress fast enough through the various necessary phases of research and development, and so will not be proved and industrially accepted methods during the next 10 to 15 years. Even if proved successful, these new pulping methods are probably best suited to the production of special pulp grades on a small scale. Their economy will rely heavily on the effective use of by-products obtained from recovered lignin and hemicellulose.

A concept that will become quite popular in the new pulp mills, and in the modernization of old bleaching plants, is the so-called medium consistency (MC) technology (Söderström, 1981). [This technology will also be used in the future CMP/CTMP pulp mills (Franzen, 1985).] The MC-technology might decrease the investment costs of new pulp mills somewhat because of less pumping and smaller piping, but increased use of more corrosion-resistant material could offset the savings obtained through the reduced need for equipment. The adaptation of MC technology to screening and bleaching will also decrease the energy consumption, because of reduced pumping.

The Nordic hardwood market pulp will gradually be absorbed by integration with paper production in these countries for economic reasons. Various less expensive hardwood pulps (eucalyptus and tropical hardwoods) will become the general market hardwood pulps.

It is also possible that during the next ten years in the case of a developing fiber-rich country — without the technical skills to run a modern bleached chemical market pulp mill and without the required high capital — wood chips will be processed into very coarse fibers in semimobile TMP or CTMP facilities located in or close to the forest. They will then be processed into high-quality fibers in industrial areas, which have the necessary equipment and other utilities. The necessary process could, for instance, be that after the one-step refiner operation the coarse fibers are flash dried with steam and packed into bales. The transportation costs per unit quantity of fiber will be lower compared with the transport of chips or logs. Also the capital costs involved will also be very much lower compared with building a complete, new chemical pulp mill in the developing country without the proper infrastructure (Croon, 1984).

Bleaching. Oxygen will probably slowly gain more ground as a bleaching agent because of its less potentially severe environmental impacts and its slightly lower running costs. However, its general acceptance is restricted by its high investment cost (Gullichsen, 1985). If a slightly lower brightness for the bleached pulp is acceptable, i.e., 86% ISO versus 90% ISO, the chlorination stage in bleaching could be avoided [7] (Söderström, 1985). Especially in the case of softwood pulps a new bleaching sequence might be as follows: oxygen, chlorine dioxide, alkali–oxygen, chlorine dioxide. There are still many controversial issues to be solved as to the advantages and disadvantages of oxygen bleaching (Virkola, 1985).

It might be possible that a move toward lower brightness in bleached chemical pulps will occur because of the increased use of fillers and/or coating in printing and writing papers. However, the increased use of four-color printing will create pressures for high brightness pulps, especially if the paper industry simultaneously tries to lower the basis weight of both the coating layer and the base sheet.

The alkali stage in bleaching will increasingly be achieved with oxygen as an additional extraction chemical, which will provide savings in bleaching chemical costs and relieve somewhat the pollution load. The increased use of MC (medium consistency) technology will decrease the running costs of the bleaching operations (energy and chemicals).

Energy aspects. The modern kraft pulp mills are already more than self-supported in energy, i.e., these mills will produce an excess of both thermal and electrical energy (*Figure 9.3*; Hartler, 1985). There are also new technologies available to replace old batch-cooking operations, thus decreasing the energy requirements of this pulping method (Ahonen and Rutishauser, 1985).

The oversupply of electrical and thermal energy in today's new pulp mills will favor their integration with paper mills, which require external thermal and electrical energy.

Environmental aspects. As the economic size of new chemical pulp mills has increased the need for efficient pollution control measures has also increased. The internal process measures are still very important for

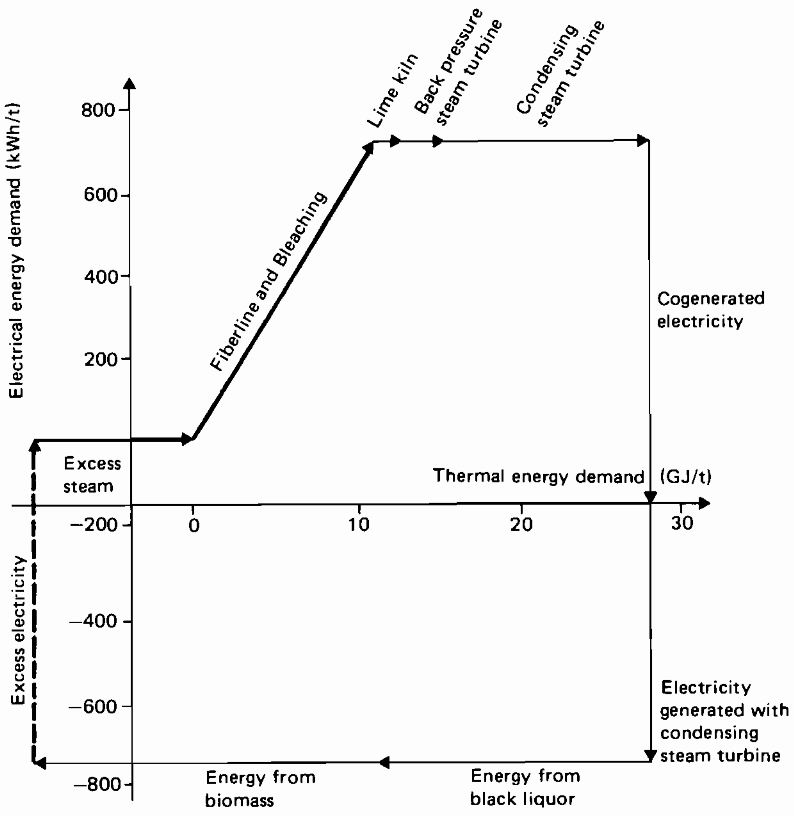

Figure 9.3 Vector diagram of consumption and generation of thermal energy and electricity in today's new bleached kraft pulp mill, where part of the procured wood (thinnings, tops, branches) and bark are used as fuel. Values are given for air-dried ton of pulp (Hartler, 1985).

decreasing the environmental pollution load of chemical pulp mills, but today extensive external (both water and air) pollution control measures are required. It is predicted that the manufacturers of pollution control equipment will have various processes available so that the pulp industry can meet the more stringent discharge codes for various pollutants. The new pollution control methods might, however, be so expensive as to be economically infeasible for smaller and older pulp mills.

A factor of some concern for the future of the bleached chemical pulp industry is the role of chlorinated lignins in wastewaters. It is not completely agreed how dangerous these compounds are or how effectively the various wastewater treatment processes remove them.

It is believed that the anaerobic wastewater treatment process will gain popularity in treating sulfur-free wastewaters, because of its favorable energy aspects. The future of anaerobic treatment processes that operate on effluents containing dissolved sulfur compounds is highly questionable (Gullichsen, 1985). The activated sludge process will maintain its significant role as a proved technology for treating the wastewaters of chemical pulp mills. However, this treatment method involves some risks due to its sensitivity to system upsets and to the leaching of phosphorus nutrients, which might fertilize the receiving waters. It seems, thus, that the classic low-load and long retention time (3–7 days) aerobic treatment in aerated lagoons will survive for some time.

It is also believed that biotechnology will continue to provide new methods and modifications of existing wastewater treatment technologies during the next five to ten years (Eriksson, 1985; Griffin, 1985).

Concluding remarks. To close this review of technical developments in the chemical pulp industry, the overcapacity of pulp production will mean a shrinking market for the associated equipment manufacturers. The simultaneous need for less expensive pulping machinery will provide ample opportunity for new technology and innovations in pulping technology, which the equipment manufacturers will have to acquire in order to stay in business.

Recycled fiber pulps

The use of wastepaper as such or as deinked pulp in the manufacture of many paper and board grades will increase, it is believed, because of:

(1) The moderate to weak financial performance of many paper companies.
(2) Government and public opinion as to the efficient use of wastepaper.
(3) The effect of market pulp import on the balance of payments of some countries.

There is plenty of opportunity for the increased use of recycled fibers in many countries, since the global addition rate of recycled fibers to paper furnish is slightly under 25% and there are industrialized countries for which this figure is well over 40%.

Besides, the various processing technologies for recycled fibers (wastepaper and deinked pulp) have improved considerably in recent years, making it possible to obtain fairly high-quality pulp even from lower quality or contaminated wastepaper. In addition, the feasible size of new recycled-fiber capacity is quite small, making it possible for paper and board mills to add new capacity in small, financially manageable steps.

Examples of new or recent technological developments in the recycled fiber treatment are:

(1) Considerably higher pulping consistencies leading to lower energy consumption and better fiber properties.
(2) High consistency at the start of refining yields stronger pulps with fast drainage.
(3) Better screening and cleaning equipment makes it easier to remove plastic contaminants.
(4) Better deinking technologies (higher consistency, more efficient chemical systems, parallel connection of washing and flotation methods) lead to brighter pulps with less ash.

The recycled fibers adapt themselves best to paper and board manufacturing with older, narrow machines, since recycled fibers always contain particles (stickies, contraries) that cause an increased need for machine stops and wash-ups. In the case of modern, wide high-speed paper and board machines such stops would considerably deteriorate the economics of manufacturing.

Thus it is understandable why the use of wastepaper in the EEC — for instance — is as described in *Table 9.3* (Attwood, 1984). In other words, most boards and packaging papers made in the EEC contain the highest proportion of recycled fiber, since these grades are manufactured mostly with relatively old and small machines that have low capital costs per ton of product and since for these grades wastepaper can be used without deinking.

9.3.2. Technical developments in the paper industry

The paper industry — including board manufacturing — will establish new grades of paper and board between already existing grades. The objectives of this product development, i.e., product differentiation, is to pay more attention to customer needs and to optimize the quality of paper for each end-use, instead of producing a few all-purpose grades. A general, overall trend is also the increased use of hardwood pulps, recycled fibers, mechanical pulps, and fillers as important components of the papermaking furnish in order to decrease the manufacturing costs by reducing the amount of bleached (semibleached) softwood chemical pulp. The pigment coating of

Table 9.3 Wastepaper use in the EEC during the early 1980s (Attwood, 1984).

Product	*Wastepaper proportion of furnish* (%)	*Proportion of EEC total use of wastepaper* (%)
Corrugated board	88	45
Other board	73	30
Packaging paper	50	8
Creped paper and tissue	40	5
Newsprint	26	5
Printing papers	4	3
Others	39	4
		100

paper and board will increase considerably, mostly due to the increased use of four-color printing in advertisements and other printing jobs and to fast-growing new applications of paper in the computer-based information-transfer business [nonimpact printing papers (NIP)].

In the following, the most important aspects of the technological development of the paper industry are reviewed, based on the assumptions that the wet forming of paper and board will be dominant and that dry forming will not gain acceptance, except for some hygienic paper products.

Stock preparation and wet end of paper machine

In addition to the general move to use fibrous raw materials that are less expensive than bleached softwood chemical pulp, papermakers will increase the application of various wet-end chemicals to give extra strength to the sheet. Similarly, there will be a trend toward separate refining of the various fiber components of the furnish in order to optimize the papermaking properties of the furnish and to save on refining energy. New refiners (for new paper capacity) and replaced old refiners will be more energy efficient than the old refiners.

The neutral or semi-alkaline papermaking will gain in popularity, because they use efficient neutral sizes to control the interaction between water and sheet and make it possible to use less expensive calcium carbonate as the filler. Besides, these conditions of papermaking produce better strength in the paper compared with conventional acidic conditions.

The consumption of fresh water in papermaking will decrease through internal improvements in white water cleaning and reuse. This trend is based upon environmental aspects, on better heat economy, and on other aspects of manufacturing costs.

The role of retention chemicals or chemical systems will become very important for efficient papermaking because of the following trends:

(1) Increased speed of paper machines.
(2) Lowering of basis weight of sheet.
(3) Increased use of twin-wire drainage.
(4) Increased use of fillers.
(5) Increased white water interactions with retention chemicals due to the increased level of dissolved solids in the white waters because of tighter circulation and increased use of thermomechanical, chemimechanical, and/or wastepaper pulps. (It might become necessary to use improved technologies in order to decrease the levels of dissolved solids in the white water system of the paper machine.)

The efficient use of retention chemicals and the monitoring of the retention level will require more colloid chemistry applications to papermaking than has been customary up to now.

Sheet forming

Twin-wire sheet forming will become the leading method in new paper (and many board) machine installations. Twin-wire technology will also become very popular in the modernization of old paper machines through the use of so-called retrofit top wire units (Ebeling, 1984). The fourdrinier concept will retain its position for paper grades that have important properties on only one side, are made from difficult to dewater pulps, or are made with narrow, small machines. The speed of new paper machines will increase, because this is a less expensive method of increasing production than is width increase (*Figure 9.4*). Similarly, modernization of older paper machines will result in increased speeds.

In future, the dewatering profile of new and modernized paper machines will probably be "tailor made" for various grades of paper in order to give a better formation and retention to the sheet. It is also highly probable that in the next five to ten years many new applications of multilayer paper production will materialize. For many paper grades this enables enhanced paper properties and better manufacturing economics. The multilayer web construction concept will also spread to many new board machines for grades previously made without layering or just with two layers. The gradual increase of the headbox consistencies — through application of new, efficient hydraulic headboxes — will also mean better production economics, in addition to better formation and profiles.

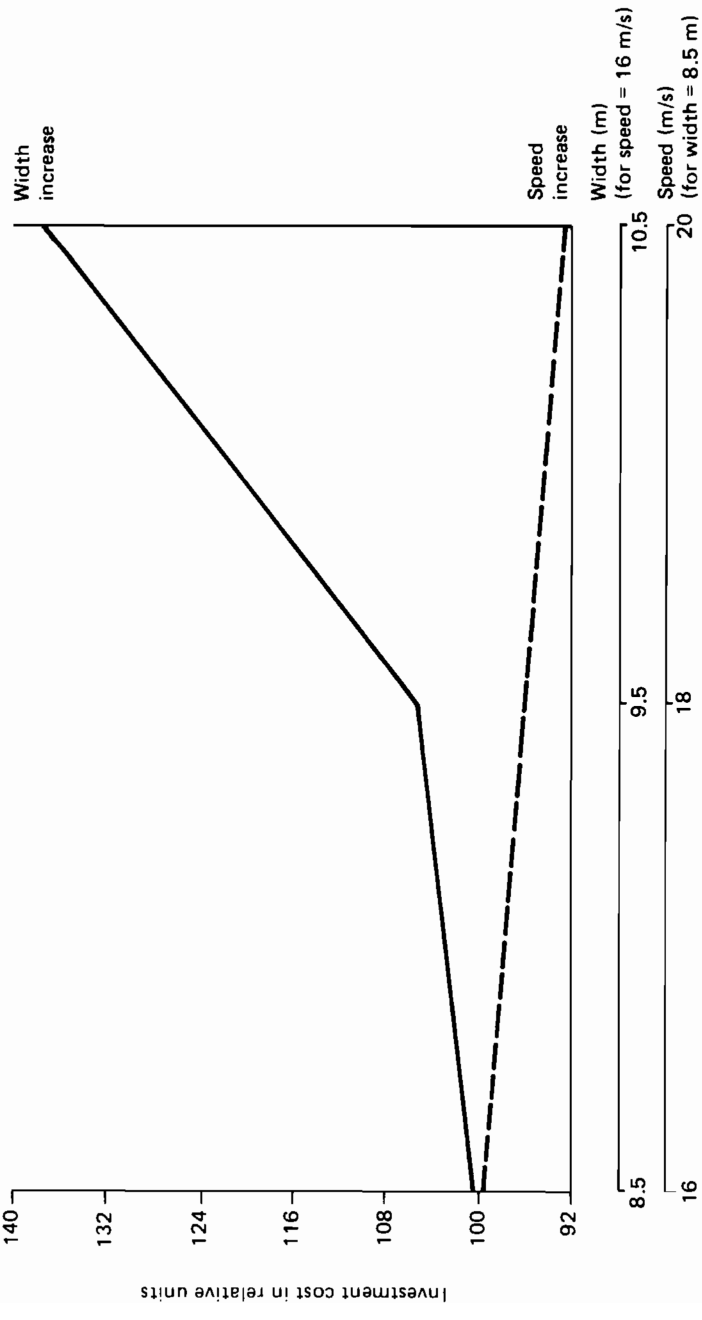

Figure 9.4 Relative unit investment cost of new newsprint paper machines as a function of machine speed and width.

Wet pressing

Technical developments in wet pressing will concentrate on obtaining higher dryness after wet pressing. However, high dryness is not the only target of wet pressing. Simultaneously, there will be demands for a more symmetric sheet structure and/or for retaining the bulk of the structure (i.e., the stiffness), despite the high dryness obtained.

Closed transfer of web through the press section will become a standard practice for the fast, new machines. It will also become popular in the modernization of press sections for the safe transfer of lighter or weaker sheets through them (thus saving in raw material costs).

Heating of the web in the press section will also become quite a standard feature for most paper and board grades to obtain better drying economies and to enable control of the cross-machine moisture profile of the web. It is also likely that during the next five to ten years wet pressing of the paper and board webs with heated press rolls will become industrially possible. This would create savings in manufacturing costs through reduced refining of pulp fibers and through increased use of higher yield fibers, in addition to reduced demand for drying energy.

The wet press felts will become more efficient and the increased application of double felt pressing will help to preserve the wet web thickness (and stiffness of the dry product), with a simultaneous increase in the dryness of the web. The increased use of controlled crown rolls in wet presses will also help to control the cross-machine moisture profile of the web.

Increase in the press nip width via an increase in the roll diameter, through flexible roll coverings or special sliding arrangements, will become standard practice in most new or modernized board machines, making it possible to save in drying costs through increased press dryness and in manufacturing costs through reduced refining and the use of less expensive fiber raw materials (Grant, 1985a).

Drying

The efficiency and effectiveness of drying will be increased as the following measures become standard practice:

(1) Breaker bars inside the drying cylinders to increase the heat transfer through the wall of the drier due to a better turbulence in the condensate layer.

(2) Efficient pocket ventilation systems make it possible to obtain an even cross-machine moisture profile and thus leave more moisture in the web.

(3) Higher dryness of the web after wet pressing plus less water pick-up during surface sizing or on-machine coating considerably reduce the consumption of drying steam, as does the lowered final dryness (previous point), which — combined — can mean savings of 10 to 20% in consumption of drying steam.
(4) More efficient heat recovery systems, together with the use of moister hot air in the drying section, reduce heating costs.
(5) Use of slalom threading of drier fabrics with controlled air streams and closed transfer of web to the drier section increase the safety of web transfer, making it possible to run faster with weaker or lighter sheets and thus increase the production of the paper machine.

It is believed that through drying will not gain ground, except for in some limited applications such as the drying of very soft tissue paper and of special porous paper grades (filter paper). Instead, it is believed that high-efficiency, deep penetrating infra-red drying technology will gain ground in on-machine surface sizing and coating applications. It is also possible that — for integrated TMP pulping — recompression of the condensate into steam would provide a drying technique for paper machines without any boiler or steam generation. Such a method might find use in places where the price of electricity is very inexpensive.

A technical development that also might materialize in the early 1990s is the so-called pressure drying concept. Advanced forms of this concept would make it possible to dry paper much faster than today, resulting in savings in investment and manufacturing costs (less expensive fibers could be used). However, if the price of electrical energy increases considerably faster than normal inflation rates, conventional "low"-pressure steam drying would probably remain the dominant drying method, because of the advantage of electricity being generated using back-pressure steam.

On-machine surface treatments

Surface sizing and coating. In many ordinary and nonimpact printing jobs, paper will require surface sizing or pigment coating in order to render its surface better suited for high-quality information transfer. In fact, the production of many coated paper grades has been growing in the US at a rate of nearly 10% per year in the middle 1980s (Grant, 1984; Allan, 1985) and is expected to grow at an average annual rate of nearly 5% during the years to come (Anon, 1985b). High growth rates have been observed also in Europe for various coated paper grades (Grant, 1984). In future, the paper web itself may perhaps be considered (for many printing papers) more or less as a carrier of the coating layers.

The technical development that will most affect the surface sizing and actual coating (on-machine and off-machine) is the so-called "short contact time" application, which was introduced in the early 1980s. This application technology has made it possible to (Grant, 1984):

(1) Increase paper machine speeds by 20 to 25% in surface sizing and to save in drying costs.
(2) Apply thinner coating layers as an "on-machine" application with very secure sheet transfer and subsequent savings in investment and running costs.

The reported pay-back period for the installation of this new coating method has been about six months, making it the market leader (*ca* two thirds) of the new coating head orders. This success is based on the lesser penetration by water into the web during the "short contact time", making it possible to use weaker webs (i.e., less expensive fibers or lighter webs), thus saving on raw materials and drying costs.

Another important area of technology utilization in the coating (or surface sizing) application is the simultaneous coating of both sides of paper or board.

With the help of high efficiency, "deep penetrating" infra-red dryers it is possible to solidify the applied coating quickly and transfer the coated sheet straight into the paper (board) machine, without any elaborate arrangements for sheet travel. There are also many new coating machines available for the heavier end of the process and for special effects (Grant, 1984; 1985b).

Calendering and supercalendering. In these subprocesses the trend is toward application of higher surface temperatures and surface moistening of the paper. This procedure will lead to better preservation of the sheet bulk (i.e., stiffness) and makes it possible to obtain an excellent smooth and glossy surface, even with a slightly "rougher-to-begin" surface than is the practice today. This development makes it possible to save in the basis weight of the sheet and in the manufacturing costs of the fibers used. The service life of supercalender rolls will increase because of better roll filling materials and larger rolls. Technical developments are also underway to make it possible to utilize supercalendering as an on-machine treatment in many cases, with savings in investment and labor costs.

The outlined developments will, at first, affect the manufacturing and quality of the newsprint and supercalendered magazine paper grades, but also many other paper and board grades will benefit from them.

In fact, these developments in the supercalendering of SC paper (supercalendered magazine paper) have been one of the reasons for the success of this paper grade, which has become a very important and fast-growing printing paper on markets in which it had not previously been used very much.

Quality developments

As has already been mentioned, there will be a greater product differentiation and closer customer contact than previously. Space does not allow us to discuss the many quality developments that are expected. However, based on technological advancements and on the need to decrease manufacturing costs, one will see a continuous decrease in the basis weight of many paper grades [for instance, newsprint, SC, and low-weight coated magazine paper (Hoppe, 1985)].

In *Table 9.4* we display the recent trend in the basis weight of newsprint. It is questionable whether any future decrease will be significant, because there are trends toward a greatly increased use of four-color printing in newspapers and to flexographic printing instead of offset printing (Metzfield, 1985). Also, some newspapers use SC magazine paper for those pages on which color printing is done. However, note that there are already some fairly large newspapers that use 40 g/m^2 newsprint.

Table 9.4 Development of average newsprint basis weight (g/m^2) in Western Europe (including Scandinavia) and in the US.

	Western Europe	*US*
1970	52.0	52.0
1975	48.8	48.8
1980	48.0	48.8
1985	46.5	47.4
1990[a]	*ca* 45	*ca* 46

[a] Predicted values.

Another quality development that is gaining ground is the double coating of both sides of the paper. This method, together with a well-formed base sheet, new special pigments, and new supercalendering technology, will make it possible to produce very high-quality coated papers at considerably lower production and labor costs.

The third quality development in printing and writing papers is the increased use of filler pigments, especially in the uncoated paper grades. This move could — in the next ten years — increase the ash level of many uncoated printing and writing papers by five to ten absolute percentage units, giving a simultaneous decrease in manufacturing costs and increase in important quality properties.

Concluding remarks

In summing up the forecasts for technical developments in the paper industry, we emphasize that there are no totally new, revolutionary developments to be expected during the 1985–1995 period. However, a broad spectrum of smaller scale technical developments, i.e., subprocess refinements, will occur to give higher machine speeds, reduced basis weight of paper, or reduced cost of furnish, and better functional properties to match the end-use requirements of the present and new applications of the various paper and board grades.

9.3.3. Process control developments

Process control remains one of the fastest-growing areas of capital investment in both the pulp and paper industries. All the new pulp and paper mills, as well as many modernizations, are equipped with advanced control (some type of mill-wide control) systems in order to carry out overall planning and coordination, besides taking care of production, quality, and energy requirements (Fadum, 1985). Even the older, smaller pulp mills and paper machines should be considered as benefitting from the installation of some computer-based process control systems (packaged supervisory control).

The real development in these control systems has taken place in the software side (Anon, 1985a). The systems have become very "user-friendly" through use of "menus" and touch screen operations. More reliable sensors are coming on the market, continuously opening up new possibilities for automation. Thus, for instance, many paper properties can be directly measured on-machine, while the paper (or board) is being manufactured. The automated laboratory, on the other hand, has greatly increased the accurate assessment of the condition of the manufacturing process.

There are also developments underway to automatically assess the maintenance needs of various critical points of the process. For instance, in papermaking such systems control the condition of rolls and felts in the press section.

Some of the fastest-growing areas of process control application are in the cross-machine control of basis weight, moisture, and thickness profiles in papermaking, in the mill-wide control of energy, and in the control of the recovery cycle in the pulp mill.

With advanced, computerized information and control systems the manufacturing process(es) will perform optimally at all times. Managers can thus discuss the removal of bottlenecks, identify reasons for frequent breakdown of particular apparatus, assess quality, or plan new installations or modernizations, instead of trying to define the continuously changing situation that exists in an uncontrolled pulp or paper mill. The following list identifies some of the economic reasons for the extremely fast pay-back of the process control measures in the pulp and paper industry (Krantz, 1985):

(1) Reduced staff, both at the production and supervisory levels. In an integrated pulp and paper mill this can give annual savings of \$250 000.

(2) Reduced fiber and chemical losses. In large, bleached pulp mills this can give total annual savings of $\$1.0 \times 10^6$.

(3) Capacity utilization of storage tanks. For instance, in a large integrated board mill the bottleneck of production was the full storage tank of pulp between the pulp and board mills. After modifications of pulp refining, the speed of the board machine could be increased by 3.8%. Better planning of the utilization of the storage tanks increased the overall capacity of the mill by 4.2%, yielding an annual saving of nearly $\$2 \times 10^6$.

(4) Integrated control of cross-machine profiles for thickness, basis weight, and moisture can increase considerably the high quality production of paper and yield a savings in fiber and drying energy of over $\$1 \times 10^6$ for a large-size, fast paper machine.

The increased application of centralized controls and information systems in the pulp and paper mills will require more education of the operators and a very efficient instrument maintenance crew in order to fully benefit from such systems.

9.4. Conclusions

The prediction of future technological developments in an industry is not an easy task, especially when the span of forecast is ten years. That the basic manufacturing technology of pulp and paper industry is a mature technology, that the profitability of the industry is not very good (with a still continuing downward trend), and that the global market situation of many important paper and board grades approaches mature conditions all ease the forecasting task somewhat.

Based on the special features of the pulp and paper industry and on the preliminary assumptions of forecasting outlined here, it is predicted that the main course of technological developments will be along the "more of the same" path. The emphasis will be on developments in subprocess optimization in order to increase production rates through removal of bottlenecks and to decrease production costs through application of less energy, less labor, less capital, and/or less expensive fiber. The need for less capital and lower manufacturing costs will override the energy expenditure aspects.

It is believed that these technological developments — although evolutionary in their nature — will assist the paper and board industry to stay in business, despite the long-term threat of the electronic communication media to printing and writing papers and despite the threat of plastics to packaging papers and boards.

The outlined technological developments have to be linked with increased marketing activity, if one wants to make full use of them. In other words, the pulp and paper industry has to become more market-oriented and to pay very much more attention to "customer's needs" when developing newer processes and products.

Notes

[1] Deinking is the removal of printing inks from wastepaper in order to remove the gray color of wastepaper fibers.

[2] During 1970 to 1980 the paper and board capacity in Western Europe increased from 39 × 10^6 ton/year to 53.3 × 10^6 ton/year. Of this capacity increase, 11 × 10^6 ton/year was due to modernization and enlargement of existing capacity. Totally new paper machines during the same period accounted for 11.7 × 10^6 ton/year. Simultaneously, about 8.4 × 10^6 ton/year of old capacity was shut down (Setälä, 1985).

[3] Although the electronic media will cut into some of the paper markets, it will also create new markets for paper, as will any increase in free time.

[4] It should be kept in mind that, although mechanical pulping uses less wood per ton of product than chemical pulping, the combined wood and energy cost in thermomechanical pulping especially are close to those of bleached, softwood kraft pulp. Besides, considerable national investments are required in the production of electrical energy in order to provide an ample supply of inexpensive electrical energy.

[5] For instance "high fidelity" newsprint, supercalendered magazine paper, and/or low-weight coated paper.

[6] Since the economic size for new, nonintegrated market kraft pulp mills has become very large — at least 1200 tons per day — the total cost of a new, greenfield, bleached kraft pulp mill approaches \$500 × 10^6 (Vaugham, 1985).

[7] This is a significant development since it would reduce to zero waste waters that contain chlorinated lignin.

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Part III

Demand for Forest Products

CHAPTER 10

The Demand for Forest Sector Products

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There are large variations between countries in per capita consumption of forest sector products. In 1979, the per capita consumption of paper was, for example, ten times larger in North America than in Latin America. This difference can, to a large extent, be explained by differences in the standard of living. In the same year, the per capita income of Latin America was also not much more than one tenth that of North America. International cross-sectional studies show that much of the variation of paper consumption follows the variation in per capita income. A simple regression of paper consumption on income for an international sample of countries gives an income elasticity of 0.92.

Among the high-income countries, however, income per capita is not a good predictor of paper consumption. In 1979, paper consumption in the US was, for instance, almost twice that in Switzerland, while per capita income in Switzerland exceeded that in the US by almost 40%. Regression among the ten highest-income countries reveals that in this group there is *practically no correlation* between the general standard of living and per capita apparent consumption of paper. Differences in prices cannot explain these cross-sectional differences.

On the whole, there is a marked difference in the use of forest sector products between the US and Western Europe, which cannot be explained by differences in the standard of living or in relative prices. In order to understand these differences, an analysis of the differences in economic and technological structure is needed. It is, of course, possible to use a time series model involving the GNP for each country. This is, however, a valid procedure only if the economic structure underlying the growing GNP changes during the prediction period in the same way as during the observation period.

Over the long term, technological changes are likely to induce different response patterns in different regions. Advances in electronic information technologies, as well as the development of super-absorbent material and new packaging materials, will probably be effective earlier and more strongly in some countries than in others. In some regions of the world, the impacts of the changing energy scene on both forest products and on competitive energy-carriers require consideration.

In this chapter we discuss alternative ways of estimating the demand function for forest products. Particular emphasis is placed on techniques that have not been widely applied to this sector. Hence our treatment of conventional approaches, reviewed more fully in Chapters 12 and 13 below, is brief compared with their importance in the literature.

10.1. Final Demand for Forest Sector Products

Demand functions describe how a given vector of price stimuli will trigger consumption responses among the commodity users. In economic theory, consumers (households or governments) are assumed to choose a set of consumer goods (food, clothing, housing, literature, etc.) such that total expenditure is constrained to be, *at most*, equal to available income. The consumer's problem is then to choose among different commodities so as to maximize some utility indicator, while staying within the limits of the available budget.

Let us assume that consumers' preferences can be captured by a scalar utility function, $u(x)$, where $x = \{x_1, x_2, \ldots, x_n\}$, a vector representing the consumption of the goods $i = (1, \ldots, n)$. The consumers aspire to maximize utility subject to their income constraint:

$$\sum_i p_i x_i = y$$

where p_i is the price of good i and y represents the total income. We then have the equivalent Lagrange problem:

$$\max_{\{x\}} L = u(x) - \lambda(p^T x - y) \tag{10.1}$$

where λ is the Lagrangian multiplier. The conditions for the maximum are:

$$\begin{aligned} &\frac{\partial u}{\partial x_i} - \lambda p_i = 0 \qquad (i = 1, \ldots, n) \\ &p^T x - y = 0 \end{aligned} \tag{10.2}$$

Let

$$\mathrm{Det}\begin{bmatrix} u_{11} & u_{12} & -p_1 \\ u_{21} & u_{22} & -p_2 \\ -p_1 & -p_2 & 0 \end{bmatrix}, \ldots, (-1)^n \ \mathrm{Det}\begin{bmatrix} u_{11} & \cdots & u_{1n} & -p_1 \\ \cdot & \cdots & \cdot & \cdot \\ \cdot & \cdots & \cdot & \cdot \\ \cdot & \cdots & \cdot & \cdot \\ u_{n1} & \cdots & u_{nn} & -p_n \\ -p_1 & \cdots & -p_n & 0 \end{bmatrix}$$

all be larger than 0. Denoting D_{ij} for the cofactor of row i and column j of the Hessian determinant given above and D for the determinant value, we also have:

$$\sum_j S_{ij} p_j = 0 \qquad (i = 1, \ldots, n) \tag{10.3}$$

where $S_{ij} = D_{ji} \lambda / D$.

The implication of condition (10.3) with the assumption of a compensated demand function is that some commodities *must* be substitutes for each other, although some *can* be complements. This means that if the price of paper increases, the consumption of some other commodities must *increase* (i.e., theater performances, car services, etc.), although some might decrease (i.e., book reading, letter writing, etc.). The extent of such substitution is the major consideration of consumer demand theory. It can further be proved that:

$$-\sum_j E_{ij} = E_{iy} \qquad (i = 1, \ldots, n) \tag{10.4}$$

where $E_{ij} = (\partial \ln x_i)/(\partial \ln p_j)$ and $E_{ij} = (\partial \ln x_i)/(\partial \ln y)$, i.e., price- and income-elasticities constrain each other. A high income-elasticity for paper thus *requires* high own- and cross-price elasticities on average (if we have aggregated away complements).

Although consumer theory sheds some light on the problem of generating testable demand functions, it tends to be *too general* for econometric purposes. As can be seen from equations (10.2) to (10.4), these conditions are not specific enough for statistical testing and estimation purposes. The only consequence of the analysis is a stimulus–response function, which is called the individual demand function, $D_{hi}(p_1, \ldots, p_i, \ldots, p_n, y_h)$, according to which the demand of each consumer h

for commodity i is determined by *all* relative prices and his or her purchasing power as represented by income y_h. These demand functions $D_{ih}(p,y_h)$, where $p = (p_i)$, can be aggregated into a household consumption:

$$D_i(p,y) = \sum_h D_{ih}(p,y_h)$$

where $y = (y_h)$. This is illustrated in *Figure 10.1.* In general, we should thus expect a heterogeneous consumer population to generate a nonlinear demand function, even if each consumer is regulated by a linear demand function.

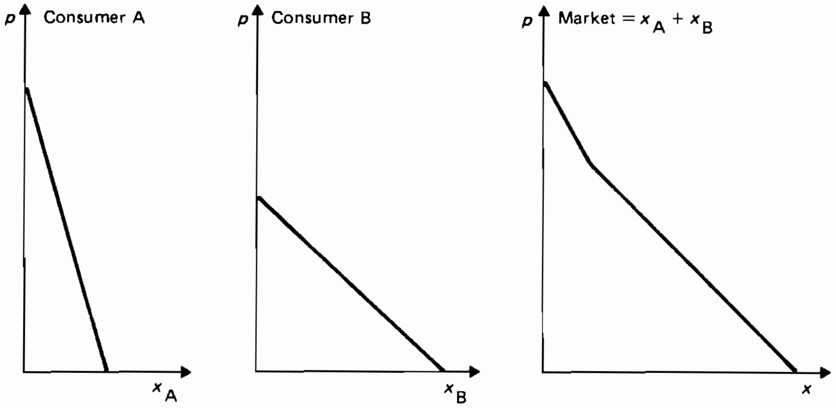

Figure 10.1.

Our arguments against the use of the demand theory discussed above for an econometric study of forest sector demand are the following:

(1) As a general theory of demand in which $u(x)$ is the preference function of any decision maker (manager of a firm, government or household purchasers), it is not specific enough to generate statistical hypotheses.

(2) As a general theory of the consumer it uses too little of the structural information on individual consumers' behavior, as developed by the behavioral sciences.

(3) If seen as a special theory of consumer demand, it would cover a very limited share (10–20%) of the total forest sector demand.

A theory of intermediate producer demand provides a better alternative.

10.2. The Theory of Intermediate Demand

In the center of intermediate demand theory is the firm with one or many plants. A commodity, such as sawnwood, is used as one of the many inputs $(\nu_1,\ldots,\nu_n)$ to be transformed by the use of fixed equipment to generate a set of outputs $(q_1,\ldots,q_s)$, say, chairs, tables, beds, and other pieces of furniture demanded by households, hotels, hospitals, offices, etc. The model of the plant can thus be illustrated as in *Figure 10.2.* The black box representation of the firm (or plant) can be summarized as:

$$F(q_1,\ldots,q_s;\,\nu_1,\ldots,\nu_n) = 0 \tag{10.5}$$

which is a transformation function or an implicit production function according to which the input vector ν is transformed into the output vector

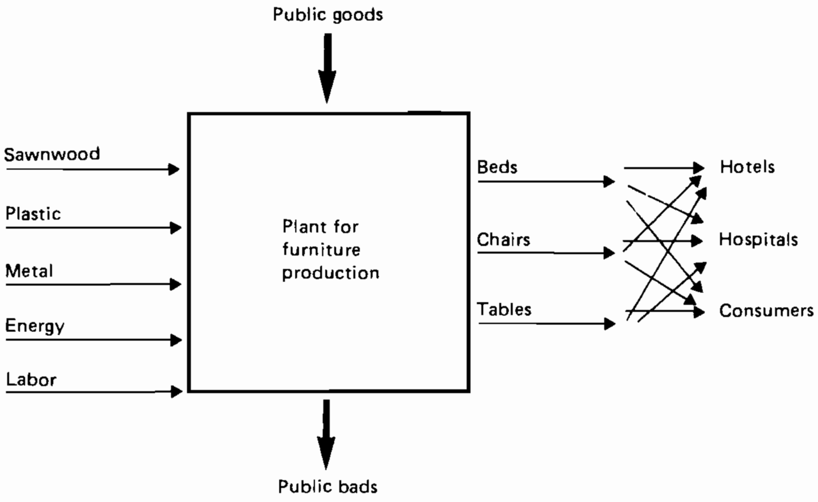

Figure 10.2.

q. The public goods and bads are neglected in the sequel. We assume that F is at least twice differentiable, increasing with q and decreasing with ν, and strictly quasi-convex.

The behavior of the firm or plant manager can, under a capitalistic regime, be assumed to be one of profit maximization (at the firm level) or cost minimization (at the plant level). The reasoning behind this assumption is one of social Darwinism. Any firm or plant operating under some rule other than profit maximization would not exist for long. Not maximizing profits in an environment where other similar firms maximize profits would imply a slower rate of capital accumulation and a relative decline in the nonoptimizing units. At a general equilibrium, where profits above market remuneration of management services are forced to zero, nonoptimizing behavior would imply bankruptcy, i.e., death, of all nonoptimizing firms. However, no such argument can be raised in favor of optimizing behavior among consumers or monopolistic organizations, such as government bodies.

Profit is defined as the difference between revenues from sales and costs of purchasing inputs:

$$V = \sum_i \pi_i q_i - \sum_j \omega_j \nu_j \tag{10.6}$$

where π_i is the price of outputs ($i = 1,\ldots,s$) and ω_j is the price of inputs ($j = 1,\ldots,n$). The profit, V, can be maximized subject to the transformation function constraint F:

$$\max_{\{q,\nu\}} L = \pi^T q - \omega^T \nu + \lambda F(q,\nu) \tag{10.7}$$

The necessary conditions of optimality of equation (10.7) are:

$$\pi_i/(\partial F/\partial q_i) = -\lambda \qquad (i = 1,\ldots,s) \tag{10.8a}$$

$$\omega_j/(\partial F/\partial \nu_j) = \lambda \qquad (j = 1,\ldots,n) \tag{10.8b}$$

$$F(q,\nu) = 0 \tag{10.8c}$$

The firm should thus adjust any pair of outputs until the ratio $(\partial F/\partial q_i)/(\partial F/\partial q_k)$ equals the given output price ratio (π_i/π_k). It should, furthermore, adjust any pair of inputs until the ratio $(\partial F/\partial \nu_j)/(\partial F/\partial \nu_l)$ equals the given relative input price (ω_j/ω_l).

Rational behavior of firms thus dictates that the firms must observe the parametrically changing input or output price vector and adjust through substitution among inputs or outputs until the "marginal rates of substitution", $(-\mathrm{d}q_i/\mathrm{d}q_k)$ and $(-\mathrm{d}\nu_j/\mathrm{d}\nu_l)$, correspond to the price ratios (π_k/π_i) and (ω_l/ω_j) or until:

$$\pi_i/\omega_j = -\left(\frac{\partial F}{\partial q_i}/\frac{\partial F}{\partial \nu_j}\right)$$

Total differentiation of equations (10.8) is a means for determining the response pattern of a firm to any given small change of output or input prices:

$$\begin{aligned} &\lambda F_{11}\mathrm{d}q_1 + \cdots + \lambda F_{1m}\mathrm{d}\nu_n + F_1\mathrm{d}\lambda = -\mathrm{d}\pi_1 \\ &\lambda F_{m1}\mathrm{d}q_1 + \cdots + \lambda F_{mm}\mathrm{d}\nu_n + F_m\mathrm{d}\lambda = \mathrm{d}\omega_n \\ &F_1\mathrm{d}q_1 + \cdots + F_m\mathrm{d}\nu_n = 0 \end{aligned} \tag{10.9a}$$

or, in matrix form:

$$\lambda H\mathrm{d}x + f\mathrm{d}\lambda = \mathrm{d}p \tag{10.9b}$$

where:

$$\begin{aligned} &H = (F_{ij})\mathrm{d}x = \{\mathrm{d}q_i,\mathrm{d}\nu_j\} \\ &f = \{F_1,\ldots,F_m\} \\ &\mathrm{d}p = \{-\mathrm{d}\pi_1,\ldots,\mathrm{d}\omega_n\} \end{aligned}$$

The consequence of a change in the price structure on the adjustable input and output quantities can be determined by the matrix inversion of λH in equation (10.9b):

$$\mathrm{d}x = (\lambda H)^{-1}(\mathrm{d}p - f\mathrm{d}\lambda) \tag{10.10}$$

It can be shown (Henderson and Quandt, 1980) that:

$$\frac{\partial q_j}{\partial p_j} > 0 \qquad (j = 1,\ldots,s)$$

and

$$\frac{\partial \nu_k}{\partial \omega_k} < 0 \qquad (k = 1,\ldots,n)$$

i.e., if an output price increases (*ceteris paribus*), the firm will *increase* that output and if the price of an input increases the firm will also *decrease* the use of that input. The slopes of input demand and output supply curves are clear-cut to an extent not found in consumer theory.

Further specification of response patterns can be achieved only if we are prepared to make the transformation function $F(q,\nu)$ more specific. One way of specifying F is by assuming that the firm (or plant) produces one output (q) only. We can then write an explicit transformation function, called a *production function*, i.e.:

$$q = q(\nu)$$

One can further specify $q(\nu)$ as, for example, the constant elasticity of substitution function, which is a special case of the Minkowski mean value function. In this function the assumption to be tested is that the elasticity of substitution is the same for all pairs of inputs:

$$q = E(\sum_j \alpha_j \nu_j^{-\rho})^{-1/\rho} \tag{10.11}$$

With profit maximization we then obtain testable hypotheses of response to derived conditions of optimality:

$$\ln(\frac{\nu_j}{\nu_l}) = k + \sigma \ln(\frac{\omega_l}{\omega_j}) \tag{10.12}$$

where the elasticity of substitution is:

$$\sigma = [1/(1+\rho)]$$

and

$$k = [1/(1+\rho)]\ln(\alpha_j/\alpha_l)$$

As can be seen from equation (10.12), the same elasticity of substitution between different inputs is assumed in this specification of the model. This assumption has been tested for three of the most important forest-product user sectors, namely *nonresidential, residential*, and *repair construction.* The data base used for this test is the constant price input–output series for Canada, 1961–1974, as published by Statistics Canada.

Equation (10.12) was estimated with a linear time-effect and a stochastic error-term, using ordinary least-squares methods. *Table 10.1*

Table 10.1 Results for constant elasticity of substitution regressions for construction sectors of Canada, based on data for the period 1961–1974.

Sector[a]	*Regression*[b,c] (t-*values of coefficients in parenthesis*)	R^2
RepC	$\ln(F/FW) = -9.2\ln(p_F/p_{FW}) - 0.1t$ (4.0) (3.0)	0.6
NRC	$\ln(LT/FW) = -0.73\ln(p_{LT}/p_{FW}) - 0.08t$ (3.0) (2.0)	0.97
NRC	$\ln(LT/FM) = -0.6\ln(p_{LT}/p_{FM}) - 0.03t$ (2.0) (3.0)	0.85
NRC	$\ln(LT/CP) = -0.86\ln(p_{LT}/p_{CP}) - 0.04t$ (3.0) (5.0)	0.91
RC	$\ln(LT/SM) = -1.95\ln(p_{LT}/p_{SM}) + 0.03t$ (3.7) (1.3)	0.67
RC	$\ln(PS/IS) = -1.84\ln(p_{PS}/p_{IS}) + 0.03t$ (4.1) (2.3)	0.71
RC	$\ln(FW/CP) = -1.4\ln(p_{FW}/p_{CP}) + 0.05t$ (2.3) (3.4)	0.61

[a] RepC, repair construction; NRC, nonresidential construction; RC, residential construction.

[b] *F*, forest products; *FW*, fabricated wood products; *LT*, lumber and timber; *FM*, fabricated metal products; *CP*, cement products; *SM*, structural metal products; *PS*, panels; *IS*, iron and steel products; *t*; time.

[c] The dependent variable is the natural logarithm of the ratio of input quantities in the sector indicated.

contains the results. Only input pairs with coefficients significantly different from zero have been included in the table. As can be seen, statistical significance criteria hardly make credible the assumption of equation (10.11) combined with a short-term, profit-maximizing behavior of firms. This is further strengthened by the fact that a number of σ-values estimated, but not reported, are not significant from zero.

10.3 Theory of Production and Interdependencies Between Firms

Modern theory of production abstains from a simplistic two- or three-factor analysis of inputs conversion into outputs. Instead, a multitude of inputs, such as wood, pulp, different types of paper products, chemicals, metals, labor, energy, etc., interact in the transformation into one or many outputs. This procedure has two main advantages. First, it better approximates the actual, technological situation of modern firms. Second, more clearly than in classical economic analysis of production by the use of land, labor, and capital inputs, it puts the emphasis on *interdependencies* between different firms or aggregates of firms as users and producers of intermediary commodities.

Two economic research fields have emerged and developed from this emphasis on interdependencies between producers. One, primarily microeconomic, class of models is *activity analysis*. The other, primarily macroeconomic, class of models is *input–output* analysis. A bridging class of models is the von Neumann type, of which input–output models and linear program (LP) models are special cases (Samuelson, 1983).

One simplification of the von Neumann model made in input–output models is the assumption that each aggregate of firms produces one commodity only or that all firm information can be converted into a commodity using a commodity framework. Here $q_{ij} = a_{ij}q_i$, where a_{ij} is the quantity of input j required per unit of output i and q_i is the output of i.

The production theory discussed in this section shows that the inputs of commodities and primary factors, such as labor, are generally influenced by the expected input and output prices. Adapting input structures to a changing price structure is the only viable behavior in a market economy, unless all the actors rigidly refuse to do so, and such an assumption is clearly at variance with common observations of firm behavior. Thus, we can safely assume that every a_{ij} is a function of the price vector p, or equivalently, $A = A(p)$ where $A(p) \equiv \{a_{ij}(p)\}$ for $(i = 1,\ldots,n)$.

It is of great importance for a consistent analysis of the forest sector to determine how each one of the users of forest products would react to a changing input-price structure. The above analysis indicates that *any* price change would lead to a change in demand for all forest products. This is, however, a highly unlikely event in any real situation, even if the theory suggests such a result. A few sectoral outputs, such as electrical energy and transportation services, enter every sector of production as inputs. In contrast, other outputs, such as wood or paper products, enter only a few sectors of production as inputs. In most of these production sectors (e.g., construction or printing and publishing) only a limited number of other inputs are used and are available for adaptation in the form of substitution.

Demand for inputs is derived above using assumptions of profit maximization and the existence of a mathematically well-behaved production function. Although profit maximization is a reasonable assumption at the level of firms, constrained cost-minimization is an alternative and probably better assumption at the level of plants within corporations. Constrained cost-minimization has certain advantages from a general, theoretical point of view, as first demonstrated by Shephard (1953), and for econometric studies, as first demonstrated by Nerlove (1965). Shephard (1953) demonstrated that, under the behavioral assumption made here, the minimized-cost function and the production function are related by a property of duality.

Shephard's lemma:

If $C(q,\omega) \equiv \min_{\nu} \{\omega^T\nu : f(\nu) \geq q\}$

and if f is continuous from above and $C(q,\omega)$ is differentiable with respect to input prices at the point q^*,ω^*, then:

$$\nu(q^*,\omega^*) = \nabla_{\omega} C(q^*,\omega^*)$$

where $\nu(q^*,\omega^*)$ is the vector of cost-minimizing input flows needed to produce the output flow q^*, given the input prices ω^*. It is thus possible to develop a model of price- and scale-dependent input demand from *either production or cost functions* postulated at the plant level. Shephard's lemma indicates that it is in most cases easier to commence from cost functions.

10.3.1. Cost functions and intermediate demand for forest products

The generalized Leontief cost function was introduced by Diewert (1971) as a suitable second-order approximation of a general input cost function. This cost function can be written as:

$$C(q,\omega,t) = F(q,t) \sum_k \sum_l b_{kl}\, \omega_k^{\alpha}\, \omega_l^{1-\alpha} \qquad (k,l = 1,\ldots,n)$$

where C is the minimized total cost, q is the output, t is the time period, $F(q,t)$ is the scale and technology function, and b_{kl} is the coefficient of substitutability between input k and input l. A possible specification of $F(q,t)$ would be $F(q,t) = q^{1/s}\mathrm{e}^{-ut}$, where s is a scale parameter and u represents a technological trend. Some experiments in estimating α have indicated that the model is well behaved with α close to 0.5 (Frenger, 1982).

If we apply Shephard's lemma, the input demand functions are:

$$\frac{\partial C}{\partial \omega_k} = \nu = 0.5 q^{1/s}\mathrm{e}^{-ut} \sum_l b_{kl}\omega_k^{-0.5}\, \omega_l^{0.5}$$

Note that only if $b_{kl} = 0$ for all $k \neq l$ and $s = 1$ would the fixed input–output coefficients be warranted.

Partial price elasticities, E_{kl}, can be defined as:

$$E_{kl} = 0.5\left[\frac{b_{kl}\omega_l^{0.5}}{\sum\limits_m b_{km}\omega_m^{0.5}} - \delta_{kl}\right] \equiv \frac{\partial\ \ln\left(\partial C/\partial \omega_k\right)}{\partial\ \ln \omega_l}$$

where δ_{kl} is the Kronecker constant and E_{kl} can be used as one measure of the substitutability of two inputs, if the same level of production (q^*) is to be maintained.

The shadow (or dual) elasticity of substitution, δ_{kl}, was introduced by McFadden (see Frenger, 1983) and is defined as:

$$\delta_{kl} = -\frac{\partial\ \ln\left(\nu_k/\nu_l\right)}{\partial\ \ln\left(\omega_k/\omega_l\right)}$$

i.e., the elasticity of the cost-minimizing ratio of inputs to a change in their relative price when cost, output, and other prices are held constant. Such elasticities have been measured for two forest-product using sectors — *manufacture of wood and wood products* and *printing and publishing* — by Frenger (1983). The results are shown in *Table 10.2*.

Table 10.2 Shadow elasticities of substitution (1975) in input demand equations for 1969–1980 in Norway (Frenger, 1983).

Input pairs	*Manufacture of wood and wood products*	*Printing and publishing*
Material–Energy	0.92	0.91
Material–Labor	1.27	1.24
Material–Capital	0.35	0.45
Energy–Capital	0.84	0.83
Labor–Capital	0.50	0.30
Energy–Labor	0.95	0.91

The elasticities of substitution are generally high for the inputs substitutable in the short run, and short- and long-run elasticities are close to each other in the Frenger study. On the basis of this study, it seems reasonable to expect *intramaterial substitution* elasticities to be high in comparison with capital–labor substitution elasticities — an assumption at variance with the approach chosen in the so-called MSG models (Johansen, 1959; Bergman and Por, 1980; Zalai, 1980).

10.3.2. An econometric study of intermediate demand

This study is based on the duality approach to input demand analysis to estimate demand functions for some forest sector products. Demands for sawnwood and panels are estimated for the construction and furniture industries. Demands for paper products are estimated for the printing and publishing industries and for a sector that we call "the office sector".

The data are again collected from input–output statistics for Canada 1961–1978, provided by Statistics Canada and by the Comparative Economic Analysis Project of IIASA.

The basic idea is to test the substitution hypothesis, as econometrically specified by the generalized Leontief cost function, and the associated input demand functions derived via Shephard's theorem. If the hypothesis can be sustained, it forms the basis for the specification of *market demand functions*, with a determination of the *minimal* number of substitute prices to be included beside the own-price in such market demand functions.

The econometric specification of the model is obtained as shown above by taking the derivatives of the ***simplified*** Diewert cost function with respect to the respective input prices:

$$C(q,\omega) = q \sum_k \sum_l b_{kl}(\omega_k/\omega_l)^{0.5}$$

with the constraint $b_{kl} = b_{lk}$, and

$$X_k^D = \frac{\partial C(q,\omega)}{\partial \omega_k} = q \sum_l b_{kl}(\omega_l/\omega_k)^{0.5} \qquad b_{kl} = b_{lk}$$

Dividing through by q, we obtain the normalized demand for the kth product as a function of the input prices:

$$\frac{X_k^D}{q} = \sum_l b_{kl}(\omega_l/\omega_k)^{0.5} \qquad b_{kl} = b_{lk}$$

where X_k^D is the demand for the kth input. The term X_k^D/q is the input–output coefficient, that is, the quantity of wood product input per unit of output. This approach is discussed in more detail in Chapter 11. For each end-use sector, there is a system of demand equations, i.e., one for each input.

Both ordinary least-squares (OLS) and seemingly unrelated regression (SURE) are used to estimate these equations. Both methods yield unbiased and consistent estimates, but SURE is more efficient, since we are dealing with systems of equations. The symmetric constraint, $b_{kl} = b_{lk}$, also implies that SURE is more accurate, because one cannot easily incorporate the constraint when using OLS. A problem when using SURE is the short time series. Only a few inputs can be included because otherwise we do not have enough degrees of freedom. If, for example, we use six inputs, the wood product included, the number of parameters to be estimated is 21 and our sample consists of 18 observations only, which means that we have insufficient degrees of freedom. Therefore, we have tried to aggregate the inputs in a suitable way.

The results of the estimation are presented in *Tables 10.3–10.6*, for each sector, respectively. Cross-price and own-price elasticities are calculated for three different years, 1961, 1970, and 1978.

Table 10.3 Parameter estimates, construction sector, SURE (*t*-values in parentheses).

	Wood	*Services*	*Cement*	*Labor*
Wood	0.0094	0.0583[a]	0.0061	-0.0216[b]
	(0.82)	(2.46)	(0.36)	(-1.96)
Services	–	0.0043	0.109	-0.0269[b]
		(0.042)	(1.39)	(-1.98)
Cement	–	–	-0.04	-0.03
			(-0.60)	(-1.75)
Labor	–	–	–	0.376[c]
				(22.2)

Cross-price elasticities	*Services*	*Cement*	*Labor versus wood*
1960	0.50	0.053	-0.17
1970	0.60	0.062	-0.22
1978	0.48	0.050	-0.14

Own-price elasticities	*Wood*
1961	-0.38
1970	-0.44
1978	-0.39

[a] Significant at the 5% probability level.
[b] Significant at the 10% probability level.
[c] Significant at the 1% probability level.

A positive value of the parameter indicates a substitute for wood and a minus sign indicates a complementary relationship. The estimated elasticities seem to be reasonable in size and sign, except for the printing and publishing sector. Labor seems to be a complement to wood in the wood-using sectors and a substitute for paper in the paper-using sectors.

10.4. Stochastic Demand Analysis

The assumption of the deterministic behavior of buyers in situations of free information about all sellers is quite unrealistic. Even if the buyers of the traded commodities have full information about the *prices* of all commodities there would be little reason to assume that the same would hold for *qualities* and *delivery times* of the selling countries. If some of the attributes of the sellers are, in fact, unobservable they must be treated as stochastic variables.

Let us assume that a buyer will choose to buy from nation r if the profit $\Pi(Z_r) > \Pi(Z_s)$ for any $s \neq r$, $s = 1,\ldots,n$. Z_r is a vector of attributes of the product supplied by country r.

Table 10.4 Parameter estimates, furniture sector (SURE) (t-values in parentheses).

	Wood	*Other material*	*Labor*
Wood	-0.04[a]	0.139[b]	-0.2
	(-2.48)	(11.12)	(-1.70)
Other material	-	0.099[b]	-0.0168
		(6.56)	(-1.39)
Labor	-	-	0.359[b]
			(22.74)

Cross-price elasticities	*Other material*	*Labor versus wood*
1961	0.76	-0.084
1970	0.87	-0.12
1978	1.04	-0.12

Own-price elasticities	*Wood*
1961	-0.68
1970	-0.75
1978	-0.92

[a] Significant at the 5% probability level.
[b] Significant at the 1% probability level.

Table 10.5 Parameter estimates, office sector, OLS (t-value in parentheses).

	Paper	*Other material*	*Labor*
Paper	-0.05[a]	0.084[a]	0.006
	(-3.4)	(5.2)	(1.1)
$R^2 = 0.73$		$D\text{-}W = 1.92$	

Cross-price elasticities	*Other material*	*Labor versus Paper*
1961	0.93	0.061
1970	0.97	0.072
1978	1.03	0.062

Own-price elasticities	*Paper*
1961	-0.99
1970	-1.04
1978	-1.09

[a] Significant at the 1% probability level.

Because of the *uncertainty* in determining the attributes Z_r, each *profitability of purchase* must be decomposed into a certain component, $\rho(Z_r)$, and an uncertain component, $\epsilon(Z_r)$.

Table 10.6 Parameter estimates, printing and publishing, OLS, 1961–1974 only (t-values in parentheses).

	Paper	*Services*	*Labor*
Paper	0.61[a]	0.77[a]	0.34[a]
	(9.75)	(8.0)	(9.3)
$R^2 = 0.88$		D–$W = 2.17$	

[a] Significant at the 1% probability level.

Thus $\Pi(Z_r) = \rho(Z_r) + \epsilon(Z_r)$, where $\rho(Z_r)$ is a deterministic function of the characteristics of attributes of deliveries from nation r, while $\epsilon(Z_r)$ is a stochastic function of the same characteristics.

$\rho(Z_r)$ is determined as the *expected* profit; i.e., $\rho(Z_r) = E[\rho(Z_r)]$. The probability of a purchase from nation r can be expressed as:

$$P_r = \text{prob}\,\{\Pi(Z_r) > \Pi(Z_s)\} \quad \text{for} \quad s \neq r \quad s = 1,\ldots,n$$

This implies that:

$$P_r = \text{prob}\,\{\epsilon(Z_r) - \epsilon(Z_s) < \rho(Z_r) - \rho(Z_s)\}$$
$$\text{for} \quad s \neq r \quad s = 1,\ldots,n$$

In order to determine the probabilities P_r explicitly, it is necessary to define a probability distribution for the *differences* $\epsilon(Z_r) - \epsilon(Z_s)$ and to express $\rho(Z_r)$ analytically.

The probability distribution should be selected so as to represent consistency of behavior with maximization. This implies that if $\epsilon(Z_r)$ and $\epsilon(Z_s)$ have one distribution, then maximum of $|\epsilon(Z_r),\epsilon(Z_s)|$ must have the same distribution.

McFadden (1974) has shown that the extreme value probability distribution (e.g., Weibull or Gnedenko):

$$P(\Gamma \leq \gamma) = e^{e^{\gamma + \alpha}}$$

where α is a parameter is a possible and simple distribution that satisfies the conditions stated, combined with profit maximization in an uncertain world. He has also shown that, under the same conditions, the choice probability function of a buying nation will be of the *logit form*:

$$P_r = \frac{e^{\rho_r}}{\sum_r e^{\rho_r}}$$

which is illustrated in *Figure 10.3*, and shows that in a random world the probability of imports from a nation (by a given nation) will be a smoothly increasing function of the expected profit of such imports.

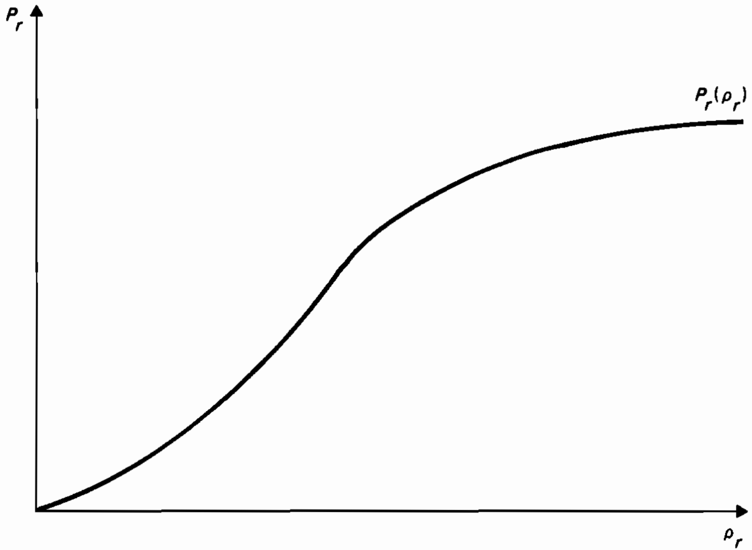

Figure 10.3.

P_r can be assumed to be influenced by the distance to the selling country, by the production capacity of that country, and by the total purchasing volumes of the buyer country. It is easy to see why the distance should have such an effect. It is well known from deterministic, general equilibrium theory that the price difference of a given commodity between two spatially separated markets should be equivalent to the unit marginal transportation and communication costs from the export to the import markets. If such transportation/communication costs are proportional to distance, then distance can be used as a proxy of costs.

An alternative specification of stochastic demand theory is given in Luce (1959). The Luce model of choice has been developed into a spatial stochastic choice model by Smith (1975).

It is assumed that the stochastic decision involves a trade-off between the attraction of each trading possibility and the deterrence of the associated costs of trade. Three axioms provide the foundation of the *stochastic choice theory:*

Independence Axiom. If a given spatial trading situation, $<R,c>$, is reduced by eliminating all but two alternatives in R, say r and s, then the relative probability of choosing r over s in the new situation remains the same.

Accessibility Axiom. If in a given spatial trading situation $<(r,s)>$, the configuration c is altered only by moving supply r to a's location, then a's probability of trading with r is not decreased.

Separability Axiom. Given any spatial interaction situation, $<(r,s),c>$, in which r and s are located together, if the configuration c is altered in any way such that r and s remain together, then a's probability of trading remain the same.

We now introduce the *trading probability function*:

$$P_{<R,c>}(r,a) = \frac{A(r)/d(c_a,c_r)}{\sum\limits_{S\in RA} (s)/d(c_a,c_s)} \qquad r \in R$$

where $P_{<R,c>}(r,a)$ is the probability of demand for a given product produced in r by an agent located in a and acting in a system of regions R on a network or configuration c, $d(c_a,c_r)$ is a trade deterring function depending on costs of purchasing from r if located in a, $A(r)$ is the attraction for a of buying from r in terms of total demand in a, supply capacity in r, quality, and other characteristics.

The function $d(c_a,c_r)$ could have many forms, for instance $d(c_a,c_r) = [\epsilon + t(c_a,c_r)]^\beta$ or $d = c \times p[\theta t(c_a,c_r)]$, with $\epsilon,\beta,\theta > 0$.

Theorem I

Every spatial trading system representable by:

$$P_{<R,c>}(r,a) = A(r)/d(c_a,c_r) \sum_{S\in R} A(s)/d(c_a,c_r) \qquad r \in R$$

is consistent with the *stochastic choice theory.*

Proof. See Smith (1975, p 1556).

Theorem II
For any pairwise complete system $<S,P>$ satisfying the Independence, Separability, and Accessibility Axioms there exist functions A and d such that for all $<R,c>$ belonging to S and r belonging to R:

$$P_{<R,c>}(r,a) = \frac{A(r)/d(c_a,c_r)}{\sum\limits_{S \in R} A(s)/d(c_a,c_s)}$$

The functions A and d are both unique up to positive scalar transformations.

Proof. See Smith (1975, p 161).

Based on this stochastic theory of choice, probabilistic demand functions have been estimated on cross-sectional data for international trade flows in 1970 (*Table 10.7*) and 1980 (*Table 10.8*). The forms are generally:

$$M_{rs}/\sum_r M_{rs} \equiv P_{rs} = \frac{(\text{Cap})_r^{\alpha}(\text{Tot. imp.})_s^{\beta} c_{rs}^{\gamma}}{\sum\limits_r (\text{Cap})_r^{\alpha}(\text{Tot. imp.})_s^{\beta} c_{rs}^{\gamma}}$$

where $(\text{Cap})_r$ is the capacity to export of country r, $(\text{Tot. imp.})_s$ is the total import of country s, and c_{rs} is the price difference between country r and country s. It is clear from the estimates that all price elasticities are significantly negative. All t-values are very large and indicate a significant difference from zero for the parameter estimates.

The size of the price elasticities might seem high in comparison with estimates based on standard time-series data. However, these elasticities reflect *long-term adaption*, in contrast to the standard time-series elasticities that reflect reactions to price fluctuations over one-, two-, or three-year periods.

In most cases, elasticity with respect to capacity is larger than elasticity with respect to the total imports of the purchasing country. This implies that the probability of imports is generally oriented to the larger producer countries rather than the smaller ones, even if the price difference is of the same magnitude. Many factors contribute to such a preference for scale: the larger a producer, the larger the differentiation of the product,

Table 10.7 Results for the stochastic, multilateral import-demand function based on OECD data on international trade flows, 1970 (*t*-values in parentheses).

Commodity	*Elasticity of* *Capacity*	*Elasticity of* *Total imports*	*Price differentials*
Total woodpulp	1.73	1.02	-1.86
	(14.9)	(6.8)	(-8.4)
Total paper and board	1.45	0.98	-1.76
	(9.4)	(8.4)	(-10.6)
Waste paper	0.31	2.29	-2.08
	(3.4)	(7.6)	(-8.7)
Newsprint	1.06	0.36	-1.52
	(9.5)	(7.5)	(-6.3)
Kraft liner	0.68	0.39	-1.09
	(9.7)	(6.8)	(-4.7)
Other wrapping and packaging paper and board	1.21	0.38	-1.23
	(4.6)	(5.8)	(-4.8)
Household and sanitary paper	1.06	0.41	-1.66
	(5.8)	(5.0)	(-8.1)
Printing and writing paper	1.36	0.61	-1.95
	(4.7)	(8.6)	(-9.0)
Fiberboard	1.01	0.80	-1.12
	(8.3)	(7.4)	(-5.0)

the flexibility of the delivery system, and the efficiency of financial and other institutional arrangements.

10.5. Conclusion

Analysis of demand for forest sector products is a complicated matter, both conceptually and in terms of data and estimation procedures. Most of these commodities are intermediary and thus not directly related to consumer demand analysis.

An intermediary approach means that input–output theory must be combined with the dual theory of factor demand, as developed by Hotelling, Shephard, McFadden, and Diewert. Theoretically, these approaches are pleasing, but the data bases necessary for implementation are available for two countries only (Canada and Norway). Also, in these cases the time series are too short to be valid for the estimation of *long-term responses.*

As an alternative, a completely different procedure has been proposed in the final section of this chapter. *Stochastic demand* or *random profit theory*, as proposed by McFadden, Luce, and Smith for the case of consumer choice, was adapted to producer choice. If this basis of analysis is

Table 10.8 Results for the stochastic, multilateral import-demand function based on OECD data on international trade flows, 1980 (t-values in parentheses).

	Elasticity of		
Commodity	*Capacity*	*Total imports*	*Price differentials*
Total woodpulp	1.78	0.93	-2.02
	(13.1)	(4.9)	(-7.6)
Total paper and board	1.35	1.11	-1.94
	(7.0)	(7.4)	(-10.5)
Waste paper	1.13	0.92	-2.36
	(7.3)	(10.7)	(-5.3)
Newsprint	1.17	0.45	-1.32
	(9.3)	(10.7)	(-5.3)
Other wrapping and packaging paper and board	0.56	0.45	-2.11
	(3.0)	(7.9)	(-9.3)
Kraft liner	0.47	0.51	-1.60
	(4.9)	(5.3)	(-4.52)
Household and sanitary paper	0.96	0.39	-1.55
	(4.5)	(4.5)	(-6.2)
Printing and writing paper	1.07	1.33	-1.85
	(3.8)	(9.0)	(-9.6)
Fiberboard	1.59	0.31	-1.97
	(5.3)	(7.1)	(-6.7)

accepted, it is possible to employ the large-scale, cross-sectional data bases of world trade for the empirical work. The resultant price elasticities may then be interpreted as long-term elasticities, because they reflect steady-state behavior in a world where international price differences tend to be quite stable. The results of this procedure are very encouraging. All estimates of price elasticities are highly significant and of the right sign. They are also consistently higher in absolute terms than the corresponding one year elasticities frequently reported in the literature.

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CHAPTER 11

Substitution and Technological Change

D.F. Batten and B. Johansson

Among its many functions, the forest sector is a producer of raw and processed timber products. Some commodities, such as pulpwood, are intermediate to the forest sector itself, but the majority of forest products are intermediate outputs for use by other industries, such as housing, construction, furniture, printing, and publishing. A small share of forest products goes directly to households for final consumption; this proportion is naturally higher in the developing countries where fuelwood is a major concern.

Throughout the world, each of these forest- and related nonforest-sector industries are undergoing gradual, but sometimes major, technological changes. More significantly, the speed of these changes differs greatly between various industries and the resultant competitive pressure is often greatest for the older, well-established industries. The forest industry is, of course, among the older group.

Irrespective of whether we consider intermediate or final users, advancing technological evolution mainly results in the substitution of new types of customer satisfaction for old ones. The basic needs may not undergo radical variation, only the ways of satisfying them. Under these circumstances, the notion of competitive substitution as a model for technological change is applicable.

In this chapter, we outline an approach to the analysis of product substitution and technological change and apply it to various markets in which forest products compete with other commodities. Markets for building materials and components are examined in detail, since the building industry is a major recipient of forest sector intermediate outputs. The discussion and analysis concentrates on the evolution of market shares in both domestic and export markets. Technological leads and lags in the product cycle are identified for up to four competing product groups.

The reported results tend to be somewhat discouraging from the viewpoint of the forest sector. Forest products appear to be losing part of their traditionally high market share in the production or export of building components and other allied products. To a lesser extent they are also gaining ground in some newer markets. The gradual net decline in (per capita) demand can be partly explained by the relatively low level of R&D expenditure devoted to forest products research, i.e., to inadequate product and process development.

11.1. Changing Demand for Forest Products

Although the forest sector delivers inputs to a wide range of manufacturing and nonmanufacturing sectors, the majority of its products are used for construction, information, packaging, and decoration in the developed economies, and for energy production in the developing economies (Andersson and Brännlund, Chapter 10, this volume). In this section we intend to show that a reliable analysis of the long-term evolution of markets for forest products must be based on studies of the chains of intermediate deliveries from forestry to forest industries and further to subsequent users.

11.1.1. The structure of intermediate deliveries

The structure of deliveries from the forest sector varies considerably between different countries. In some regions of the world a large share of forest sector output is sold on the export markets, while others display a strong concentration on domestic deliveries. Another source of variation is the split between intermediate deliveries and sales to the household sector. Among the intermediate deliveries there are three major user categories: wood products industries, the paper and pulp sector, and the building and construction sector.

In *Tables 11.1–11.3* we illustrate important differences in delivery patterns for three countries that have quite different industrial traditions. The three tables describe for Australia, Canada, and Sweden the proportions in which other sectors consume the output from forestry, from sawmills, and from veneer and plywood producers.

The comparatively low share of intermediate deliveries for Sweden is explained by a high share of exports. It is important to base forecasts on an examination of delivery patterns for two reasons:

(1) Delivery patterns reflect the industrial specialization of an economic region and the degree of specialization also changes at a slow pace

Table 11.1 Domestic intermediate deliveries from forestry during the second half of the 1970s (UN–ECE Standardized Input–Output Tables, and the Statistical Bureaux of the respective countries).

Distribution of forestry deliveries to	*Australia* (%)	*Canada* (%)	*Sweden* (%)
1 Fabricated wood products	70	58	40
2 Paper and pulp	12	38	58
3 Intermediate deliveries as a share of output	65	NA	75

Table 11.2 Domestic intermediate deliveries of sawmill products (lumber and timber) during the second half of the 1970s (source as for *Table 11.1*).

Distribution of sawmill deliveries to	*Australia* (%)	*Canada* (%)	*Sweden* (%)
1 Fabricated wood products	27	36	33
2 Furniture	3	5	–
3 Construction	58	51	19
4 Paper and pulp	NA	NA	25
5 Intermediate deliveries as a share of output	94	NA	52

Table 11.3 Domestic intermediate deliveries of veneer and plywood during the second half of the 1970s (source as for *Table 11.1*).

Distribution of veneer and plywood deliveries to	*Australia* (%)	*Canada* (%)	*Sweden* (%)
1 Fabricated wood products	52	25	27
2 Furniture	25	5	23
3 Construction	18	66	45
4 Intermediate deliveries as a share of output	95	NA	66

when relative prices change along a steady trend (Batten and Johansson, 1985; Johansson and Larsson, 1985).

(2) Changes of input coefficients for a sector can be analyzed as processes of logistic substitution between competitive products on a delineated submarket.

11.1.2. Decomposition of demand: sectors, product groups, and products

In the framework outlined here we identify sectors as customers demanding commodities as inputs for ongoing activities. For each sector we may also identify different customer groups, each with specific input requirements and substitution possibilities. Let x_{iH} denote the input quantity of product i to sector H. A product group I is defined as a set of products that satisfy the same type of need or function for sector H. An example of such a group is the set of various materials that can be used as facing for a building (e.g., bricks, metal, and timber products).

Let a_{iH} be an input coefficient, x_H the output quantity from sector H, and α_{IH} group I's share of sector H's output value. Moreover, let p_i signify a product price and p_H a sector price. Then we have:

$$\begin{aligned} a_{iH} &= x_{iH}/x_H \\ \alpha_{IH} &= \sum_{i \in I} p_i a_{iH}/p_H \end{aligned} \tag{11.1}$$

Among the a_{iH} coefficients we also include the labour input coefficients. This means that:

$$\pi_H = p_H - \sum_i p_i a_{iH} \tag{11.2}$$

denotes the gross profit per unit output in sector H, and:

$$\hat{\alpha}_{IH} = \alpha_{IH} p_H/(p_H - \pi_H) \tag{11.3}$$

denotes group I's share of sector H's (current) input costs. The long-term value of π_H must be sufficiently large to cover the costs of accumulated investments in material and nonmaterial capital. Hence, as long as the average capital–output ratio of the sector remains approximately unchanged over time, π_H must remain fairly constant — in order to allow for continued investments in the sector. Short-term fluctuations in π_H will, to a large extent, follow or reflect fluctuations in p_H relative to $\sum_i p_i a_{iH}$. Hence, for long-run analysis, α_{IH} may be used as a proxy for $\hat{\alpha}_{IH}$ [1].

We may now introduce the following cost share (or value share) coefficients:

$$\begin{aligned} r_{iH} &= p_i a_{iH} / \sum_{i \in I} p_i a_{iH} = \rho_{iH} a_{iH} / \alpha_{IH} \\ \sum_{i \in I} r_{iH} &= 1 \end{aligned} \tag{11.4}$$

where $\rho_{iH} = p_i / p_H$. Letting $\dot{r}_{iH} = \mathrm{d}r_{iH}/\mathrm{d}t$ we may decompose $\dot{r}_{iH}$ into a price and a technique effect (for α_{IH} constant):

$$\dot{r}_{iH} = \underbrace{\dot{\rho}_{iH} a_{iH} / \alpha_{IH}}_{\text{price effect}} + \underbrace{\rho_{iH} \dot{a}_{iH} / \alpha_{IH}}_{\text{technique effect}} \tag{11.5}$$

which means that for known paths of $r_{iH}(t)$ and $\rho_{iH}(t)$ we may obtain $\dot{a}_{iH} = a_{iH}(\dot{r}_{iH}/r_{iH} - \dot{\rho}_{iH}/\rho_{iH})$. As a next step we may then examine the change in quantity flows:

$$\dot{x}_{iH} = \dot{a}_{iH} x_H + a_{iH} \dot{x}_H \tag{11.6}$$

It is important to note that equation (11.5) is independent of the sectoral change, $\dot{x}_H$. The latter only influences $\dot{x}_{iH}$ in equation (11.6). The development in value terms, $p_i x_{iH}$, is determined by the information in both equations (11.5) and (11.6), since $p_i x_{iH} = r_{iH} \alpha_{IH} p_H x_H$.

In the sequel we make use of the following types of substitution coefficients:

$$\begin{aligned} S_{iH} &= r_{iH} / (1 - r_{iH}) \\ S_{IH} &= \alpha_{IH} / (\bar{\alpha}_H - \alpha_{IH}) \end{aligned} \tag{11.7}$$

where $\alpha_H = 1 - \pi_H / p_H$, and where $\bar{\alpha}_H$ signifies the trend value of α_H. If $\dot{S}_{iH}/S_{iH}$ and $\dot{S}_{IH}/S_{IH}$ are constant over time, it follows by definition that $r_{iH}(t)$ and $\alpha_{IH}(t)$ have logistic forms.

Substitution in favor of product $i \in I$ occurs for $\dot{S}_{iH} > 0$. Given that α_{IH} is constant we may distinguish between the following two cases of steady change:

(1) Pure attribute superiority when $\Delta\rho_{IH} > 0$ and $\Delta a_{iH} \geq 0$, which gives $\Delta r_{iH} > 0$.

(2) Combined price and attribute superiority when $\Delta\rho_{iH} < 0$, $\Delta a_{iH} > 0$, and $|\Delta\rho_{iH} a_{iH}| \leftarrow |\Delta a_{iH} \rho_{iH}|$, which also gives $\Delta\tau_{iH} > 0$, where $|X|$ denotes the absolute value of X.

11.1.3. Changing market shares for forest sector products

There currently exist many observations that indicate falling market shares for a variety of forest sector products. Such products are being replaced by commodities based on, e.g., metals and plastics. Before providing some examples of these processes, we illustrate the implications of the analytical machinery introduced in the previous section.

Consider a sector H, which we may call "information dissemination", that includes printing and publishing activities. Let the paper input to this sector be indexed by $i \in I$. Some forecasts indicate, first, that the paper content, a_{iH}, is falling, and, second, that the associated value share, τ_{iH}, is decreasing, and that printing as such, α_{IH}, is being reduced. From the formula:

$$p_i x_{iH} = \tau_{iH} \alpha_{IH} p_H x_H \tag{11.8}$$

it is obvious that the impacts on producers of newsprint and other types of printing paper are also affected by the total production of sector H. That is, information production, x_H, may increase fast enough to offset the declining shares, expressed by $\dot{\tau}_{iH} < 0$ and $\dot{\alpha}_{IH} < 0$. This illustrates that a long-term forecast must consider the whole chain. We show in subsequent sections that there are good reasons to carry through the analysis along the sequential steps described by formula (11.8). An illustration of this stepwise, hierarchical procedure is given in *Figure 11.1*, as regards substitution within a group and substitution between groups.

An example from the Swedish construction sector may help to further illustrate the method outlined above. Let x_H represent a quantity or fixed-price measure of the construction activity, α_{IH} the share of $p_H x_H$ that consists of dwelling production, and τ_{iH} the share in value terms of each input, $i \in I$, used as floor covering. In this case the construction activity has been falling for several years, so that $\Delta x_H < 0$; the dwelling construction has been falling at an even faster rate which means that $\Delta\alpha_{IH} < 0$. *Figure 11.2* illustrates how the change of τ_{iH} components (step 1 in *Figure 11.1*) may be studied separately from the changes in α_{IH} (step 2 in *Figure 11.1*) and x_H (step 3).

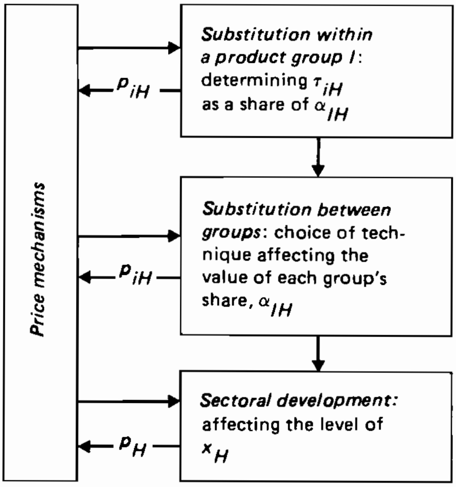

Figure 11.1 A sequential chain based on separability of substitution within and between groups.

We end this section with an example of an aggregate substitution process. Consider formula (11.7) and let the substitution coefficient be $S = \alpha/(1-\alpha)$, where α denotes the ratio: forest sector construction input divided by all other material construction inputs (metal, mineral, and chemical). Assuming that $\dot{S}/S$ is constant, it follows that α develops logistically, i.e., $\dot{\alpha} = \beta\alpha(1-\alpha)$. The coefficient β satisfies:

$$\ln S(t) = \mu + \beta t \tag{11.9}$$

where t denotes time and μ is a constant. In *Table 11.4* we have calculated the β-coefficient for the period 1965–1975 in a set of OECD countries. The message is rather clear. In the majority of these countries, the aggregate share of forest sector inputs is declining at a steady pace.

11.2. Substitution Models of Technological Change

Under competitive conditions, profit-maximizing producers may also be modeled as cost minimizers for a given output level. Let $V_i = a_{iH}x_H = x_{iH}$,

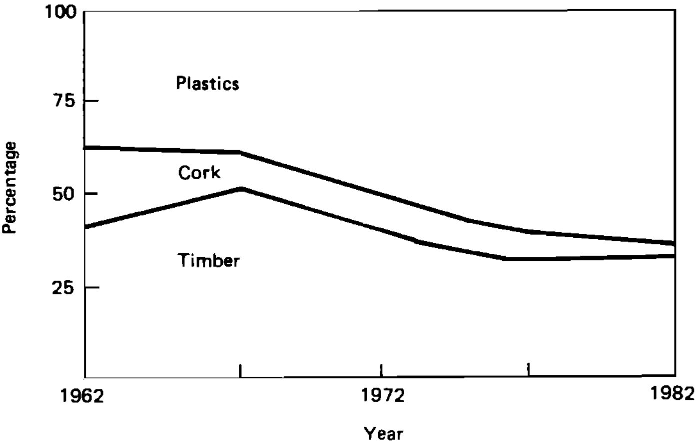

Figure 11.2 Market shares for materials used as floor covering (Sweden).

as specified in equation (11.1), and let G_H be a production function such that $x_H = G_H(V_1, V_2,...)$. A producer's incentive to substitute input factors for one another is expressed by the following cost-minimization problem:

$$\min \sum p_i a_{iH}$$

subject to:

$$\begin{aligned} &G_H(V_1, V_2,...) \geq \bar{x}_H \\ &a_{iH} = V_i/\bar{x}_H \end{aligned} \qquad (11.10)$$

where $\bar{x}_H$ is a given output level and p_i the price of product i. The solution to this problem is associated with an "optimal" cost function C_H:

$$C_H(x_H, p_1, p_2,...) = \min \{\sum p_i V_i : G(V_1, V_2,...) \geq x_H\} \qquad (11.11)$$

If the production technology is neoclassic and well behaved (Fuss *et al.*, 1978), the cost function in equation (11.11) will be real-valued and will satisfy conditions of monotonicity, continuity, concavity, and homogeneity.

Table 11.4 Substitution coefficient of forest sector construction inputs (UN–ECE Standardized Input–Output Tables).

Country	S (1965)[a] (%)	S (1975)[a] (%)	β = *annual rate of change* (%)
Spain	0.210	0.111	−7.1
Portugal	0.211	0.143	−3.9
Austria	0.130	0.086	−3.4
West Germany	0.259	0.187	−3.3
Italy	0.138	0.102	−3.0
Australia	0.340	0.270	−2.3
UK	0.226	0.198	−1.9
Japan	0.319	0.277	−1.4
Netherlands	0.268	0.232	−1.4
Czechoslovakia	0.134	0.121	−1.0
Canada	0.233	0.213	−0.9
Sweden	0.459	0.423	−0.7
Norway	0.492	0.477	−0.3
Denmark	0.234	0.266	+1.4

[a] S represents the construction inputs from the forest sector divided by construction inputs from the metal, mineral, and chemical sectors.

If C_H, in addition, is differentiable, we may apply Shephard's lemma (1953), saying that:

$$\partial C_H / \partial p_i = V_i \tag{11.12}$$

11.2.1. Translog functions

The relation in equation (11.12) can be used to formulate systems of factor demand functions. During the 1970s a special form of the C_H function came into use under the name "translog cost function" (Christensen *et al.*, 1971). This function became popular because it is nonrestrictive as regards substitution possibilities among factor inputs.

Using the condition in equation (11.12), substitution between various production inputs belonging to a product group I may be estimated and analyzed. Let f_I denote the aggregate cost share of this product group in sector H and let f_i be product i's value share of f_I, where i may signify a forest sector product [2]. Then we can write:

$$f_i = \gamma_i + \sum_j \gamma_{ij} \ln p_j \tag{11.13}$$

where:

$$\sum_{i \in I} \gamma_i = 1 \qquad \sum_{i \in I} \gamma_{ij} = 0 \qquad \gamma_{ij} = \gamma_{ji}$$

Equation (11.13) is specified for the case when the aggregate price $p_I = \sum f_i p_i$ is kept constant. This procedure is based on an assumption about separability of substitution within a group I and between groups I.

From estimations of equation (11.13), one may express how a 1% change in p_i/p_j is associated with a percentage change of the ratio x_{iH}/x_{jH} (Allen elasticity of substitution) as follows:

$$\sigma_{ij} = (f_i f_j + \gamma_{ij}) f_i f_j \tag{11.14}$$

Formula (11.14) describes a marginal substitution possibility in a framework of comparative statics. If we attempt to apply the approach outlined in equations (11.13) and (11.14) to a dynamic analysis, we run into inconsistencies. Consider γ_{ij} and γ_i as constants and differentiate equation (11.13) with respect to time, which yields:

$$\dot{f}_i = \sum_j \gamma_{ij} \dot{p}_j / p_j \qquad \text{for all } i$$

It is obvious that this formulation does not guarantee that we satisfy the two constraints $\sum f_i = 1$ and $\sum p_i f_i = p_I$. These constraints imply that:

$$\sum_{i \in I} \dot{f}_i = 0$$

$$\sum_i \dot{f}_i p_i / p_I + \sum f_i \dot{p}_i / p_I = 0$$

In the subsequent section we discuss an approach that includes the above type of constraints.

11.2.2. Logistic substitution models

In this section we outline a logistic substitution model, originally developed for the microanalysis of market penetration and technological change (see, for example, Fisher and Pry, 1971; Peterka, 1977; Batten and Johansson, 1984a). This particular model turns out to be a pragmatic simplification of a more general evolutionary model of industrial dynamics in an economic system with self-organizing properties (Batten, 1982), and may be related to innovation processes at various levels of aggregation. We restrict our discussion to a market share version for the analysis of two or more products competing for their share of a specific market, where each product belongs to a well-specified product group.

Experience has shown that, under certain competitive conditions, the dynamic processes of market penetration and product or process substitution tend to proceed exponentially in the early years, but to slow down later as the market becomes saturated. In relative terms, the substitution process follows an S-shaped curve. Quite often, the logistic distribution can provide a convenient framework for modeling this process through time. Such an approach is in keeping with the theories of innovation diffusion and the product cycle. It can also be given a theoretical foundation in terms of Lancaster's (1971) characteristic model of consumer behavior (see, for example, Batten and Johansson, 1984b, 1985). We elaborate on this theoretical basis in Section 11.2.3, where a general model of market penetration and substitution is outlined.

Although the logistic function is certainly not the only one that could be adopted for this purpose, it turns out to be a very practical choice for analyzing changes in relative market shares. This is because it can be completely characterized by just two constants: the early growth rate and the time at which the substitution is half complete (half-life). Numerous studies have now been conducted that confirm the logistic property of most evolutionary (birth–death) processes.

Mathematically, the substitution process can be modeled as the differential form of the two-parameter logistic function:

$$\dot{f}(t) = \alpha f(t)\{1 - f(t)\} \tag{11.15}$$

where $f(t)$ is the fraction of the market that the new technology has penetrated at time t, $1 - f(t)$ is the amount of old technology still in use, and α is the rate constant — or, in Mansfield's (1961) terminology, the rate of imitation or adoption. Equation (11.15) has both the property of exponential growth — that is, proportionality to the amount of growth achieved, $\alpha f(t)$ — and the property of constrained growth — that is, proportionality to the amount of growth yet to be achieved, $\alpha\{1 - f(t)\}$.

This differential equation is solved by rearranging the terms and integrating both sides (now dropping the time index):

$$f/(1 - f) = \mathrm{e}^{\{\alpha(t - t_h)\}} \tag{11.16}$$

or

$$\log\{f/(1 - f)\} = \alpha(t - t_h) \tag{11.17}$$

where t_h is the time when the substitution is half complete (i.e., $f = 0.5$ when $t = t_h$) and the maximal rate of growth is achieved. This indicates a very convenient property of the logistic function for empirical analysis: when the substitution data are plotted in the form of $f/(1 - f)$ as a function of time on semilogarithmic graph paper, the points should form a straight line (as illustrated in *Figure 11.3*). This property appears to hold with extraordinary precision for a wide range of forest sector products (Batten and Johansson, 1984a, 1985; Johansson and Larsson, 1985).

It is convenient, in addition, to characterize a substitution by its "takeover time", defined as the time required to move from $f = 0.1$ to $f = 0.9$ (Fisher and Pry, 1971). The takeover time, t_s, is inversely proportional to the rate constant:

$$t_s = 2 \log 9/\alpha \tag{11.18}$$

If the dimensionless time, τ, is defined in the form:

$$\tau = 2(t - t_h)/t_s \tag{11.19}$$

formula (11.17) may be written in dimensionless form. This makes it possible to plot different substitution processes on the same graph.

11.2.3. Economic choice and product attributes

An important feature of the substitution model introduced in Section 11.2.2 is that it describes the evolution of a product's market share, but not the total production of each particular commodity. This is in line with the

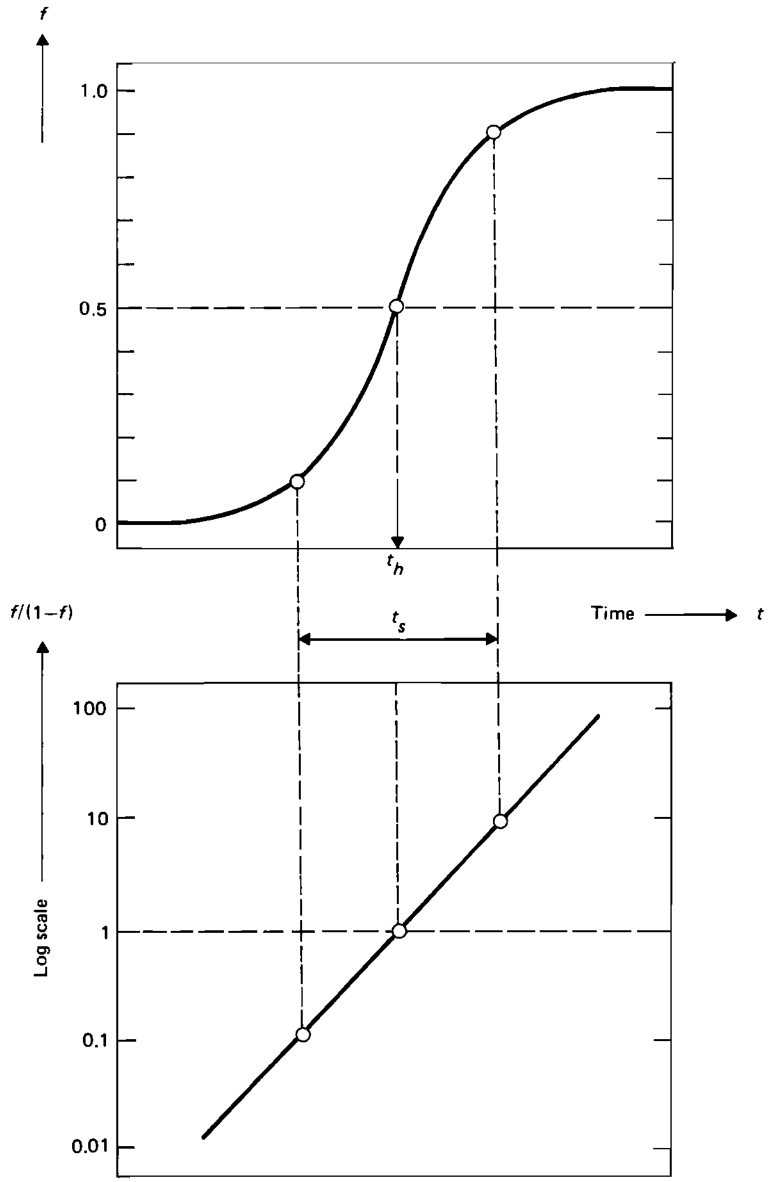

Figure 11.3 General form of the logistic substitution model.

sequential or hierarchical method of analysis suggested earlier. An obvious reason for this separation procedure is that the development of market shares is, to a large extent, a steady, time-invariant process; it exhibits a smooth regularity, which is only modestly affected by fluctuations in the product group as a whole (i.e., fluctuations in the production volume of sectors for which the product group constitutes a set of substitutable inputs).

In a comprehensive presentation, Peterka (1977) provides an elegant solution as to how smooth substitution processes may be related to assumptions about economic mechanisms. However, his contribution does not shed much light on the price competition between substitutes that might disturb the regularity in the medium term. Moreover, the parameters of a logistic substitution process must be thought of as a reflection of movements of relative prices in combination with technical changes. A model framework developed by Batten and Johanson (1984b, 1985) provides a basis for analyses of the above type of issues.

The foundation of the model is a Lancaster (1971) framework in which different customer groups $l \in L$ have preferences with regard to the "objective" attributes or characteristics of each product that belongs to a given group of substitutes. The preference functions, u^l, may reflect technical possibilities of customer group l (e.g., industrial sector l) to substitute between two or several distinct products (materials). The attribute of a product is described by a vector of characteristics.

Let $x = \{x_i\}$ be a vector of products, $i \in I$, $B(x)$ denote a transformation of such a vector into its associated vector of characteristics, and $u^l[B(x)]$ denote group l's evaluation of this characteristics vector, where u^l is continuous, quasi-concave, and has positive first-order derivatives. By m^l we signify the budget that group l, at each point in time, allocates to products in the product group I. Letting $p = \{p_i\}$ be the vector of pertinent prices, we may describe group l's demand for products by means of a vector function $F^l(p,m^l) = \{F_i^l(p,m^l)\}$. Assuming that customers behave economically, F^l may be defined as:

$$F^l(p,m^l) = \{x \in K(p,m^l) : u^l[B(x)] = \max u^l[B(x)]\} \tag{11.20}$$

where $K(p,m^l)$ is the set of product combinations that satisfy the budget constraint $px \leq m^l$. When B is a matrix that transforms products into characteristics, the solution to equation (11.20) can be expressed in terms of positive budget shares $\mu_i^l(p)$, showing the fraction of m^l that is used to purchase product i. Hence, we may write for customer group l:

$$x_i^l = F_i^l(p,m^l) = \mu_i^l(p)m^l/p_i \tag{11.21}$$

When the products in I are sufficiently differentiated (see Johansson, 1978) the share functions will be positive and continuous in p. If the differentiation between products is too weak, the functions $\mu_i^l(p)$ will, for individual groups, display discontinuous responses to certain price changes at singularity points. In either case the maximal demand from group l is $D_i^l(p) = m^l/p_i$ and:

$$D_i(p) = \sum_l D_i^l(p) \tag{11.22}$$

At each point in time the market is characterized by a supply x_i and a demand $\sum_l \mu_i^l(p) m^l/p_i = \mu_i(p)M$, where $M = \sum m^l/p_i$. By $\beta_{ii}x_i$ we signify the amount that is actually sold; $\beta_{ii} = \beta_{ii}(p)$ equals unity if $x_i < \mu_i(p)M$. With the help of the $\mu_j(p)$ information we may express the amount of $D_i(p)$ that is satisfied by sales of product j; this amount is signified by $\beta_{ij}x_j$. When prices are selected with perfect sensitivity to demand conditions we have that $\beta_{ii} = 1$ for each i. If prices charged and quantities supplied do not completely match each other, there may be shortages in the market. For such situations a more elaborate version of equation (11.21) must be used.

To complete the model in equations (11.20) to (11.22), we specify the following supply behavior:

$$\dot{x}_i = \begin{cases} N_i(p,x) \text{ if } \bar{x}_i \geq x_i \\ 0 \text{ otherwise} \end{cases} \tag{11.23}$$

$$\dot{\bar{x}}_i = \delta_i(\pi_i)\, \dot{x}_i$$

where $N_i(p,x) = \alpha_i x_i \{D_i(p) - \sum_j \beta_{ij} x_j - (1 - \beta_{ii}) x_i\}$, $\bar{x}_i$ is the capacity to supply product i, π_i is the profit per unit output of i, $(1 - \beta_{ii})$ is the proportion of x_i that is not sold at a given point in time, δ_i is a capacity change function (investment), and α_i is supply response coefficient, which, in general, will be a function of π_i. With this model it is possible to distinguish between the evolution of $\dot{x}_i/x_i$ and the change in market share $\dot{\mu}_i$, which becomes:

$$\dot{\mu}_i = c_i(t)\, \mu_i(1 - \mu_i) \tag{11.24}$$

When $c_i(t)$ is constant, equation (11.24) is Verhulst–Pearl's equality, which describes a logistic growth path of μ_i of the type outlined in Section 11.2.2. The variable μ_i represents the same type of fraction as f in equation (11.15).

11.2.4. Illustration of substitution processes

According to the model outlined in equations (11.20)–(11.24), we may conclude that when product attributes are unchanged a fall in f_i/f_j is associated with an increase in the corresponding price ratio p_i/p_j — and *vice versa*. *Table 11.5* illustrates this mechanism with regard to the domestic market for panels in Sweden.

Table 11.5 Relative prices and domestic shares in the Swedish market for panels (Swedish Central Bureau of Statistics, Industry and Trade Statistics, Stockholm, 1962–1981).[a]

Ratio	*1960*	*1965*	*1970*	*1975*	*1980*	*Type*
p_i/p_1	100	89	116	207	196	Veneer sheets
f_i/f_1	100	110	82	39	44	
p_i/p_1	100	79	94	61	66	Particle board
f_i/f_1	100	122	230	195	193	
p_i/p_1	100	91	123	105	155	Fiberboard
f_i/f_1	100	65	47	25	29	
p_i/p_1	100	98	101	96	110	Plaster board
f_i/f_1	100	167	256	194	250	

[a] p_i = price and f_i = domestic market share; $j = 1$ refers to plywood; the price variable here represents producers' prices.

Figure 11.2 gives a historical picture for the use of different materials used in floor covering. An extrapolation to the year 2000 is provided in *Figure 11.4*, which shows that timber materials retain an almost constant, but not growing share, while plastic materials are expanding fast.

In *Table 11.4* we identify a reduction in the aggregate use of wood materials in the construction sector. This trend was shared by most OECD economies, including Sweden. *Table 11.6* reveals that this decline is far from uniform for all types of forest sector inputs to the construction sector.

Most of our examples of substitution have been restricted to the Swedish markets for specific building components. In *Table 11.7* we provide examples from various sectors that use forest sector products as

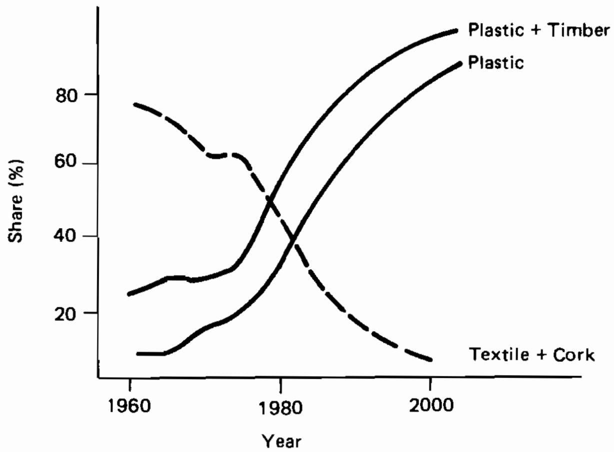

Figure 11.4 Market share for floor covering materials on the domestic Swedish market (Johansson and Larsson, 1985).

Table 11.6 Market share in Sweden for timber as facing material (Johansson and Larsson, 1985).[a]

Type of house	*Share f (%)* 1968	1980	2000	*Rate of change in* $f/(1-f)$	*t-value*	R^2
Single-family						
individually built	34	80	90	0.14	8.9	87
built in group	42	63	85	0.06	5.7	87
All types of dwellings	19	54	94	0.14	8.9	87

[a] The substitution equation is $\ln[f/(1-f)] = \alpha + \beta t$; β = rate of change.

inputs. These illustrations of processes that are changing the demand for timber materials refer to various parts of the world.

11.3. Substitution, Specialization, and Export Flows

In this section we extend the previous analysis of substitution processes pertinent to the forest sector. In the earlier discussion the focus has been on domestic markets. However, substitution can also be estimated with good precision with regard to the export flows from a country. In addition, we provide another indicator that is useful for analyses of the forest sector

Table 11.7 Some international examples of substitution affecting the demand for forest products (Fisher and Pry, 1971; Sharif and Kabir, 1976; Blackman, 1974; Peterka, 1977; Bureau of Agricultural Economics, 1985).

		Substitution		*Half-life,* t_h	*Takeover time*
Nations	*Market*	*New*	*Old*	(Year)	(Years)
Global	Energy	Coal	Wood	1875	130
	Energy	Oil and gas	Wood and coal	1958	90
US	Floors	Plastic	Hardwood	1966	25
	Merchant marine	Metal	Wood	1910	60
	Recreational marine	Fiberglass	Wood	1968	30
Sweden	Facing of multi-family dwellings	Timber	Brick veneer	2015[a]	110
	Frames and doors	Steel and aluminum	Wood	2025[a]	>110
	Panels	Particle board	Plywood and veneer	1970	70
	Floors	Plastic	Wood and cork	1972	No complete penetration
Australia	Panels	Particle board	Plywood	1960	60
	Cement board	Wood fiber	Asbestos	2005[a]	40
	Packaging	Plastic	Paper	2015[a]	80

[a] Forecasts only.

change processes. This indicator measures a country's or a region's degree of specialization as regards various types of products or product groups.

In this section we summarize three basic observations:

(1) Every group of substitutes regularly contains some products that acquire an increasing share of the market of the group. Consequently, other products experience a declining share. As shown in Section 11.2, this process can be described statistically and with high precision by means of two time-invariant parameters.

(2) A product with an expanding share of the domestic market regularly captures — with a certain delay — an increasing share of the total export sales of its product group.

(3) The substitution among export sales of a product group generally develops with a lag and a higher speed than the corresponding substitution in the domestic market. The statistical estimates are usually more significant for the export flows than for the domestic sales.

(4) Substitution processes as described above influence the development of a nation's specialization profile. Measures of specialization generally evolve at a slow pace along a predictable cycle.

11.3.1. Export flows and substitution within product groups

In formula (11.23) the substitution process is reflected by a supply behavior that generates the change processes $\dot{x}_i$ and $\dot{\mu}_i$. By recognizing delivery regions, r (nations or groups of nations), and purchasing regions, s, we may extend the model to include a distinction between domestic and export markets. At a fine level of specification one may examine, for each product group I:

$$\begin{aligned} x_i^{rr} &= \text{domestic deliveries} \\ x_i^{rs} &= \text{deliveries from } r \text{ to } s \\ e_i^r &= \sum_s x_i^{rs} = \text{exports form } r \end{aligned} \tag{11.25}$$

From this we may define the product group share variables:

$$\begin{aligned} f_i^{rr} &= p_i^r x_i^{rr} / \sum_{i \in I} p_i^r x_i^{rr} \\ f_i^{rs} &= p_i^s x_i^{rs} / \sum_{i \in I} p_i^s x_i^{rs} \\ f_i^E &= \sum_{s \neq r} p_i^s x_i^{rs} / \sum_{s \neq r} \sum_{i \in I} p_i^s x_i^{rs} \end{aligned} \tag{11.26}$$

In Section 11.2 we focused on the share variable $\hat{f}_i^r = \sum_s p_i^r x_i^{sr} / \sum_s \sum_i p_i^r x_i^{sr}$, which describes the consumption share in country r. Here, we make use of the substitution coefficients introduced in equation (12.7) and define $S_i^{rs} = f_i^{rs}/(1 - f_i^{rs})$, $S_i^E = f_i^E/(1 - f_i^{E)}$, and $\hat{S}_i^r = \hat{f}_i^r/(1 - \hat{f}_i^r)$. For the specification $S_i = \alpha_i + \beta_i t$ we have observed (Batten and Johansson, 1985):

$$\begin{aligned} \hat{\alpha}_i^r &> \alpha_i^E \\ \hat{\beta}_i^r &< \beta_i^E \end{aligned} \tag{11.27}$$

The inequalities in expression (11.27) mean that for a product with $\dot{S}_i > 0$, the introduction takes place earlier (or at a higher level) on the domestic market; on the other hand, the substitution process is faster on the export market. Analogously, in a decline phase f_i^E is reduced at a faster pace than $\hat{f}_i^r$. An illustration of this phenomenon is given in *Figure 11.5*.

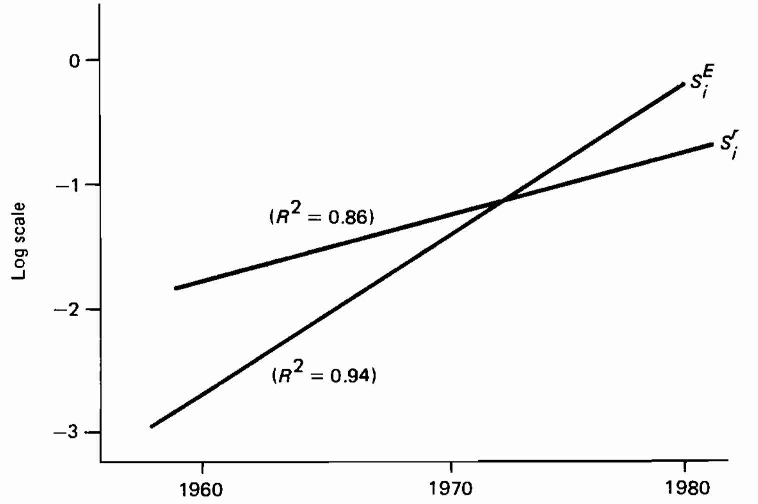

Figure 11.5 Particle board as a share of the panels market; development of S_i^r and S_i^E for Sweden (Johansson and Larsson, 1985).

11.3.2. Specialization analysis for forest products

The introduction of new products usually occurs in a limited number of locations in the economic geography of the world. In general, we may conjecture that these places have a comparative advantage at the stage of initiation. Furthermore, product development increases the number of product variants; expanding production also brings about improvements of the production technique; and, finally, growing demand in various places of the world causes market changes. The result of these three categories of change is that the comparative advantage for the production of the different product variants slowly shifts from the initiating regions, the leaders, over to the adapting regions, which we may call the followers (see Andersson and Johansson, 1984).

Figure 11.6 provides a classical picture of how a follower region may develop from an importing region (with a low level of specialization) to an exporting region (with a high level of specialization). The figure also mimics the substitution regularities illustrated in *Figure 11.5*. In Batten and Johansson (1985) the relationships between substitution and specialization processes are examined and analyzed.

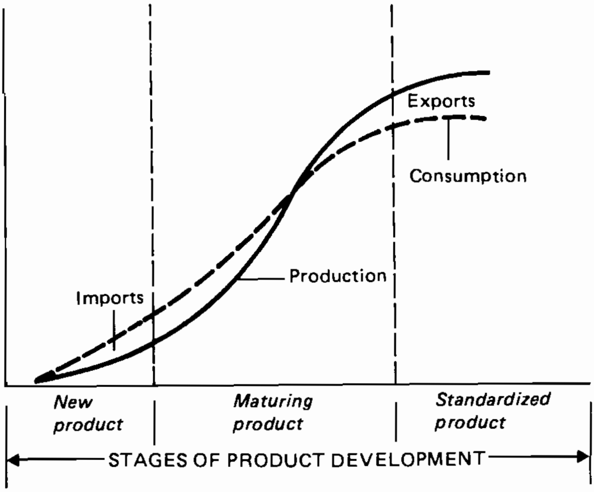

Figure 11.6 Trade switching in the product cycle of a follower region (Vernon, 1966).

The specialization of a country r may be measured by means of the following specialization coefficient:

$$\delta_i^r = x_i^{rr} / \sum_s x_i^{sr} = (x_i^r - e_i^r)/(x_i^r + m_i^r - e_i^r) \tag{11.28}$$

where x_i^r denotes production, m_i^r imports, and e_i^r exports for country r. The subsequent empirical analyses focus on the level of δ_i and its change over time, i.e., $\Delta\delta_i$. In *Figures 11.7* and *11.8* we depict the regularities of a specialization process for a leader and a follower region. By δ_H and δ_L we denote a high and a low degree of specialization. The bold arrows indicate the general process of specialization adjustments, usually a very slow process. The broken arrows indicate how political protection of a declining industrial production may slow down and temporarily avert the change process. Such protection includes tariffs and subsidies.

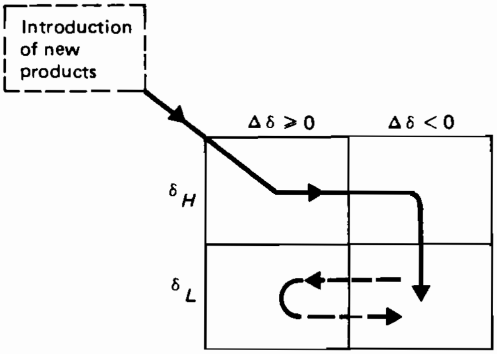

Figure 11.7 Specialization dynamics of a leader region.

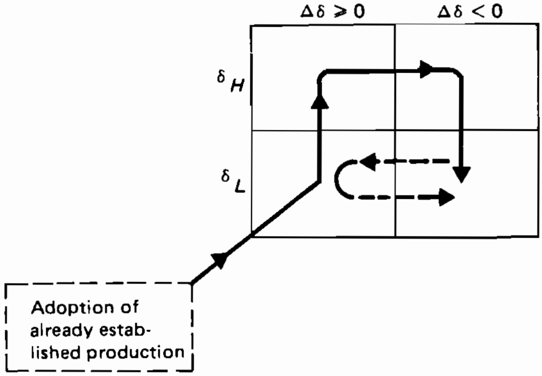

Figure 11.8 Specialization dynamics of a follower region.

With the help of the above scheme, we illustrate in *Figure 11.9* the specialization of forest product sectors with regard to all OECD countries. The arrow in the figure indicates a shift in the specialization of pulp production in the period after 1977. The average value of δ in the upper left box was (in 1977) 95%. The same value in the lower left box was 74% (see Andersson and Johansson, 1984).

Information of the type contained in *Figure 11.9* can be gathered for individual countries and products or categories of products. We illustrate this by studying the specialization in various countries and regions of the

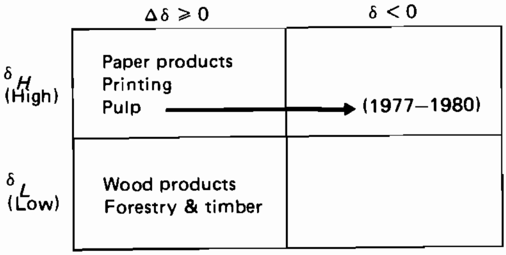

Figure 11.9 Specialization process for the OECD economies, 1971–1977 and 1977–1980 (Andersson and Johansson, 1984).

world with regard to forest products used by the construction industries. The following categories of products are considered:

(1) Sawnwood (*Figure 11.10*).
(2) Fiberboard (*Figure 11.11*).
(3) Wood panels (*Figure 11.12*), including plywood, veneer sheet, and particle board.

In both North America and Asia sawnwood specialization has been gradually reduced since the beginning of the 1960s. Among the selected regions, Sweden is the only example of declining fiberboard specialization, where the substitution over to other materials has been fast and steady.

Western Europe has, during the last 20 years, experienced a low and declining specialization with regard to different kinds of wood panels. The Nordic region, which is a part of Western Europe, has particle board as its specialization, while plywood plays a similar role in North America. The USSR displays a high specialization in all types of panels recorded here. These change processes are depicted in *Figures 11.13–11.15*.

	$\Delta\delta > 0$	$\Delta\delta < 0$
δ (1976–1981) > 90	Finland Sweden USSR	Asia
δ (1976–1981) < 76	Western Europe	North America US

Figure 11.10 Sawnwood specialization among regions, 1961–1981 (UN Trade Statistics).

	$\Delta\delta \geqslant 0$	$\Delta\delta < 0$
δ (1976–1981) ≈ 95	Asia Finland North America US USSR	Sweden
δ (1976–1981) ≈ 60	Western Europe	

Figure 11.11 Fiberboard specialization, 1961–1981 (UN Trade Statistics).

	$\Delta\delta \geqslant 0$	$\Delta\delta < 0$
δ high	Finland (97) North America (91) US (91) USSR (98)	Asia (89) Sweden (88)
δ low		Western Europe (69)

Figure 11.12 Specialization process for wood panels, 1961–1981 (UN Trade Statistics). The δ value for 1976–1981 is given for each region within brackets.

	$\Delta\delta \geqslant 0$	$\Delta\delta < 0$
δ high	Finland (99) Sweden (95) USSR (100)	Asia (92) North America (94) US (94)
δ low		Western Europe (79)

Figure 11.13 Particle board specialization, 1961–1981 (UN Trade Statistics). The δ value for 1976–1981 is given for each region within brackets.

	$\Delta\delta \geqslant 0$	$\Delta\delta < 0$
δ high	North America (90) US (90) USSR (97)	Asia (90) Finland (94)
δ low		Nordic region (34) Sweden (43) Western Europe (34)

Figure 11.14 Plywood specialization, 1961–1981 (UN Trade Statistics). The δ value for 1976–1981 is given for each region within brackets.

	$\Delta\delta \geqslant 0$	$\Delta\delta < 0$
δ high		USSR (87)
δ low		Asia (73) Finland (19) Sweden (32) Western Europe (64) North America (NA)

Figure 11.15 Veneer sheets specialization, 1961–1981 (UN Trade Statistics). The δ value for 1976–1981 is given for each region within brackets.

11.4. Conclusions

In this chapter we have outlined an approach to the analysis of product substitution and technological change and applied it to various markets in which forest products compete with other types of commodities. Building on the relatively simple foundation of logistic substitution models, we have sought to develop a general model of market penetration in accordance with Lancaster's (1971) characteristic model of consumer behavior. This general model is not as fatalistic as the logistic assumption that portrays the future as being uniquely predetermined by the recent past.

By extending our analyses beyond the domain of domestic markets and into the export arena, the following observations can be made:

(1) Among groups of competitive substitutes there are generally some products that are increasing their market share and some others that are consequently losing ground; this substitution process can be described reliably using two time-invariant parameters.
(2) A product that enjoys an expanding share of the domestic market regularly captures an increasing share of the corresponding export market; the substitution among export markets generally follows the domestic penetration with a certain time lag, but may proceed more quickly.
(3) These two substitution processes each influence the development of a nation's degree of specialization in particular products or groups of products; measures of specialization generally change rather slowly and follow a predictable path.

In order to illustrate these processes, we have concentrated in particular on the markets for building materials and components, since the forest sector has, for many years, been heavily reliant upon the building sector as a major customer for some of its intermediate outputs. Although our reported results are preliminary and sporadic, they tend to be rather discouraging from the viewpoint of the forest sector as a whole. In the vast majority of OECD countries, forest products appear to be steadily losing part of their traditional market shares in the production or export of building components and allied products. To a lesser extent, they are also gaining ground in some newer markets.

The steady decline in intermediate (and per capita) demand for the more traditional classes of forest products can be partly explained by the relatively low level of R&D expenditure devoted to forest products research (less than 1% of value added) compared with that devoted to R&D by other building materials sectors and other nonforest products industries. This inadequate commitment to products, processes, and market development suggests that wood-based building materials will become less and less competitive in the domestic markets of most industrialized nations and will therefore be replaced increasingly by nonwood-based inputs, such as metals, plastics, and ceramics. Without any compensating penetration into other, newer markets for forest products, an important consequence would be that the wood-oriented economies of the world will have a weaker position on the international market.

Notes

[1] It should be observed that the subsequent analysis does not depend on the extent to which π_H is constant.

[2] f_I and f_i are the same type of coefficients as $\hat{\alpha}_{IH}$ in equation (11.3) and r_{iH} in equation (11.4), respectively.

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CHAPTER 12

Demand for Sawnwood and Panels

W. McKillop and S. Wibe

The ultimate purpose of production is consumption. This applies to every production activity and to every kind of product. Product demand is, therefore, in one way or another, consumer demand, and the theory of consumer demand is the core of all demand theories.

Not all products are, however, consumer goods. Some products are used mainly as inputs in the production of other goods; these "producer" or *intermediate goods* are consumed indirectly, in the form of other goods. Simplifying the production system into two different products (A and B), we may illustrate the different routes from production to consumption as in *Figure 12.1*.

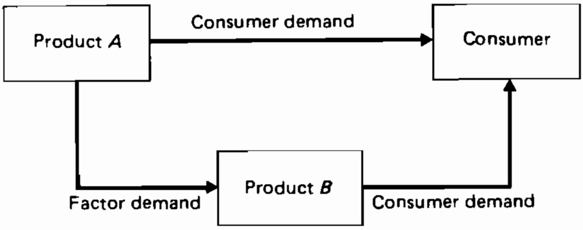

Figure 12.1 Possible demand alternatives in a production system.

It is apparent from *Figure 12.1* that there are three types of models that can be used for demand analysis:

(1) *Consumer demand models*, which seek to establish the determinants of final consumption. These models can be used for all kinds of products, consumer goods as well as intermediates.

(2) *Factor demand models*, which are specifically designed to handle the demand for intermediates. These models are also called producer demand models. Turning to *Figure 12.1*, these models seek to establish the link between the level of output of B and the demand for A.

(3) *Combined factor and consumer demand models*, which are also specifically designed to handle the demand for intermediate goods, but in addition to (2), they also seek to estimate the demand for final consumption goods. With reference to *Figure 12.1*, these models combine factor demand models (from B to A) with consumer demand for B.

These three kinds of models are discussed briefly in Section 12.1; the different empirical techniques available are analyzed in Section 12.2; in Section 12.3, we review some important studies of demand for sawnwood and panels in Europe and North America; and in Section 12.4 we conclude with a summary of the strengths and weaknesses of alternative demand approaches and give some suggestions for future research.

12.1. Theoretical Demand Models

12.1.1. Consumer demand models

The traditional Slutsky-Hicks model

The traditional demand model is derived from the analyses of Slutsky (1915) and Hicks (1946). This well-known model deals with utility maximization and consumer choice under budget constraint. The solution to the utility maximization problem of individual i is a set of demand functions f for each product j:

$$q_j^i = f^i(Y^i, P_1, \ldots, P_m) \qquad j = 1, \ldots, m \tag{12.1}$$

where q_j^i is the demand for j, Y^i is the income level, and $P_1, \ldots, P_m$ are the prices of $q_1, \ldots, q_m$.

Demand functions derived from traditional demand theory thus emphasize the importance of income Y^i and prices $P_1, \ldots, P_m$ [1]. Of particular importance, in terms of the demand for sawnwood and panels, is that "prices" also include the price of time, i.e., the interest rate. The interest rate has a considerable impact on the demand for housing, which, in turn, is extremely important for the demand for sawnwood and panels. Other important prices are, naturally, those of competing or complementary building materials, such as cement, bricks, etc.

Lancaster's consumer demand model

Traditional demand theory has been remarkably robust as a general explanation of consumer demand and very few changes have been made to the fundamental theoretical structure. However, in the late 1960s, Professor Kelvin Lancaster (1971) proposed a new approach, which opened up new and interesting insights into the subject. The simple observation made by Lancaster was that all goods possessed "characteristics", and that it was these characteristics, and not the products *per se*, that the consumer demanded. Thus, the consumers did not just demand oranges, but rather the orange's vitamins, calories, etc., and they would immediately switch to new products if the combination of characteristics and price proved superior to that of oranges.

Formally, Lancaster's theory implied that the qualities of products also enter the demand functions. If z_{ij} is the "amount" of quality i in good j, then the demand for q can be written, omitting the notation for a specific individual:

$$q_j = f(Y,P_1,\ldots,P_m,z_{11},\ldots,z_{1m},\ldots,z_{nm}) \tag{12.2}$$

The general observation (that quality matters) is rather trivial. But Lancaster's theory makes it possible to go further and derive "shadow prices" of different qualities. In this way the theory can improve our understanding of the deeper forces behind the determinants of demand. It must, however, be added that it is not easy to quantify qualities (or characteristics) and Lancaster's theory has so far had very little impact on empirical research of wood products [2]. Nevertheless, we consider that Lancaster's approach might prove fruitful in the study of the demand for sawnwood and panels, since the quality of wood, e.g., as a building material, in relation to the qualities of other competing materials is essential to demand. Wood competes with other products, especially in terms of qualities, and its quality performance will, in the long run, determine demand.

Information and acceptance models of demand

A third variant of consumer demand theory are models based on the theory of information, which emphasize the importance of time rather than of prices and income. Time is needed to inform a given market of a product, especially as some people need more information on new products than others. Accordingly, the time taken for information and acceptance is often more important than prices, especially for new products. (This approach is expanded in Chapter 11.)

There are many ways of producing information models of demand. The simplest way is probably to start with a given population (a market) and to assume that people are normally distributed with respect to the time of acceptance of the product (or the time taken to persuade them to use the product) [3]. Total sales will increase very gradually in the beginning, but accelerate when the acceptance level of the "average consumer" is approached. After that, sales will rise more and more slowly, since the given population sets a limit to the market. The resultant curve for total sales will follow an S-shape or logistic path (*Figure 12.2*) [4].

Logistic sales models can also be formulated from the theory of information diffusion. Assume, first, that the total market equals B (units, customers, etc.) and that demand (and sales) at time t equals $q(t)$ units. The absolute growth of demand at t, $\mathrm{d}q/\mathrm{d}t$, is assumed to be a function of:

(1) *Total sales up to time t, $q(t)$.* This assumption is made for the reason that total sales is an index of the number of people who can provide information on the product to relatives, neighbors, etc.

(2) *Remaining market at t, $B - q(t)$.* This assumption is natural since the chance that a piece of information will reach an uninformed potential buyer will decrease when $q(t)$ approaches B.

The simplest model that incorporates both of the assumptions made under (1) and (2) is a multiplicative model:

$$\mathrm{d}q/\mathrm{d}t = A_o q(t)[B - q(t)] \tag{12.3}$$

Solving for $q(t)$ yields the familiar formula for the logistic curve:

$$q(t) = \frac{B}{1 + a_1 \mathrm{e}^{a_2 t}} \tag{12.4}$$

where $a_1 > 0$ and $a_2 < 0$.

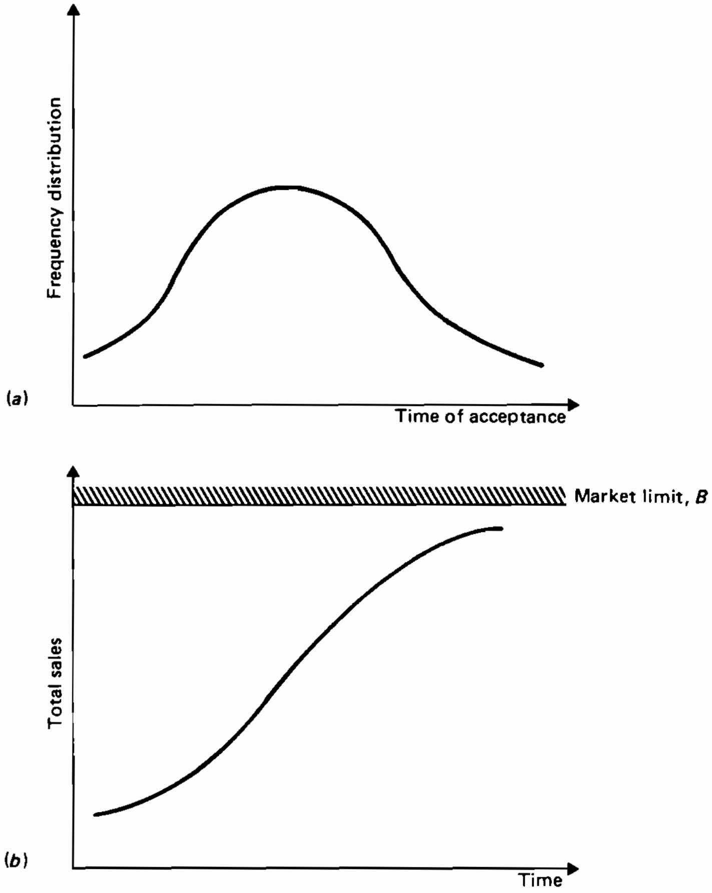

Figure 12.2(a) Frequency distribution of a population with respect to time of acceptance of a new product; *(b)* time path of total sales for a product with a market limit.

Logistic models, such as model (12.4), are usually very powerful in explaining the time development of demand, especially when applied to new products. They are also very useful in the analysis of the market shares for products. In these cases, B in equations (12.3) and (12.4) is set to 1 and $q(t)$ is interpreted as the market share for the product.

If information-based models are added to the traditional theory of demand, time is introduced as an argument in the demand functions:

$$q_j = f_j(Y, P_1, \ldots, P_m, t) \tag{12.5}$$

More specifically, if we assume that the logistic model is added neutrally, we obtain:

$$q_j = f_j(Y, P_1, \ldots, P_m)/(1 + a_1 e^{a_2 t}) \tag{12.6}$$

A combination of the logistic curve and the traditional demand function as presented in equation (12.6) has not been used in empirical research to date. When time is introduced, the usual specification is the simple exponential function: $q = e^{a_2 t} f_j(Y, P)$. However, a combined model, such as equation (12.6), seems to be a promising alternative.

12.1.2. Factor demand models

The starting point for all factor demand models is the production function (this approach is discussed in more detail in Chapter 6). In order to introduce this concept, we now use q as the quantity notation for output, L as notation for labor input, and $v_1, \ldots, v_k$ as notation for the input of factors $1, \ldots, k$, including capital.

The production function is now defined as the relation:

$$q = F(L, v_1, \ldots, v_k) \tag{12.7}$$

For every production function there is a least-cost function (cost function for short) relating prices and output to total cost C [5]:

$$C = H(q, P_1, \ldots, P_k, P_L) \tag{12.8}$$

According to Shephard's lemma [for early derivations see Hotelling (1932) and Samuelson (1947)], the derivative of cost with respect to input price equals the optimum quantity of input:

$$v_i = H_i(q, P_1, \ldots, P_k, P_L) \qquad i = 1, \ldots, k \tag{12.9}$$

where $H_i = \partial H/\partial P_i$. Equation (12.9) can be interpreted as the factor demand functions for inputs $1, \ldots, k$. The specific form of $H_i(\ )$ is, of course, determined by the form of the production function $F(\ )$. However, it is not necessary to derive the form of $H_i(\ )$ from $F(\ )$; it is often easier to assume a suitable form of equations (12.9) or (12.8) directly. Since the pioneering efforts by Christensen *et al.* (1973) and Brendt and Wood (1975), it has become increasingly popular to use a ***translog cost function***, which is a Taylor expansion, in two steps, of an ***arbitrary*** (logarithmic) cost function. If the production function is ***homothetic*** [6], then the output level can be multiplicatively separable from the cost function. More specifically, if the production function is homogeneous of degree 1 (constant returns to scale) we can write equation (12.9) as:

$$v_i = qG(P_1,\ldots,P_k,P_L) \qquad i = 1,\ldots,k \tag{12.10}$$

Dividing both sides in equation (12.10) by q, we obtain coefficients of v_i/q as a function of prices. Total demand for v_i is then obtained by multiplying the input coefficients with the level of output [7].

Production functions differ with respect to the period of production and the level of aggregation, and these differences are carried over to the factor demand functions. If, for instance, the production function is a short-run function only, defined for a plant with an existing capital structure, then capital is usually considered as a fixed input and excluded from the cost functions (which are essential for the demand for wood products). In order to incorporate the effects of new investments, it is necessary to model long-run cost and production functions with capital as a variable factor of production (Wibe and Heathfield, 1986, Ch 1). Since the production function shifts over time due to technological progress, we also need to add "time" to the arguments of long-run cost and production functions [8].

Comparing factor demand models with consumer demand models, we find that the only substantial difference is that the level of income, Y, is substituted for the level of output. It is also possible to repeat the analysis in Section 12.1.1 for factor demand and add "characteristics" of the effects of information diffusion to the models.

12.1.3. Combined factor and consumer demand models

The decisive weakness of consumer demand models, when applied to intermediate products, is that they neglect all reactions within the production system. These models, therefore, cannot provide a deeper understanding of the determinants of demand. The weakness of factor demand models is that they neglect the link to the consumer. Combined models seek to overcome these problems, first, by using factor demand models to estimate the demand for the good as an intermediate and, second, through the use of consumer demand models to establish the links to the consumer.

It is obvious that combined models easily become very complicated, so it is necessary to simplify the production system. The standard simplification is to assume that all production functions are of the Leontief type (1941) with fixed input coefficients:

$$q = \min\ (L/a_L, v_1/a_1, \ldots, v_m/a_m) \tag{12.11}$$

where $a_L, a_1, \ldots, a_m$ are the fixed coefficients. If we assume such functions for every sector, we can express the production system as a set of linear equations. If q_j is the gross production of product $j(1,\ldots,m)$, c_j the final consumption of j, and a_{ij} the input coefficient of good j in the production of product i, we have the following relations [9]:

$$\begin{aligned} q_1 &= a_{11}q_1 + a_{12}q_2 + , \cdots , + a_{1m}q_m + c_1 \\ &\cdot \\ &\cdot \\ &\cdot \\ q_m &= a_{m1}q_1 + a_{m2}q_2 + , \cdots , + a_{mm}q_m + c_m \end{aligned} \tag{12.12}$$

In matrix notation:

$$Q = AQ + C \tag{12.13}$$

Solving for Q, we obtain:

$$Q = (I-A)^{-1}C \tag{12.14}$$

If the input coefficients of the system are known, equation (12.14) can be used to transform consumer demand (for C) into final demand for a commodity without neglecting any of the feedbacks in the production system. It is, of course, also possible to modify the model, e.g., by estimating the sensitivity of the input–output coefficients with respect to prices [10].

12.2. Empirical Issues

The objective of empirical demand analysis is to estimate aggregate sawnwood or panel demand functions for groups of countries, individual countries, or major regions within countries, as opposed to simply forecasting consumption.

12.2.1. General types of demand studies

Empirical studies or models of the demand for sawnwood and panels may be classified into following three broad groups:

(1) Econometric models specified on the basis of theory versus *ad hoc* models.
(2) Studies using cross-sectional data as opposed to time-series data.
(3) Short-term versus long-term models.

The choice of explanatory variables in *ad hoc* models of sawnwood and panel demand may be arrived at in several ways. It may be based on observations of the behavior of users of sawnwood and panels through, for example, interviews of builders or manufacturers. A defect of the interview approach is that the concepts of demand schedules and demand shifters will be alien to most users. Thus, it is difficult for an analyst to interpret and collate statements made by these users. Results of interviews may, however, significantly contribute to an analyst's general understanding of the demand process.

Alternatively, choice of explanatory variables in *ad hoc* models may be based on the intuitive judgment of the analyst. This may be an appropriate approach when the investigator has a good understanding of the industry being studied. However, care must be taken to ensure that the explanatory variables chosen in this way are, in fact, valid demand shifters. For example, one might decide on an intuitive basis that the average cost of an input, such as the average labor cost per unit of output, in a lumber-using process would be an appropriate demand shifter. Data might then be collected on average labor cost per unit of output and used in an empirical analysis. This may be a mistake for two reasons. In the first place, economic theory tells us that the correct shifter is the unit price of the input (in this case the wage rate), not the average cost per unit of output, because changes in the average cost for the input may represent movement along cost curves rather than shifts in these curves. Second, data on average input cost per unit of output are often difficult and expensive to obtain, whereas unit prices of inputs are usually obtainable from published sources.

Econometric models specified using theory generally avoid the pitfalls just described, but the simple theoretical specification must be modified on the basis of the analyst's knowledge of the industry in question. Because estimation of demand schedules rather than the forecasting of price and consumption is being considered here, econometric models will be ***structural*** rather than ***reduced-form*** in nature. However, some theoretical (structural) demand schedules for sawnwood and panels may be referred to as "partially reduced form" if they incorporate shifters, such as income and population, derived from higher level demand relationships.

Most studies of sawnwood and panel demand, whether based on theoretically specified econometric models or on *ad hoc* models, will use time-series data, because the principal objective is to estimate relationships for a single country or region. The advantage of a single-region or single-country study is that a detailed understanding of the particular demand situation may be developed and the model specifically tailored to fit it. On the other hand, cross-section or combined cross-section/time-series analysis may be necessary when intercountry comparisons are desired or when there are insufficient time-series data.

Studies of sawnwood and panel demand may be classified as long term if they use annual data, short term if they use monthly or quarterly data, and very short term if based on the use of weekly data. Other lengths of observation period are generally not useful or empirically feasible. The length of observation period depends on the objectives of the study. Results based on weekly, monthly, or quarterly data are usually of greatest interest to persons engaged in the manufacturing and marketing of wood products. Long-term studies are of value primarily in investment planning for the forest industries (including both timber growing and the design of manufacturing facilities) and in the formation of national and regional forest policies.

12.2.2. Data needs

The most effective and complete estimation model, in most instances, is one that has been specified on the basis of theory and uses the level of output of the industry demanding sawnwood or panels as a major shifter. A model specified in this way requires the following data:

(1) Current and past consumption of the sawnwood or panel product.
(2) Current and past prices of the product.
(3) Current and past prices of inputs in the demanding industry, including labor wage rates in construction, the price of competing or

complementary materials (such as concrete, plastics, or steel), and the unit price of energy used in manufacturing.

(4) Level of output of the demanding industry, such as construction or manufacturing.

These are the data needs of a basic model that has not yet been modified to represent the complexities of reality or the availability of information. Information on product price and consumption may need to reflect imports of the product or its close substitutes. The definition of the product can be broadened to include imported wood products of a similar nature; or, imported sawnwood and panels can be treated as competing products and represented by their import price in the demand function. In this case a separate demand function might be estimated for the imported, competing commodity.

Price information for both the product and inputs may be available in index form or in monetary units. In either case, the analyst must decide whether to deflate these data and whether to use an all-commodity consumer price index or producer price index, or an implicit GNP deflator. Available price data will frequently be free on board (FOB) mill. In such cases, deflating by the all-commodity producer price index is appropriate. Theoretically, if a model is completely specified, it should make no difference to the econometric results if prices and other monetary variables are deflated or undeflated. Experience suggests, however, that "deflated" models tend to yield more meaningful results in terms of *a priori* correct signs on coefficients.

A decision must also be made on the type of information to use for the level of output of the demanding industry. Data on construction activity may be available either in value terms or in physical units. If wood use per unit of floor space varies significantly between types of structures it may be desirable to disaggregate any measure of construction output. For example, it may be preferable to separate residential and nonresidential construction, or even to disaggregate residential construction into single- and multiple-family dwellings. Information on the level of output of manufacturing or other demanding industries may be represented by an index of industrial production or by value of output by sector.

12.2.3. Estimation techniques

Demand equations for sawnwood and panels are generally part of a larger system of demand and supply relationships. In many cases there are more than one current endogenous variable in each equation, which requires the use of estimation techniques other than ordinary least squares, unless the system is recursive in nature (Johnston, 1972). A demand equation for sawnwood, for instance, may have on the right-hand side the prices of sawnwood, steel, concrete, and wood-based panels, in addition to various other demand shifters. In most studies oriented toward wood products steel and concrete prices are treated as exogenous, but proper estimation requires that sawnwood and panel prices be treated as endogenous.

As noted above, quantity of sawnwood or panels demanded will depend on "own price", both current and lagged. The lag structure is not likely to be simple. If it is represented by numerous, individual lagged terms there will be a loss of degrees of freedom and an increase in multicollinearity. One alternative is to utilize the lagged value of the dependent variable (consumption) in a partial-adjustment, adaptive expectation or Koyck-lag formulation (Maddala, 1977). Alternatively, one may include only a single "own price" term, such as current price, and recognize that its estimated coefficient, due to omission-of-variable bias, may represent the effects of both lagged and unlagged prices (Rao and Miller, 1971). If the lagged value of the dependent variable is used as an explanatory variable and serial correlation exists, iterative estimation techniques may be necessary to avoid inconsistency (Maddala, 1977).

12.3. Review of Studies of Sawnwood and Panel Demand

In this review, studies are characterized, first, by the length of observation period (year, quarter, or month), second, by the type of product (sawnwood, plywood, or other panel products), and, third, by the econometric character of the model.

12.3.1. Annual models

Eight models are described below in approximate chronological order.

The McKillop (1967) study estimated demand relationships over the 1929–1960 period for lumber and plywood in the US as part of a larger system, including supply and demand relationships for lumber, plywood, paper, paperboard, and building paper and board. Models were specified on the basis of theory and knowledge of the forest industries. Sawnwood and plywood demand relationships included the value of construction in the US, wages in construction, index of manufacturing production, freight rates, and the ratio of past lumber or plywood prices to past prices of other building materials. The estimation technique was two-stage, least-squares.

Adams and Blackwell (1973) used 1949–1969 data to estimate US lumber and plywood demand in what they described as a combined "industrial process and market" model. The quantity of plywood demanded for use in construction was expressed as a function of total US housing starts and the ratio of past plywood prices to past lumber prices. Demand for plywood in other uses was expressed as a function of a "link" variable and the ratio of its past price to that of a weighted average price of substitutes. The "link" variable (a "weighted average of GNP originating in all industries except lumber and wood products and construction") was obtained by using the 1958 US input–output table. The single demand equation for lumber also used this link variable, together with housing starts, the percentage of starts in one- and two-family dwellings, and the ratio of past lumber prices to past plywood prices. Because their model was recursive (possessing a triangular coefficient matrix), Adams and Blackwell used ordinary least-squares.

Mills and Manthy (1974) concentrated on Douglas fir, Southern pine, and "structural species" of softwood lumber. They estimated two types of demand and supply relationships, referring to them as "primary" and "secondary". The major shifters in their primary demand equation were value of construction (residential, nonresidential, and upkeep and repair), dwelling starts, and percentage of starts with more than three units per structure. "Own" price was the only price variable in each equation. The "secondary" demand equations used, in place of direct measures of construction activity, mortgage rates and proxies for rates of family formation. Prices of other materials (steel and plywood) also appeared in secondary demand equations. Relationships were estimated using two-stage least-squares and data for the period 1947–1970.

Robinson (1974) used 1947–1967 data and two-stage least-squares to estimate an econometric model of Douglas fir and Southern pine lumber and stumpage markets. The total quantity of Douglas fir lumber demanded was expressed as a function of the real price of Douglas fir, the real price of Southern pine, freight rates for Douglas fir, the real value of residential construction per dwelling unit, and the number of dwelling units (including mobile homes). Robinson also used the US/Canadian rate of exchange as a demand shifter, in contrast to McKillop (1967) who included it in supply relationships. In addition, a quasi-demand function that explained the quantity of Douglas fir consumed per dwelling unit was also estimated, but a demand equation for Southern pine lumber was not presented. A preliminary model resulted in a positive coefficient for own price, and although it was not significantly different from zero, Robinson chose to represent the Southern pine lumber market by a relationship that expressed real price as a function of the real price of Southern pine stumpage, the production of Southern pine lumber, and the productivity in Southern pine sawmills.

Berck (1978) estimated demand equations for lumber and plywood for each of six regions within the US using 1954–1974 data in logarithmic form. The plywood equations expressed quantity demanded as a function of the output of construction and home furnishings, and the prices of plywood and lumber relative to the average hourly earnings of production workers.

Schuler (1978a,b) used two-stage least-squares to estimate supply and demand for insulation board (1978a) and hardboard (1978b) in the US, using 1950–1974 data and 1950–1977 data, respectively. The quantity of insulation board demanded depended on its price, housing starts, residential improvements, and disposable income. Explanatory variables in the hardboard demand equation were of the same type, except for the addition of the price of hardwood plywood.

Buongiorno *et al.* (1979) estimated income and price elasticities of demand for sawnwood and wood-based panels using 1963–1973 data from 43 countries in a combined cross-section/time-series analysis. Two types of model were estimated; both used per capita consumption as the dependent variable and a double-logarithmic form. The "static" model used per capita income, price, and a country-specific dummy variable as explanatory variables. Analysis of covariance (ordinary least-squares) was used to estimate this model on the premise that prices were exogenous, since unit values of imports and exports were used. The "dynamic" model included lagged per capita consumption in addition to the three explanatory variables in the static model. It was estimated using generalized least-squares.

As part of a study examining competition between wood products and substitute materials, McKillop *et al.* (1980) used two-stage least-squares to estimate demand functions for softwood lumber and plywood in the US. The quantity of softwood plywood demanded was regressed on the total US housing starts, the index of industrial production, and the hourly wage of carpenters, and plywood and building board prices lagged by one year. A type of distributed lag was used for the prices of softwood lumber, steel, aluminum, and plywood in the softwood lumber demand equation. Other explanatory variables in the lumber relationship were the total housing starts, the percentage of starts in one- or two-family units, the index of industrial production, and the lagged wages of carpenters.

Adams and Haynes (1980) in their Timber Assessment Market Model (TAMM) did not utilize a conventional, econometric approach to deal with regional demand for softwood. Regional elasticities of demand were derived from an estimate of elasticity for the US as a whole by assuming that the "ratio of regional elasticities to the national elasticity is the same as the ratio of regional to national prices." Regional estimates of elasticities for plywood were obtained by regressing the quantity demanded on regional price and regional *per capita* personal income.

The Data Resources Inc. "FORSIM" model consists of an "accounting" equation and a "use factor" equation, which relate to "end-uses" for lumber and panel products (Cardellichio and Veltkamp, 1981). End-use activities are defined as single family and multifamily housing starts, non-residential construction, index of industrial production, etc. Use factors are the amount of a wood product used per unit of each end-use activity. Use factor equations use the following explanatory variables: time trend, price of the wood product relative to major substitutes, and price of the wood product relative to "either the overall price level or relative to the price of the end-product for which wood is used." Cardellichio and Binkley (1984) also employed an end-use approach in their modeling of the demand for hardwood lumber.

The USDA Forest Service, in its various "timber outlook" studies, has traditionally used an end-use approach to forecast wood products consumption. In its 1982 report (USDA Forest Service, 1982), it combines this approach with the results of the TAMM model (Adams and Haynes, 1980). The end-use approach is not designed to estimate demand functions (price/quantity relationships) *per se*, but, by computer simulation or other means, it can be used to trace the effect of a price change on the quantity demanded and thus yield estimates of demand elasticities.

One reason for utilizing an end-use approach in studying demand for wood products is to decrease the chance of structural change in econometric models. Spelter's (1984) use of the diffusion theory of market penetration in models of softwood plywood and particle board demand was also motivated by concern over the possibility of structural change. Plywood use-factor equations were estimated for a range of end-uses using nonlinear, least-squares and, primarily, a Gompertz functional form. Lumber, particle board, styrofoam, and structural particle board prices were used to represent the effect of competitive materials over the periods 1948–1981, 1956–1981, 1973–1981, and 1976–1981, respectively.

Luppold (1984) used data for 1960–1979 to construct an econometric model for US hardwood lumber. The quantity demanded was expressed as a function of the lagged rates of interest, a time trend, the lagged prices of hardwood lumber, wood furniture, and hardboard, and the lagged wage rates in the furniture industry. A price equation was estimated in addition to a demand and supply equation. It expressed price as a function of lagged price, lagged quantity demanded, lagged mill stocks, and dummy variables representing an increase in exports after 1972.

McKillop (1984) constructed an eight-equation econometric model to estimate demand and supply elasticities for upper and common grades of Douglas fir and hemlock lumber. Exogenous demand shifters were the total

US housing starts, the proportion of starts in one- or two-family structures, and the Federal Reserve Board index of industrial production. Endogenous demand shifters were the price of hemlock uppers (or commons) in the Douglas fir uppers (or commons) demand equation, and vice versa.

The FAO study by Baudin and Lundberg (1984) was a pooled, cross-sectional, time series study, using annual data from 196 countries for the period 1966–1981 [11]. Products studied were sawnwood and panels, with the quantity measured by apparent consumption (production less exports plus imports). Product price was measured by the unit export value (for net exporters) or the unit import value (for net importers) and converted into a real price in 1975 US$. Information on these variables was taken from the *FAO Yearbook of Forest Products* (FAO, 1983). Several demand models were calculated, most of them with price, GNP, population, and/or value-added in construction as independent variables. In some models time and country-specific dummies were added. The technique used was ordinary least-squares regression.

The ECE/FAO study by Lundback (1984) took a somewhat different approach and was more a study of factor demand than one of consumer demand. The demands for sawnwood and panels were linked to an activity index, which was constructed by weighting the output of industries with the highest wood consumption. Lundback also adjusted this index to account for differences between countries, and the demand functions included the prices of competing materials.

The Swedish demand for sawnwood 1950–1980 was the subject of a study by Carlen and Wiberg (1983). They used as explanatory variables the relative prices of wood and brick, the number of self-contained houses, and the number of blocks of flats. They also tested models using the lagged values of these nonprice variables.

Three additional IIASA studies, discussed below, all calculate input–output coefficients using prices as explanatory variables [see equation (12.10)]. They all used the same data base (the Canadian I–O matrices for 1961–1978). The level of output in the wood-consuming industries was not determined.

The study by Andersson (1984) used a CES (constant elasticities of substitution) cost function, which was estimated using ordinary least-squares regression. A generalized Leontief cost function was used by Andersson *et al.* (1984) in an analysis using the SURE (seemingly unrelated regression) method. In Brännlund *et al.* (1984) forecasts of wood input coefficients were made based on different assumptions of price developments up to 1990.

12.3.2. Quarterly models

In an analysis of Japanese–North American trade in forest products, McKillop (1973) used quarterly data for 1950–1970 to estimate Japanese demand for US and Canadian lumber. The quantity of US lumber demanded was estimated as a function of residential construction in Japan, the index of manufacturing production in Japan, the price of Canadian lumber shipped to Japan, the price of Philippine wood imports to Japan, and stocks of lumber in Japan. The quantity of Canadian lumber demanded by Japan was explained by residential construction, the price of domestic Japanese cedar lumber, and stocks of lumber. Because of the quarterly observation period, many endogenous variables appeared in lagged form. This permitted the use of ordinary least-squares, although two-stage least-squares was employed for those equations in which current endogenous variables appeared on the right-hand side.

Adams (1974) estimated lumber and plywood demand equations as part of an econometric model that focused on the effect of National Forest timber supply in the Douglas-fir region. New orders for lumber were estimated as a function of the current and lagged price of lumber, lagged lumber shipments, current and lagged number of housing starts, and seasonal adjustment variables. The variables in the plywood demand equation were similar, except that the value of all new construction was used in place of residential construction. Two-stage least-squares and 1961–1970 data were used to estimate the relationships.

12.3.3. Monthly models

The role of lagged variables and seasonal adjustment variables becomes increasingly important as the length of observation period decreases. McKillop (1969), in his study of the short-term market for redwood lumber, expressed new orders as a function of the price of redwood lumber, the price of cedar lumber, and housing starts. Each of the explanatory variables were lagged by three or four months. In addition, a seasonal index of new orders was used to represent institutionalized patterns of new orders. The recursive nature of the econometric model permitted its estimation by ordinary least-squares. Data covered the period 1957–1964.

Buongiorno *et al.* (1979) analyzed monthly imports of softwood lumber to the US using 1965–1978 data. Ordinary least-squares with logarithmic transformation of variables were used to compare a number of alternative models. The quantity of imports was the dependent variable in each, alternative import-demand equation. Various combinations and transformations of housing starts, import price, and domestic lumber prices were used as explanatory variables. Two models utilized the lagged value of imports as an explanatory variable.

Rockel and Buongiorno (1982) used 1968–1977 data to analyze the derived demand for softwood lumber, plywood, hardboard, and particle board in residential construction in the US. A cost function (corresponding to a generalized Cobb–Douglas production function) was estimated using ordinary least-squares and factor demand equations were obtained from it using Shephard's lemma. Explanatory variables of the cost function were housing starts, time, price indexes of softwood lumber, particle board, hardboard and other materials, and wages in construction.

Chou and Buongiorno (1983) estimated own-price and cross-price elasticities of US demand for imported hardwood plywood using monthly imports from five principal sources for the 1974–1979 period. A model with constant elasticity of substitution between sources and an Almon-type lag in prices was estimated using a modification of Zellner's SURE method (Maddala, 1977). Total US demand for hardwood plywood imports was formulated as a function of US housing starts and the relative import price. The effect of a change in price from a particular source was decomposed into a market expansion (contraction) effect and a substitution effect.

12.4. Demand Analysis in Perspective

Theoretically based econometric models that utilize information on relevant demand shifters represents the most fruitful type of demand analysis for sawnwood and panels, although they may have to be modified by the inclusion of use-factors and other information when there is a danger of significant structural change. A major element of demand models that deserves fuller investigation is the dynamics of substitution and technological adaptation. To date this aspect has been studied mainly through empirical analyses of different forms of lag structures for the prices of wood products and competing materials. Significant opportunities appear to exist for the adaptation of conventional demand theory to the specific dynamic processes that characterize markets for sawnwood and panels.

Our review of the literature reveals a substantial lack of *European* studies. Furthermore, those that do exist are very limited from a methodological point of view. Essentially, all the quantity studies use traditional, consumer demand models and none has tested fully the factor demand approach. One obvious suggestion is to study the European situation using a greater variety of models. More specifically, we believe that factor demand models and combined factor and consumer demand models should be tried. We believe that the great dispersion of prices and cultural habits in Europe, as compared with North America, might yield interesting insights into the factors behind the demand for wood and wood products.

We must also point to the lack of demand studies for developing countries. Since these economies have large, unfilled needs for housing and industrial buildings, we believe that they will constitute important markets for wood products in the future. Detailed investigation of the demand in these countries will, therefore, be of great value.

There is also a need for in-depth research into the relationships between the level of the rate of interest and the demand for sawnwood and panels. This relationship has been studied in a number of US models, but nevertheless we feel that more detailed knowledge is required. These studies are, of course, of greater urgency if the present situation, with high, real interest rates, continues.

Finally, we would like to stress the importance of increased, detailed research on the substitution process and the sensitivity of wood demand to changes in the prices of competing products. In particular, we would like to point out the need for a future-oriented study on the use of wood as building material.

Notes

[1] Individual incomes are transformed into per capita income in aggregate demand studies.

[2] Lancaster's approach has, however, been used in empirical demand studies for recreation, transportation, housing, automobiles, etc.

[3] See Rogers (1962) and Stapleton (1976). For a general discussion of market penetration models, see Kotler (1971).

[4] We assume that the product is a nondurable good and that sales is a flow variable. The exact curve for total sales will, of course, follow a normal cumulative distribution function. But such a curve has a typical logistic shape and can be approximated by the simple equation for a logistic curve.

[5] For a discussion on the modeling of cost and production relations for forest models, see Chapter 6.

[6] A homothetic function can be written as a monotonic transformation of a function homogeneous of degree 1 in the inputs (Whitaker and McCallum, 1971).

[7] In forestry literature this approach has come to be called the "use factor approach". It is described in Cardellichio and Binkley (1984).

[8] Of course, time can be a poor proxy for technical change. Time proceeds at a steady rate, technical progress does not.

[9] Normally, final consumption also includes investment and export. Final use is therefore a more exact description of the concept.

[10] For a more detailed description of I–O demand modeling, see Barna (1954) or Cameron (1968).

[11] In addition to the studies mentioned here there also exist some older FAO/ECE-related analyses, namely, FAO/ECE (1964, 1969). FAO/ECE also regularly produce expert studies on future consumption in the OECD area. These studies are published in the *Supplement to Timber Bulletin for Europe*. Although not discussed here, they, of course, provide a valuable source of statistics and expert judgments on the consumption of sawnwood and panels.

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CHAPTER 13

Demand for Paper and Board: Estimation of Parameters for Global Models

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Until the mid-1970s forecasting world paper and board consumption was relatively easy: there was a steady growth in the world economy, which drove paper consumption to new, record levels year after year. Neither real prices of paper and board nor demand shifters, other than income, changed. Consequently, it was possible to use simple forecasting models with economic development and time trend as the only explanatory variables.

The first oil crisis and its consequences badly disturbed this steady development. After 1974 the whole world economy suffered a long-lasting recession and many industries had serious difficulties coping with the new economic situation. The effects on world paper and board markets were also strong: the main consequences for the whole paper industry were stagnation for several years, large demand fluctuations independent from economic development, rapid real price increases, and an accelerated restructuring process.

With the slow-down of economic growth, the use of GDP as the only explanatory variable for paper consumption no longer produced satisfactory results. There was a growing interest among researchers to introduce more explanatory variables, especially prices of paper and board and prices of substitutes, into consumption models.

In this chapter we present some estimation results for paper and board consumption functions, with special emphasis on the long-term price and income elasticities of demand. The results described here are based largely on practical forecasting work in a forest industry consulting company, Jaakko Põyry. Data problems related to elasticity measurement are discussed and estimation results compared with those from consumption studies by other researchers. Attention is also paid to the dynamic aspects of elasticities, i.e., to changes in the numerical values of elasticities over time and income level, as well as to their variation across countries and different paper grades.

13.1. Models Used for Estimating Income and Price Elasticities of Demand

Most of the recent, international, long-term consumption studies of the pulp and paper sector have been based on pooling cross-sectional and time-series data instead of using the traditional country-by-country time-series analysis. As Buongiorno (1978) has stated, pooling alleviates problems posed by short time-series, small variability in the data, and high collinearity between explanatory variables measured in value terms.

Both static and dynamic models have been used for estimating consumption functions. One of the most important static functions, widely used in general demand studies, is (Houthakker, 1965):

$$C_{ijt} = A_j \, Y_{it}^{b_j} \, P_{ijt}^{c_j} \, P_{ijt}'^{d_j} \, \epsilon_{ijt} \tag{13.1}$$

where i, j, and t refer to a specific country, product, and year, respectively, C is consumption per capita, Y is income (or GDP) per capita, P is the price of the product in question, and P' is the price of the most direct substitute.

A dynamic version of model (13.1), based on Nerlove's (1958) partial adjustment model, is:

$$C_{ijt} = A_j \, C_{ij,t-1}^{\lambda_j} \, Y_{it}^{b_j} \, P_{ijt}^{c_j} \, P_{ijt}'^{d_j} \, \epsilon_{ijt} \tag{13.2}$$

where the only difference to equation (13.1) is the introduction of a lagged, dependent variable $C_{ij,t-1}$ (the consumption in the previous year) into the model. The quantity demanded in period t depends on, among other things, the quantity demanded in previous periods; this is due to a habit-formation process that is characteristic of human behavior (Houthakker and Taylor, 1966). In the case of paper and board, the habitual nature of consumption is evident (Åberg, 1968).

Nerlove's dynamic theory allows a distinction between short-term and long-term demand elasticities (Nerlove and Addison, 1958). Nerlove postulates that equation (13.1) represents, in fact, the long-term demand if demand is adjusted immediately to changes in explanatory variables:

$$\log C^*_{ijt} = a_j + b_j \log Y_{it} + c_j \log P_{ijt} + d_j \log P'_{ijt} + \epsilon_{ijt} \tag{13.3}$$

where C^*_{ijt} is the long-term equilibrium of consumption, which would be observed if all explanatory variables remained at a fixed level for a sufficiently long time. Since Y_{it}, P_{ijt}, and P'_{ijt} change continuously, C^*_{ijt} is never observed. To measure the ratio between C_{ijt} and C^*_{ijt}, the hypothesis used is that the ratio (C^*_{ijt}/C_{ijt}) is closer to unity than the ratio $(C^*_{ijt}/C_{ij,t-1})$, because there tends to be greater coincidence between short- and long-term demand in year t than between short- and long-term demand in successive years (Nerlove and Addison, 1958; see also Koutsoyiannis, 1973). This implies that:

$$\frac{C^*_{ijt}}{C_{ijt}} = \left[\frac{C^*_{ijt}}{C^\lambda_{ij,t-1}}\right]^\lambda \qquad 0 < \lambda < 1 \tag{13.4}$$

where λ measures the velocity of adjustment to demand rigidities. By substituting equation (13.4) into equation (13.3):

$$C^*_{ijt} = \left[\frac{C_{ijt}}{C^\lambda_{ij,t-1}}\right]^{1/(1-\lambda)} = a_j\, Y_{it}^{b_j}\, P_{ijt}^{c_j}\, P'^{\,d_j}_{ijt}\, \epsilon_{ijt} \tag{13.5}$$

so that

$$C_{ijt} = a_j^{(1-\lambda)}\, Y_{it}^{b_j(1-\lambda)}\, P_{ijt}^{c_j(1-\lambda)}\, P'^{\,d_j(1-\lambda)}_{ijt}\, C^\lambda_{ij,t-1}\, \epsilon_{ijt} \tag{13.6}$$

or

$$C_{ijt} = A_j\, Y_{it}^{B_j}\, P_{ijt}^{C_j}\, P'^{\,D_j}_{ijt}\, C^\lambda_{ij,t-1}\, \epsilon_{ijt} \tag{13.7}$$

we obtain the short-term consumption function, from which it is possible to estimate both the short- and long-term elasticities by computing from the regression and of the relationships:

$$b_j = \frac{B_j}{1-\lambda} \qquad c_j = \frac{C_j}{1-\lambda} \qquad d_j = \frac{D_j}{1-\lambda} \qquad 0 < \lambda < 1$$

where capitals refer to short-term elasticities and lower case to long-term elasticities. The closer λ is to unity the faster the velocity of adjustment, the static model being an ultimate case where the adjustment of consumption is completed in one year $(\lambda = 1)$.

In several international studies either a static, equation (13.1), or a dynamic, equation (13.2), model, or both, has been used for estimating forest products consumption functions (with or without some modifications); for example, among others, those by Buongiorno (1977, 1978, 1979), FAO (1977), Baudin and Lundberg (1984), and Suhonen (1984). In the FAO (1977) study, an additional explanatory variable, literacy rate L_{it}, was introduced into the static consumption model for newsprint and printing and writing papers in the developing countries, the model thus being:

$$C_{ijt} = a_j \, Y_{it}^{b_j} \, P_{ijt}^{c_j} \, P_{ijt}'^{d_j} \, L_{it}^{e_j} \, \epsilon_{ijt} \tag{13.8}$$

In his work, Wibe (1984) used a simplified "dynamic" function in which time, T, was used to represent (as a yearly index) substitution effects over time:

$$C_{ijt} = A_j e^{\alpha_j T} \, Y_{it}^{b_j} \, P_{ijt}^{c_j} \, \epsilon_{ijt} \tag{13.9}$$

where T is time measured in years and α_j is interpreted as the yearly rate of substitution for forest products.

In several earlier studies of paper demand, income (or GDP/capita) was the only explanatory variable in the cross-sectional consumption models (e.g., FAO, 1960, 1963a,b; Sundelin, 1970, 1976). The relationship between paper consumption and income per capita in these models was assumed to be an S-shaped curve based on Engel's law of diminishing marginal utility with increasing income.

13.2. Data Problems Facing Elasticity Measurement

When using international data for cross-sectional or pooled cross-sectional and time-series analysis, there arise some data problems that may have a drastic effect on the estimation of results. These problems include, among others:

(1) Availability of valid and reliable price data directly comparable with similar data series from other countries.
(2) Choice of an appropriate deflation method for all value data.
(3) Exchange rate variation when converting value data from national currencies into a common currency.

Availability of suitable price data is a problem because value data on domestic consumption are normally not available. The *FAO Yearbook* statistics include only import and export values of commodities traded internationally. Recent efforts by FAO to collect domestic price series for forest products have yielded relatively short time series for a few countries, with varying product classification. Only a few developed countries systematically publish domestic price series for specific paper and board grades. For building a global model, the contribution of these price series is insufficient. Therefore, the most suitable available information on price levels for many countries is the unit value of imports or exports. FAO (1977) and Buongiorno (1978) used average export (free on board, FOB) values for net exporting countries and average import (cost, insurance, and freight, CIF) values for net importing countries. This approximation seems justified for countries that are either major importers or major exporters of paper and board grades. Problems arise when imported or exported quantities are small and/or there are clear quality/grade differences in comparison with domestic consumption, i.e., export or import prices do not represent the average prices of domestic consumption of a certain product group. Fortunately, this heterogeneity has serious effects only for a few countries and products; in many cases domestic prices closely follow world market prices, with allowance for differences in transportation and other trading costs. Buongiorno (1978) made a comparison between wholesale domestic price and unit values of foreign trade of newsprint for five countries, resulting in correlation coefficients that varied from 0.90 (FRG) to 0.99 (US). However, this does not hold for all countries and products. Before any statistical analysis the unit value data series should be checked and distorted price series replaced by domestic price estimates.

Deflation of value data should always be done using national deflators and national currencies. FAO unit-value data are directly expressed in current US dollars. These figures include both the US inflation and changes in exchange rates. Consumption is more a function of *real income* and *real prices* than a function of *money income* and *nominal prices*, because the consumer can maximize his or her utility function only in respect of real commodities and then one has to adjust the unit-value series with respect to US inflation. In some studies (e.g., FAO, 1977; Wibe, 1984; Suhonen, 1984) the prices in current US dollars have simply been divided by the US wholesale price index, which closely follows the index of export prices of manufactured goods. Then it is assumed that changes in official exchange rates sufficiently reflect differences in cost developments between the US and other countries. Some researchers have used US nominal prices as such, without deflating them at all (see, e.g., Buongiorno, 1978). In these cases it is possible that the numerical values of the estimated elasticities are distorted by the likely correlation between price and time (or inflation).

Exchange rate variations cause comparability problems between countries. As stated in an earlier paper (Uutela, 1983), the choice of base year and currency used in cross-sectional studies may affect rankings between countries with respect to GDP per capita and product prices. It has been shown that when using the same per capita income and per capita paper consumption data — but base year 1978 instead of 1970 for the US dollar exchange rate for GDP figures — the country rankings change and the variation in the data increases, thus reducing the overall fit of the cross-sectional model remarkably (JPI, 1982). Large fluctuations in the value of the US dollar since the beginning of the period of flexible exchange rates in the early 1970s render it difficult to make reliable comparisons of purchasing power and commodity prices over time and between different countries.

Practical experience has shown that when using the same data and time period, but different deflators and exchange rate manipulations, one numerical value of elasticity parameters can vary heavily (e.g., income elasticity from 1.0 to 1.6, own-price elasticity from −0.15 to −0.40; see Uutela, 1984). Therefore, it seems that more attention should be paid to data preparation work before elasticity estimation. The following comments can be made:

(1) Domestic deflators should be preferred to common deflators, because change in exchange rates may not strictly follow different cost developments between countries.

(2) Exchange rate variations should be excluded from the price series if most of consumption is domestically produced and domestic pricing is not affected by foreign currencies. If the bulk is imported, it would be logical to include exchange rate changes, which affect world market prices, in the price series that is to be used.

13.3. Some Experiences from Work Done at a Consulting Company

Until the mid-1970s, there was little interest in studying the effects of price changes on paper and board consumption because:

(1) Real prices did not change much from the early 1950s up to 1973.
(2) In contrast to many other industrial products, paper and board do not have suitable or acceptable substitutes at a low price (FAO, 1977).
(3) Paper and board are complementary products whose share of the total price of products to which they are related is very small and, therefore, even large price increases do not much affect their consumption (USDA Forest Service, 1973).
(4) Price variables include short-term variation, which can reduce even the coefficient of determination in long-term consumption models (FAO, 1960).
(5) The consumption of paper and board is habitual and thus the effects of price movements are weak (Åberg, 1968).
(6) The use of price as an exogenous variable in a practical forecasting situation requires that reliable price forecasts be available; forecasting price developments may be even more difficult than forecasting future demand levels.

Rapid increases in real prices of paper and board in 1973–1977 caused a growing interest in the study of their effects on consumption, which led to studies (FAO, 1977; Buongiorno, 1978) in which price parameters had values that significantly differed from zero. However, in the late 1970s real prices began to decline again, more or less returning to the same development path as before the oil crisis. Therefore, Jaakko Pöyry Companies suggested a study (Suhonen, 1984) of the importance of price variables in consumption models by using data material that also included the latest price developments.

13.3.1. Data and models used

The models used were of types (13.1) and (13.2). By using a stepwise regression procedure, it was possible to study the effects of the introduction of a lagged, endogenous variable on the statistical properties of the consumption model. Separate models were constructed for newsprint, printing and writing papers, wrapping and packaging papers, as well as for sack paper. Substitute prices used were printing and writing paper prices for newsprint and vice versa, and low-density polyethylene (LDPE) prices for wrapping and packaging papers and sack paper.

The data material included 40 countries and the years 1965–1980 for newsprint and printing and writing papers, and 14 countries and the years 1970–1980 for wrapping and packaging paper and sack paper. In the latter case the number of countries was limited by the availability of relevant price series for LDPE. Twenty-three of the 40 countries are developed countries and 17 are newly industrialized or developing ones. Data were collected mostly from Jaakko Pöyry's Forest Products Market and Price Data Banks, *FAO Yearbooks*, and LDPE series from several professional publications, national statistics, and earlier studies (e.g., UNIDO, 1981; SRI, 1981). GDP figures were deflated by national GDP deflators and converted into US dollars using the 1970 exchange rate. Prices were deflated by the US wholesale price index. No adjustments for fluctuating exchange rates were made.

All the models were estimated from pooled, cross-sectional, time-series data to broaden the variation range of observations. A dummy variable was set for each country to absorb the specific variation between countries that could not be explained by differences in income, prices, and prices of substitutes in past consumption. Therefore, the estimated model was:

$$\begin{aligned}\log C_{it} = {} & a + b \log C_{i,t-1} + c \log Y_{it} + d \log P_{it} \\ & + e \log P'_{it} + z_i \sum_{k=1}^{k-1} D_{ik} + \epsilon'\end{aligned} \tag{13.10}$$

where k refers to the number of countries for every product j in question. The numerical values of dummy variables measure how much a country deviates from the average level of estimates calculated from the pooled data.

Additionally, the data material was grouped, according to the level of GDP per capita in 1980 and the period of observation, into clusters to analyze whether elasticities varied systematically between different income classes and over time. A separate consumption model was built for the EEC region, which is composed of countries with relatively similar economic and cultural backgrounds.

13.3.2. Statistical tests used

In addition to the traditional calculation of adjusted coefficients of parameters and the Student's t-statistic, some other statistical tests were also made. Autocorrelations of residuals were tested using the Durbin–Watson statistic, calculated both from the original country-specific data and from data sorted into a rising order according to the GDP per capita. Homoscedasticity was tested with the help of the Goldfeld–Quandt test, based on splitting one regression residual into two subsamples, one with low and the other with high values of explanatory variable, and then calculating an F-ratio for the two variances (see Goldfeld and Quandt, 1965). Since the consumption models included a lagged endogenous variable, special attention was paid to detecting the consequences of possible multicollinearity in them. The approach adapted here was Frisch's confluence analysis (Frisch, 1934; see also Koutsoyiannis, 1973), based on the value $r_{x_i x_j}$:s, $\bar{R}^2$, and a stepwise procedure to study the effects of new variables on the values of the estimates of parameters and standard errors first introduced in the consumption models. The importance of differences between different data clusters (different time periods or different GDP per capita classes) was tested by using analysis of variance (F-test).

13.3.3. Estimation results

The results of the regression analyses and statistical tests for newsprint are presented in Appendix 13.1. Note that the coefficients Y_t, P_t, and P_t' refer to short-term elasticities. Based on Nerlove's partial adjustment theory (Nerlove, 1958), it was possible to calculate the long-term elasticities presented in *Table 13.1*. The coefficient of adjustment, λ, measures the velocity of adjustment. Although it is impossible to calculate the number of periods required for a complete adjustment (the function used is asymptotic with regard to time), it is possible to choose some arbitrary percentage of adjustment and calculate the number of periods required to achieve this, or to calculate the percentage of adjustment after a certain number of periods. According to Nerlove and Addison (1958), the number of periods, N, required for adjustment to within, e.g., 5% of the long-term equilibrium level may be determined by the formula:

$$(1 - \lambda)^N = 0.05 \tag{13.11}$$

where λ is the coefficient of adjustment (or 1 minus the coefficient of the C_{t-1} variable) and N is the number of periods required. This method was later been used by, among others, Yadav (1975) for calculating elasticities for the subsequent periods.

Table 13.1 Estimated long-term elasticities for newsprint (Suhonen, 1984).

	Long-term elasticities				*Percentage of*
Data group[a]	*Income*	*Own-price*	*Cross-price*	*Coefficient of adjustment* (λ)	*adjustment after 3 years* (%)
All data, 1965–1980	+0.84	-0.30	+0.06	0.64	95
Years 1965–1972	+1.13	-0.18	+0.03	0.77	99
Years 1973–1980	+1.04	-0.17	+0.11	0.84	100
GDP per capita, < US$ 1000	+1.02	-0.28	+0.09	0.58	92
GDP per capita, US$ 1000–3000	+1.19	-0.73	+0.02	0.36	74
GDP per capita, > US$ 3000	+0.59	-0.04	+0.01	0.71	98
EEC region	+0.75	-0.45	+0.36	0.57	92

[a] GDP per capita in 1980, measured in US$ at 1970 prices.

The estimated parameters for C_{t-1} and Y_t differed significantly from zero in all cases, even at the 0.99 confidence level. The own-price variable was important at the 0.90 confidence level in all the other cases, except for the income group GDP per capita > US$ 3000, whereas cross-price elasticity was important only for the years 1973–1980 and for the EEC region (see Appendix 13.1).

In general, income elasticity tended to decrease over time and with increasing GDP per capita, although the highest income elasticity was measured in the group GDP per capita US$ 1000–3000. Own-price elasticities varied between -0.04 (richest countries) and -0.73 (medium-income countries). The latter figure depends heavily on the low coefficient of adjustment (short-term elasticity is only -0.26), which indicates a strong dependency on past consumption (or the habitual nature of consumption) rather than a high price sensitivity. The EEC region, which predominantly imports newsprint, seems to be more price-sensitive than average.

The choice of the period for estimation affected the numerical values of estimates. Over the entire period 1965–1980 the price variable appears to have varied more than in 1965–1972 or 1973–1980. Correspondingly, the value of income elasticity for the complete data set was lower.

Printing and writing papers

The results for printing and writing papers are presented in Appendix 13.2, and the corresponding long-term elasticities in *Table 13.2*. The price variable used to represent prices of substitutes for printing and writing papers was the price of newsprint.

Table 13.2 Estimated long-term elasticities for printing and writing papers (Suhonen, 1984).

	Long-term elasticities			*Coefficient of adjustment*	*Percentage of adjustment after 3 years*
Data group[a]	*Income*	*Own-price*	*Cross-price*	(λ)	(%)
All data, 1965–1980	+1.52	-0.00	-0.14	0.61	94
Years 1965–1972	+1.25	-0.24	+0.53	0.62	95
Years 1973–1980	+1.31	+0.16	-0.27	0.79	99
GDP per capita, < US$ 1000	+1.47	+0.08	-0.15	0.62	95
GDP per capita, US$ 1000–3000	+1.42	-0.21	+0.08	0.52	89
GDP per capita, > US$ 3000	+1.43	-0.01	-0.18	0.87	100
EEC region	+1.56	+0.02	-0.11	0.75	98

[a] GDP per capita in 1980, measured in US$ at 1970 prices.

Again, the estimated parameters for lagged consumption and income were important in all the models. In contrast with this, own-price and substitute price received unexpected signs in several equations, and when they had the expected signs, the coefficients differed significantly from zero in only one case (years 1965–1972, see Appendix 13.2). One reason for this inelasticity may be found in the price series used. The breakthrough of coated printing paper grades, which have higher prices, made the internal grade structure of printing and writing papers in the 1970s more heterogeneous. The average price, and also the relative price, of printing and writing papers increased; meanwhile, consumption grew strongly due to advantageous developments in end uses and production technology (JP, 1984). Additionally, the use of newsprint price as a substitute for printing and writing paper was a somewhat arbitrary choice, made for the lack of better variables. Actually, newsprint and other printing papers compete strongly only in a few end uses.

The income elasticities measured were notably higher than for newsprint (between 1.25 and 1.56, compared with 0.59 to 1.19 for newsprint). There was no clear tendency in respect of GDP per capita or time; income elasticities were, in most cases, between 1.3 and 1.5, the highest numerical value being for the EEC region.

Since the values of own-price and cross-price elasticities were largely meaningless, the effects of multicollinearity were cautiously tested. With the help of Frisch's confluence analysis and a stepwise regression procedure it was noticed that multicollinearity did not affect the regressions; price elasticities did not change much regardless of the set of variables used in the regressions.

Wrapping and packaging papers and boards

The data material for wrapping and packaging papers and boards, as well as sack paper, were more concise than those for newsprint and printing and writing paper, consisting of 14 developed countries and 11 years. The estimation results are presented in Appendix 13.3 and the long-term elasticities in *Table 13.3*.

Table 13.3 Estimated long-term elasticities for wrapping and packaging papers and boards (Suhonen, 1984).

	Long-term elasticities			*Coefficient of adjustment*	*Percentage of adjustment after 3 years*
Data group[a]	*Income*	*Own-price*	*Cross-price*	(λ)	(%)
All data, 1970–1980	+0.62	-0.10	-0.03	0.71	98
Years 1970–1975	+0.93	-0.03	-0.16	0.53	90
Years 1976–1980	+0.82	+0.19	-0.09	0.65	96
GDP per capita, < US$ 3000	+1.27	-0.11	-0.32	0.57	92
GDP per capita, > US$ 3000	+0.28	-0.02	+0.05	0.81	99
EEC region	+0.62	-0.07	-0.18	0.71	98

[a] GDP per capita, measured in US$ at 1970 prices.

Lagged consumption and income were important variables in explaining consumption, except for the highest income group, whereas own-price and substitute-price variables were not important at all, having either wrong signs or too large a standard error (see Appendix 13.3).

The almost complete inelasticity of consumption to price changes may be a consequence of the low value of packaging materials in relation to the total value of the final products to be packed or to the total costs of the whole distribution system. No single variable could be found that unambiguously explained the complete substitution mechanism; prices of packaging materials may be of minor importance compared with, e.g., traditional packaging and/or the distribution system replaced by a new alternative system.

The use of the price of LDPE as a substitute price also has some disadvantages. First, the substitution effects of LDPE are limited to a number of products (mainly wrapping papers) only. In the case of carton boards, LDPE can even be considered as a complementary product, because boards used for packaging liquids are normally coated with LDPE. Second, technological development in the manufacture of shrink foils and other films from LDPE was not taken into account when constructing price series. Today it is possible to produce many times more plastic film from the same quantity of LDPE than it was in the early 1970s (Volpert, 1982).

Income elasticity for wrapping and packaging papers and boards behaved as expected; it decreased with increasing GDP per capita and also over time. Compared with cultural papers, the income elasticities were even somewhat lower than those measured for newsprint.

Sack paper

The results of regressions for sack paper are shown in Appendix 13.4 and the corresponding long-term elasticities in *Table 13.4*. It can be seen that in this case short-term and long-term elasticities were quite similar due to the high values of the coefficient of adjustment.

Table 13.4 Estimated long-term elasticities for sack paper (Suhonen, 1984).

	Long-term elasticities			*Coefficient of adjustment*	*Percentage of adjustment after 3 years*
Data group[a]	*Income*	*Own-price*	*Cross-price*	(λ)	(%)
All data, 1970–1980	+0.12	–0.46	+0.21	0.61	94
Years 1970–1975	+0.60	–0.36	+0.15	0.80	99
Years 1976–1980	+0.18	–0.26	+0.15	0.67	96
GDP per capita, < US$ 3000	+0.69	–0.53	+0.02	0.64	95
GDP per capita, > US$ 3000	–0.07	–0.26	+0.15	0.78	99
EEC region	–0.37	–0.56	+0.13	0.96	100

[a] GDP per capita, measured in US$ at 1970 prices.

In most cases the estimates of parameters for lagged consumption were significantly different from zero at the 0.90 confidence level. The price of LDPE has a positive sign in all equations, but the standard errors were too large to make it an important explanatory variable. Income elasticities for the highest income group and the EEC region were negative, indicating that sack paper has already passed the saturation phase of its life cycle and is thus an inferior commodity at high income levels.

Price elasticities varied between -0.26 and -0.56, which means that sack paper was the most price-sensitive of the four paper grades investigated here. It is also the bulkiest product of those studied here. Similarly to newsprint, the EEC region is a major importer of sack paper, and it has the most negative value.

13.4. Comparison of Results with Other Studies

There are not very many international studies that deal with elasticity measurement from paper consumption models. The studies referred to here include FAO (1960, 1977), Buongiorno (1978), and Wibe (1984), whose results are compared with the results of Suhonen (1984) discussed earlier. It should be remembered that strict comparisons between different studies may sometimes be confusing because of different sets of countries examined, different deflation methods and exchange rate manipulations, and different time periods of observation, as well as because of different explanatory variables used in the consumption models. From the perspective of global trade modeling it is, however, important to compile the existing results from earlier works for use as references when establishing relationships between consumption, prices, substitute prices, income, and other possible demand shifters.

13.4.1. Income elasticities

Income elasticities had already been measured in an early work by FAO (1960), where a clear tendency of decreasing income elasticities with increasing GDP/GNP per capita was found. Elasticities were measured by using time-series data of both individual countries and cross-sectional comparisons between countries from a model in which income per capita was the only explanatory variable. In a later study by FAO (1977) it was noted that for cultural papers the highest income elasticities were to be found in high- and medium-income countries, whereas for industrial paper grades they were found in the low- and very low-income countries. When price effects and literacy level were taken into account in the model, the income elasticities measured for developing countries drastically decreased.

A summary of income elasticities measured in different studies is presented in *Table 13.5.* For comparison, all GNP/GDP per capita figures were converted into constant US$ 1975 prices. It should be noted that the results from Buongiorno (1978) and Suhonen (1984) refer to long-term

Table 13.5 Comparison of income elasticities measured in different paper consumption studies.

			Income elasticity		
Study/ income group[a]	*Explanatory variables included in the model*	*Time period*	*Newsprint*	*Printing and writing papers*	*Other paper and board/ packaging paper and board*
FAO (1960)	Y_t	Before 1960			
GNP per capita,					
> US$ 3000			0.4–0.8	0.5–0.8	0.5–1.3
US$ 1500–3000			0.8–1.1	0.9–1.2	0.8–1.6
US$ 750–1500			1.1–1.5	1.2–1.6	1.1–2.0
< US$ 750			1.5–2.9	1.6–2.8	1.5–3.0
FAO (1977)	Y_t, P_t	1963–1973			
GDP per capita,					
> US$ 3000			0.7	1.4	1.0
US$ 1500–3000			0.5	1.5	1.4
US$ 700–1500			0.8	1.6	1.7
< US$ 700			0.7	0.7	1.7
Buongiorno (1978)	Y_t, C_{t-1}, P_t, P'_t (for cultural papers only)	1963–1973			
GDP per capita,					
Average			1.0	1.3	1.6
≥ US$ 2600			0.8	1.6	1.4
< US$ 2600			1.1	1.2	1.7
JP/Suhonen (1984)	Y_t, C_{t-1}, P_t, P'_t	1965–1980 (cultural papers)			
GDP per capita,					
Average			0.8	1.5	0.6
> US$ 4750		1970–1980 (other grades)	0.6	1.4	0.3
US$ 1600–4750			1.2	1.4	1.3
< US$ 1600			1.0	1.5	–
Wibe (1984)	Y_t, P_t, time	1970–1979			
GDP per capita,					
Average			1.2	1.2	1.2
> US$ 2500			0.9	1.3	1.1
US$ 600–2500			1.4	1.5	1.4
< US$ 600			1.4	1.4	1.1

[a] GNP/GDP at US$ 1975 prices.

elasticities, whereas the income elasticities of other studies are to be interpreted as short-term elasticities.

For newsprint and industrial grades, there seems to be a falling trend in income elasticity with rising income, whereas in the case of printing and writing papers the highest elasticities seem to be in medium- and high-income countries. It is also important to include price and/or other variables in the models for developing countries, otherwise the income variable absorbs variation, which, in fact, does not belong to it. These variables include the literacy rate used by FAO (1977) and a supply availability index, which was found to be an important explanatory variable first by Gregory (1966) and then, in a later study, by Uutela (1979).

There have also been discussions as to whether developing countries with increasing income will follow the same per capita consumption patterns as industrialized countries. In another study, Wibe (1983) argues that the developing countries do not follow the path set by the already industrialized nations, but have a lower consumption of paper products because of the availability of "new" technologies (e.g., radio, television, plastics, etc.). This was also the *a priori* expectation of a study by Uutela (1979). However, the results were not as expected, but showed instead that the countries that achieved a certain GDP per capita level in the 1970s consumed more paper and board per capita than those countries that had reached the same GDP level in the 1950s or 1960s. The interpretation of this surprising result may be that, although there are nowadays more substitutes for paper and board than, e.g., in the 1950s, there are, on the other hand, also many more end-use applications (and industries) for paper and board (e.g., computer printouts, consumer packages).

A summary of the different elasticities presented in *Table 13.5* and other experiences gained from practical work is given in *Table 13.6*. The assessment is partly subjective and applies only to countries with average economic, cultural, social, etc., conditions. In extreme cases the values of elasticities may considerably differ from those in *Table 13.6*. However, they may give the reader some indication of the magnitude of income elasticities in different product groups and income classes.

13.4.2. Own-price elasticities

Price elasticities tend to vary widely, depending on the product, country group, time period for measurement, and the way the price variable is valued. Therefore, the price elasticity estimates compiled in *Table 13.7* must be interpreted very carefully. FAO (1977) and Buongiorno (1978) concluded that in low-income countries, which normally also import most of their paper products, consumption is seriously affected by price increases. Suhonen (1984) found only very small correlations with income levels; the price variable was not significant at all for printing and writing papers and wrapping and packaging papers, and only slightly significant for newsprint and sack paper.

Table 13.6 Summary of the numerical values of income elasticities based on earlier studies and practical experience of forecasting work.

Income group[a]	*Newsprint*	*Printing and writing papers*	*Other paper and board/packaging paper and board*
High income (GDP per capita, > US$ 3000)	0.4–0.8	1.0–1.5	0.3–1.2
Medium income (GDP per capita, US$ 1500–3000)	0.6–1.2	1.2–1.8	1.0–1.6
Low income (GDP per capita, < US$ 1500)	0.7–1.5	0.7–1.5	1.4–2.0

[a] GDP per capita in 1980, measured in US$ at 1970 price.

Any conclusions as to the numerical level of the price elasticities in *Table 13.7* are difficult to make. However, newsprint seems to be the most price-sensitive and printing and writing paper may be the least price-sensitive product. The studies by FAO (1977) and Suhonen (1984), in which the same deflation method but different time periods were used, produced results of largely the same magnitude. Wibe's (1984) study resulted in the most negative price elasticities.

13.4.3. Cross-price elasticities

The results from the few paper consumption studies that include substitute prices as an explanatory variable are not very encouraging. In FAO's (1977) study even the sign of the cross-price elasticity was, contrary to the *a priori* expectation, being negative in most equations. Newsprint gives the best results; for industrial grades, there is only one international study known to the author that deals with substitute prices. The results from three studies are presented in *Table 13.8*. The prices of substitutes used in all three studies were printing and writing paper price for newsprint and vice versa, and LDPE price for packaging paper and board in the study by Suhonen (1984).

The poor results are partly explained by the choice of substitute variables. As discussed earlier in this chapter, prices of different materials as such may not be decisive factors for buying or consumption decisions for paper and board; there are many intervening variables, such as labor intensity and costs, flexibility of use, or product performance, which together determine the ranks between different alternatives. It is a question of

Table 13.7 Comparison of own-price elasticities measured in different paper consumption studies.

			Own-price elasticity		
Study/ income group[a]	*Explanatory variables included in the model*	*Time period*	*Newsprint*	*Printing and writing papers*	*Other paper and board/ packaging paper and board*
FAO (1977)	Y_t,P_t	1963–1973			
GNP per capita,					
> US$ 3000			-0.2	-0.3	-0.1
US$ 1500–3000			-0.3	+0.1	-0.1
US$ 750–1500			-0.5	-0.3	-0.3
< US$ 750			-0.8	-1.2	-0.7
Buongiorno (1978)	$Y_t,C_{t-1},$	1963–1973			
GDP per capita,	P_t,P_t'				
Average	(for cultural		-0.7	-0.5	-0.7
≥ US$ 2600	papers only)		-0.6	-0.2	-0.3
< US$ 2600			-0.8	-0.7	-0.8
JP/Suhonen (1984)	$Y_t,C_{t-1},$	1965–1980			
GDP per capita,	P_t,P_t'	(cultural			
Average		papers)	-0.3	-0.0	-0.1
> US$ 4750		1970–1980	-0.3	+0.1	-0.1
US$ 1600–4750		(other	-0.7	-0.2	-0.0
< US$ 1600		grades)	-0.0	-0.0	–
Wibe (1984)	$Y_t,P_t,$	1970–79			
GDP per capita,	time				
Average			-1.1	-0.8	-0.9
> US$ 2500			-2.6	-0.4	-1.3
US$ 600–2500			-0.7	-0.5	-0.3
< US$ 600			-0.6	-1.1	-1.4

[a] GNP/GDP at US$ 1975 prices.

system substitution rather than *product or price substitution*. For this reason, traditional price theory may not be able to explain paper and board consumption.

The effects of real substitutes for paper and board, such as new electronic information media or plastic-based packaging systems, are extremely difficult to quantify and include as explanatory variables in consumption models. There are hardly any statistics that could measure these relationships. Even the national input–output statistics normally have too rough a classification of products and industries for paper and board substitution analysis. The best applicable method might be a market research approach; it would require, product by product, a thorough analysis of the most important end-use sectors to understand their decision-making

Table 13.8 Comparison of cross-price elasticities measured in different paper consumption studies.

			Cross-price elasticity		
Study/ income group[a]	*Explanatory variables included in the model*	*Time period*	*Newsprint*	*Printing and writing papers*	*Other paper and board/ packaging paper and board*
FAO (1977)	Y_t, P_t	1963–1973			
GNP per capita,	P'_t,				
> US$ 3000	literacy rate		+01	-0.6	–
US$ 1500–3000			-0.0	-0.3	–
US$ 0750–1500			+0.3	-0.6	–
< US$ 750			+0.1	-0.0	–
Buongiorno (1978)	Y_t, C_{t-1},	1963–1973			
GDP per capita,	P_t, P'_t				
Average	(for cultured		+0.1	+0.3	–
≥ US$ 2600	paper only)		+0.0	+0.2	–
< US$ 2600			+0.4	+0.3	–
JP/Suhonen (1984)	Y_t, C_{t-1},	1965–1980			
GDP per capita,	P_t, P'_t	(cultural			
Average		papers)	+0.1	-0.1	+0.0
> US$ 4750		1970–1980	+0.0	-0.2	+0.1
US$ 1600–4750		(other	+0.0	+0.1	-0.3
< US$ 1600		grades)	+0.1	-0.2	–

[a] GNP/GDP at US$ 1975 prices.

patterns and buying practices. This would not be possible without extensive field work based on interviews and deep discussions with people in the relevant branches.

13.5. Conclusions

The basic aim was to compile in this chapter some practical results from income and price elasticity measurements. The following conclusions can be drawn:

(1) The numerical values of income and price elasticities are sensitive to the explanatory variables included, to the deflation methods and exchange rate treatments used to convert income and price variables into constant prices and a common currency, as well as to the time period for observations. So far, too little attention has been paid to

these data manipulations before undertaking the numerical estimation.

(2) Short-term and long-term elasticities should be distinguished; the consumption of many paper and board grades is habitual and does not react to changes in income and/or prices immediately, i.e., within one year. Thus, the use of dynamic models (e.g., the partial adjustment model) for measuring elasticities is preferable.

(3) The velocity of adjustment to changes in income and prices is faster in high-income countries than in low-income ones. The adjustment processes seem also to accelerate with time, which may be an indication of growing flexibility because of the increasing supply of commodities and stiffer competition in a high-income society.

(4) The use of country-specific dummy variables in pooled cross-sectional and time-series models is essential; otherwise the measured price and income elasticities may absorb some of the variations caused by other variables omitted from the regression, which results in serial correlation of the regression residuals; i.e., the numerical values of elasticities will be meaningless. In some earlier studies, the statistical properties of consumption models are not discussed in detail, leaving the reader dubious as to the validity of the results.

(5) Elasticities tend to change with income levels and over time. The use of constant elasticities for a longer period than 10 years may lead to unrealistic forecasts.

(6) Income (GDP per capita) is the most important explanatory variable for all paper grades, except grades that have already passed their saturation level (e.g., sack paper in industrialized countries). The numerical values of income elasticities vary on both sides of unity; when using the three-grade classification the lowest values are for newsprint and the highest for printing and writing papers (industrialized countries) or for industrial paper and board (developing countries).

(7) With increasing income, there is a tendency for the income elasticities of newsprint and industrial grades to fall. In the case of printing and writing papers, the highest income elasticities seem to be in the medium-income class; the elasticities for the high-income group also exceed unity in most countries.

(8) Measured own-price elasticities vary a lot, depending on the time period, model type, and price variable used for observations. Of the different paper grades studied here, sack paper and newsprint were the most price-sensitive and printing and writing papers the least price-sensitive products. This is an indication of the decreasing importance of price as the unit value of products grows; the bulkier

the product, the more price-sensitive it seems to be. It is also evident that price becomes all the more important a variable as the level of disaggregation of the products grows. Net importing countries seem also to be more price-sensitive than self-sufficient countries.

(9) Price elasticities seem to decrease over time and with increasing income. The inelasticity of consumption of some grades is likely to be the result of the lack of cheap substitutes for paper products. The high-price elasticities measured for developing countries may, at least partly, be caused by insufficient supply restricting consumption rather than the price level as such.

(10) The results of the use of substitute prices for paper products are not very encouraging. It is extremely difficult to find appropriate substitutes for paper products that can be measured in quantitative terms. It is also questionable as to whether conventional consumer price theory can be used to explain system substitution, when many other nonprice factors may be more decisive for consumption choices than the material prices alone.

(11) Substitution of forest products for other commodities will be the Achilles' heel in the demand analysis for forest products. The future of mature industries, as the forest industries are, may depend more on the ability to compete successfully with other commodities than on changes in external economic conditions.

Appendices

Appendices 13.1–13.4 are given on the following pages, followed by the references to this chapter.

Appendix 13.1: Consumption Models for Newsprint

Data group	*Estimates of parameters*[a]									
	Constant	C_{t-1}	Y_t	P_t	P_t'	$\bar{R}^{2}$[e]	$D-W$[f]	$G-Q$[g]	n[h]	$ANOVA\ (F^x)$[i]
Complete data set, 1965–1980	-1.468	+0.364 (0.035)[b]	+0.536 (0.058)[b]	-0.190 (0.048)[b]	+0.041 (0.046)	0.987	2.52	0.18 (1.36)	640	
Years 1965–1972	-3.894	+0.228 (0.052)[b]	+0.868 (0.061)[b]	-0.138 (0.106)	+0.020 (0.060)	0.990	2.67	0.19 (1.76)	320	1.16
Years 1973–1980	-4.165	+0.163 (0.055)[c]	+0.875 (0.060)[b]	-0.139 (0.061)[c]	+0.092 (0.053)[c]	0.987	2.70	0.42 (1.76)	320	
GDP per capita, < US$ 1000	-2.480	+0.425 (0.052)[b]	+0.592 (0.062)[b]	-0.163 (0.077)[c]	+0.053 (0.065)	0.964	2.35	0.52 (1.63)	272	635.7[b]
GDP per capita, US$ 1000–3000	-0.862	+0.638 (0.049)[b]	+0.429 (0.070)[b]	-0.261 (0.054)[b]	+0.008 (0.051)	0.965	2.07	1.10 (1.86)	176	
GDP per capita, > US$ 3001	-0.955	+0.289 (0.070)[b]	+0.422 (0.066)[b]	-0.027 (0.072)	+0.009 (0.061)	0.880	1.89	1.66 (1.81)	192	
EEC countries	-1.311	+0.426 (0.072)[b]	+0.427 (0.090)[b]	-0.258 (0.066)[b]	+0.203 (0.076)[b]	0.978	2.38	1.68 (2.12)	128	

[a] The figures in parentheses under the coefficients are standard errors.

[b–d] Coefficients that significantly differ from zero at the 0.99, 0.95, and 0.90 confidence levels, respectively.

[e] $\bar{R}^2$ is adjusted coefficient of determination.

[f] $D-W$ is the Durbin–Watson statistic.

[g] $G-Q$ is the Goldfeld–Quandt statistic (figures in parentheses refer to the relevant percentage points of the F-distribution).

[h] n is the number of observations.

[i] $ANOVA$ is the computed F-statistic for testing differences between data clusters (time period, GDP per capita class).

Appendix 13.2: Consumption Models for Printing and Writing Papers

Data group	*Estimates of parameters*[a]									
	Constant	C_{t-1}	Y_t	P_t	P'_t	$\bar{R}^{2e}$	$D-W^f$	$G-Q^g$	n^h	$ANOVA\,(F^x)^i$
Complete data set, 1965–1980	–4.916	+0.389 $(0.035)^b$	+0.928 $(0.055)^b$	–0.003 (0.041)	–0.085 $(0.043)^c$	0.986	2.01	0.19 (1.36)	640	
Years 1965–1972	–4.830	+0.376 $(0.050)^b$	+0.773 $(0.063)^b$	–0.151 $(0.059)^c$	+0.330 $(0.101)^b$	0.993	1.87	0.16 (1.76)	320	9.22^b
Years 1973–1980	–5.213	+0.213 $(0.052)^b$	+1.038 $(0.070)^b$	+0.123 $(0.060)^c$	–0.212 $(0.070)^b$	0.985	2.07	0.17 (1.76)	320	
GDP per capita, < US$ 1000	–4.839	+0.384 $(0.055)^b$	+0.914 $(0.093)^b$	0.052 (0.069)	–0.092 (0.086)	0.941	2.04	0.44 (1.63)	272	1040.8^b
GDP per capita, US$ 1000–3000	–3.745	+0.477 $(0.064)^b$	+0.739 $(0.115)^b$	–0.108 (0.078)	+0.039 (0.075)	0.950	1.99	0.58 (1.86)	176	
GDP per capita, > US$ 3001	–6.176	+0.126 $(0.071)^d$	+1.246 $(0.114)^b$	–0.005 (0.069)	–0.159 $(0.065)^b$	0.908	1.79	0.37 (1.81)	192	
EEC countries	–6.262	+0.252 $(0.081)^b$	+1.169 $(0.139)^b$	+0.014 (0.076)	–0.082 (0.075)	0.956	1.76	0.40 (2.12)	128	

[a–i] See Appendix 13.1.

Appendix 13.3: Consumption Models for Wrapping and Packaging Papers and Boards

Data group	Estimates of parameters[a]									
	Constant	C_{t-1}	Y_t	P_t	P'_t	$\bar{R}^2$[e]	*D–W*[f]	*G–Q*[g]	n[h]	*ANOVA* (F^z)[i]
Complete data set, 1970–1980	+0.162	+0.294	+0.443	-0.074	-0.023	0.935	2.25	1.16	154	
		(0.082)[b]	(0.149)[b]	(0.069)	(0.063)			(2.09)		
Years 1970–1975	-1.138	+0.474	+0.491	-0.017	-0.086	0.914	1.88	0.83	84	4.51[b]
		(0.117)[b]	(0.123)[b]	(0.081)	(0.086)			(9.28)		
Years 1976–1980	-1.896	+0.350	+0.533	+0.126	-0.061	0.943	1.97	2.15	70	
		(0.094)[b]	(0.087)[b]	(0.077)	(0.067)			(9.28)		
GDP per capita, < US$ 3000	-2.000	+0.431	+0.725	-0.062	-0.182	0.938	1.97	0.43	55	116.6[b]
		(0.129)[b]	(0.231)[b]	(0.087)	(0.095)[d]			(5.05)		
GDP per capita, > US$ 3000	+1.557	+0.190	+0.224	-0.016	+0.041	0.861	1.76	0.80	99	
		(0.108)[d]	(0.188)	(0.093)	(0.079)			(2.69)		
EEC region	+0.219	+0.295	+0.441	-0.051	-0.128	0.660	2.19	1.62	77	
		(0.113)[c]	(0.191)[c]	(0.102)	(0.078)			(3.79)		

[a–i] See Appendix 13.1.

Appendix 13.4: Consumption Models for Sack Paper

Data group	*Estimates of parameters*[a]									
	Constant	C_{t-1}	Y_t	P_t	P'_t	$\bar{R}^{2e}$	$D-W^f$	$G-Q^g$	n^h	*ANOVA* $(F^z)^i$
Complete data set, 1970–1980	+0.959	+0.392 $(0.077)^b$	+0.073 $(0.039)^d$	-0.280 $(0.125)^c$	+0.126 (0.088)	0.741	2.08	1.73 (2.09)	154	
Years 1970–1975	-1.953	+0.205 (0.135)	+0.477 $(0.127)^b$	-0.287 $(0.157)^d$	+0.112 (0.135)	0.825	2.07	5.14 (9.28)	84	13.54^b
Years 1976–1980	+0.407	+0.329 $(0.103)^b$	+0.122 $(0.068)^d$	-0.171 (0.248)	+0.100 (0.149)	0.582	1.90	3.15 (9.28)	70	
GDP per capita, < US$ 3000	-0.501	+0.364 $(0.131)^b$	+0.442 $(0.178)^c$	-0.340 $(0.196)^c$	+0.010 (0.149)	0.734	2.29	1.25 (5.05)	55	9.91^b
GDP per capita, > US$ 3000	+1.865	+0.218 $(0.105)^c$	-0.053 (0.298)	-0.202 (0.184)	+0.119 (0.131)	0.733	1.96	4.20 (2.69)	99	
EEC region	+6.443	+0.037 (0.121)	-0.356 $(0.091)^b$	-0.533 $(0.144)^b$	+0.124 (0.084)	0.769	2.12	0.84 (3.79)	77	

[a–i] See Appendix 13.1.

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CHAPTER 14

Household Demand for Fuelwood

J.G. Laarman

To model the demand for firewood and charcoal by households — collectively referred to as fuelwood for the purposes of this analysis — is to entertain a series of intellectual puzzles. Is the model one of demand for energy, for a commodity, or for a bundle of amenities? When is fuelwood an intermediate good and when is it a final good? What is the framework of economic exchange when the fuelwood consumer is also the fuelwood producer? Do woodstove technologies augment thermal energy supply or reduce fuelwood demand?

Aside from these and other mainly conceptual issues are a number of practical constraints that add to the difficulty of model making. First is the diverse character of the populations of interest: poor and rich, rural and urban, subsistence and commercial, household and industrial, tropical and temperate. Second is the wide dispersion of fuelwood studies, many of which are popular rather than technical and remain unpublished and not readily accessible.

Finally, the empirical basis for fuelwood modeling is gravely deficient because of missing and inadequate data. The data problems are partly explained by three key characteristics of fuelwood consumption:

(1) Fuelwood is obtained from both forest and nonforest sources.
(2) Consumption is concentrated in the world's poorest households.
(3) Neither organized markets nor monetary prices exist for the bulk of household consumption.

Additional quantification problems arise from the fact that units of fuelwood measurement are often crude and subjective, as when expressed in headloads, armloads, and stacks. Factors to convert from volume measures and weight measures into energy equivalents (e.g., calories, BTUs) are very unsatisfactory.

In the light of these many research obstacles it is not inconsistent to find a number of studies on fuelwood supply (mainly in the biological sense), but few that address the concepts and estimation of fuelwood demand. For fuelwood-demand studies the elements of applied work, theoretical advances, and policy analysis are still immature and only loosely connected.

If not unexpected, the shortage of demand studies is disturbing, considering the social and economic importance of the product. FAO estimates that fuelwood may account for over half of the world's forest extractions (*Table 14.1*), and may be consumed by approximately half of the world's population (Montalembert and Clement, 1983). These rough figures imply gross underinvestment in models to explain and predict demand for the world's most widely consumed wood product.

Table 14.1 Fuelwood as a proportion of roundwood extractions by world regions, 1981 (FAO, 1983).

	Roundwood (10^6 m^3)	*Fuelwood* (10^6 m^3)	*Proportion* (%)
Industrialized market economies			
North America	548	104	19
Western Europe	250	38	15
Oceania	28	1	4
Other	49	8	16
Developing market economies			
Africa	392	353	90
Latin America	390	294	75
Near East	81	66	81
Far East	653	564	86
Other	7	6	86
Centrally planned economies			
Asian CPE	304	231	76
Eastern Europe and the USSR	440	94	21
All industrialized	1 314	245	19
All developing	1 828	1 513	83
World	3 142	1 759	56

In this chapter I outline a framework for understanding fuelwood demand, subject to the deficient world knowledge in this area. The next sections describe the particular characteristics of fuelwood resources in relation to economic exchange. This is followed by an overview of the analytical techniques that may hold promise for demand estimation.

14.1. Characteristics of Fuelwood Resources and Markets

In *Table 14.2* I present the principal attributes of fuelwood resources to guide the construction of theoretical demand models. In the table I draw distinctions between the fuelwood in industrialized and developing countries, although many distinctions are more a matter of degree than of kind.

Table 14.2 Attributes of fuelwood resources pertinent to demand theory.

Attribute		*Industrialized countries*	*Developing countries*
(1)	Exchanged among many buyers and sellers	Yes	Sometimes
(2)	Appropriated with labor, not cash	Often	Very often
(3)	Rival in consumption	Yes	Yes
(4)	Exclusion of "free riders"	Usually	Difficult
(5)	Open-access resource	Sometimes	Often
(6)	External diseconomies in production	Plausible	Sometimes
(7)	External diseconomies in consumption	Yes	Plausible
(8)	Amenity values in production	Often	Often
(9)	Amenity values in consumption	Often	Plausible

14.1.1. Extra-market appropriation

The demand for fuelwood is complicated by the noncommercial channels through which so much fuelwood is appropriated. The absence of formal markets poses conceptual difficulties in modeling the consumer's side of economic exchange. In rural settings economic exchange may involve only a single economic agent who offers labor time (exchanged for an alternative use of that time) to acquire and transport fuelwood for self-consumption. Hence, a household or individual is both producer and consumer. This model of self-sufficiency is usually identified with low-income households in developing economies. Households account for more than 85% of national fuelwood consumption in Gambia, India, Kenya, Lebanon, Sudan, Tanzania, Thailand, and Uganda (Arnold and Jongma, 1978). But fuelwood consumption by households also accounts for a high proportion of total consumption in industrialized regions, such as the Nordic countries (Lunnan and Veidahl, 1981) and the US (Skog and Watterson, 1984).

In many institutional settings, fuelwood is not a purely private good. For fuelwood to be a private good, two conditions must hold:

(1) There is rival consumption.
(2) Suppliers can exclude nonpayers from appropriating it.

The tangible nature of firewood and charcoal insures that the first condition is met.

However, the ownership condition is not as easily satisfied in the light of cultural, traditional, and legal institutions that govern the acquisition of fuelwood. Particularly in many parts of the developing countries, fuelwood is appropriately classified as an open-access resource (Ciriacy-Wantrup and Bishop, 1975). Exclusive-use rights to particular sources of fuelwood can be difficult to establish and maintain. This retards the pace of fuelwood commercialization and holds back the formation of monetary prices.

14.1.2. Externalities

External effects — mainly of the environmental variety — exist for both fuelwood production and consumption. On the production side, vegetation removal may have negative consequences for soil and water regimes (Eckholm, 1975). On the consumption side, smoke, particulates, and gases may adversely affect the health and general living of whole communities (Allwine, 1981). Since the spillovers are principally external diseconomies, too much fuelwood will be consumed relative to a hypothetical standard in which all costs are confined to fuelwood participants.

14.1.3. Fuelwood goods versus fuelwood products

That different "goods" are obtained from one or more fuelwood products should be studied in relation to consumer theories of the kind advanced by Becker (1965), Lancaster (1966), and Stigler and Becker (1977). These theories contend that human satisfaction (i.e., utility in the formal demand framework) is provided by the characteristics of products and the process of their consumption, not by the products themselves. In addition, utility is determined, in large measure, by the consumer's allocation of time for the entire consumption process — including preparation, acquisition, actual consumption, and recollection.

This essential distinction between products and goods is highly relevant in the light of the amenity values so pervasive in much of fuelwood production and consumption. On the production side, many individuals in

Western societies apparently obtain psychological benefits (in terms of health, leisure, and outdoor experience) from household production of fuelwood. Fuelwood consumption in fireplaces exemplifies amenity values in consumption. In Third World societies, amenity values in fuelwood consumption are typically different from this, relating to areas of life such as religious rites and food flavoring. Also important are amenities such as ignition reliability, odor and degree of smokiness, and storage convenience (Cecelski *et al.*, 1979).

Negative characteristics may be observed, too. Among these are dirtiness, compromise of home safety, and health risks (e.g., respiratory problems and back strain). Fuelwood use is often associated with inferior social status and economic backwardness — especially in traditional societies (Moss and Morgan, 1981, p 30).

In the "goods" model of consumer choice, the consumer weighs these negative characteristics against the positive ones noted previously, subject to constraints of time and budget. This view provides the rationale for exploring fuelwood demand through the household production function, as described in Section 14.4.

14.2. Price and Income Relationships

Particularly in the developing countries, most fuelwood consumption studies have been conducted by sociologists, anthropologists, foresters, and geographers. The economist's framework of own-price, cross-price, and income elasticities of demand has not been widely applied (even though some fuelwood expenditure surveys may lend themselves to reinterpretation in this formulation).

14.2.1. Prices

The willingness-to-pay to obtain different quantities of a product — the central demand concept — is only poorly understood in the case of fuelwood. Because the demand for fuelwood includes both market and extramarket components, some prices are explicitly paid in money while others are implicitly paid in labor. Nor is there always a distinct division between market and nonmarket segments. For example, many households apparently exchange both money and labor in combination.

This coexistence of monetary and nonmonetary prices in a given fuelwood economy presents serious difficulties for the definition and estimation of price elasticities. The analyst may need to propose and estimate two or more different fuelwood demand schedules — each with different price units, expected elasticities, and positions. This approach rapidly leads to a sectoral model and a multiequation framework, where each of several sectors has its separate price behavior for fuelwood.

Following conventional microeconomic theory, the price elasticity of fuelwood demand should increase with the number and closeness of fuelwood substitutes. In some developing economies the range of potential substitutes encompasses not only petroleum fuels and electricity, but also animal dung, biogas, bagasse, crop residues, coconut shells and husks, wastes from wood-processing plants, bamboo, and other forms of biomass (Hyman, 1984). This large number of potential substitutes suggests that, in principle, the price elasticity of demand for fuelwood should be high.

On the other hand, the various amenity values that enter into the choice of fuels conceivably serves to segregate the alternatives. As the perception of the fuelwood "goods" (as opposed to products) becomes narrower and more specific, demand for them becomes more inelastic. Therefore, demand should become increasingly inelastic with the breadth and cultural complexity of end-uses beyond merely utilitarian combustion. In the matter of energy substitutability, Western-trained analysts sometimes have difficulty recognizing social and cultural barriers of importance to traditional Third World populations (Newcombe, 1981).

Many analysts assume that the dramatic and worldwide escalation of petroleum fuels prices over the past 10–12 years has been a major exogenous force to shift fuelwood demand (e.g., Attiga, 1979; Stoddard *et al.*, 1979; Fergus, 1983). Because this particular cross-price relationship is at the heart of leading policy concerns, it should command the primary attention of modelers. Substitution toward wood and away from "modern" energy has slowed or even reversed the long-term secular trend. A challenging question posed by this historical reversal is whether the cross-price elasticity is different in concept and magnitude when substitution is toward fuelwood rather than away from fuelwood.

14.2.2. Income

The sign and magnitude of the income elasticity are determined by the types of fuelwood goods in question and by the income level of the consumer. One hypothesis is that the income elasticity of demand is positive at low income levels (a superior good), but then flattens and ultimately becomes negative at high income levels (an inferior good). Food consumption (and the derived demand for household energy) increases as low incomes increase, but eventually substitution by alternative fuels takes place as incomes increase still further. The Engel curve for household fuelwood may look like that in *Figure 14.1*, with maximum fuelwood consumption occurring in middle-income developing countries (Laarman and Wohlgenant, 1984).

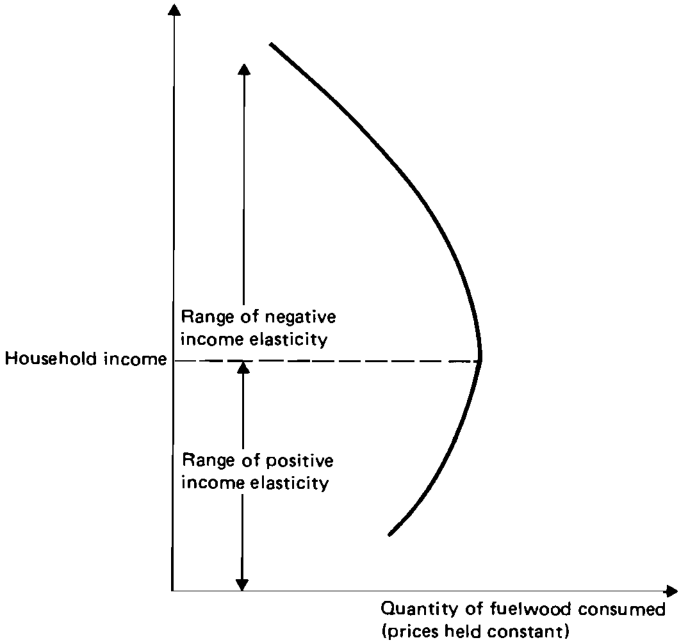

Figure 14.1 Hypothetical relationship between household income and household fuelwood consumption.

This conceptual view applies mainly to fuelwood as an input for household cooking and heating. It does not describe the likely income relationships for fuelwood as a provider of amenity benefits in high-income Western households, nor for fuelwood as an energy source in industrial establishments.

14.2.3. Rate of adjustment

Price- or income-induced changes in fuelwood consumption may be slowed by several factors (Nerlove, 1958): habit persistence, uncertainty about whether changing fuel prices are temporary or permanent, and technological rigidities in the form of fixed capital needed to use alternative fuels. On this latter constraint there are empirical estimates for selected regions (Hughart, 1979, p 15).

These constraints imply that a static framework, in which instantaneous (i.e., one-period) adjustments are assumed, is inappropriate. Rather, the circumstances of fuelwood consumption suggest the need to evaluate and choose from the menu of model specifications based on distributed lags (Intriligator, 1978, pp 176–186) or alternative theoretical foundations (Johnson *et al.*, 1984, especially Ch 5).

14.3. Assessing Willingness-To-Pay

Just as for any other product, the Marshallian demand schedule for fuelwood shows the different quantities of fuelwood that consumers will purchase at different prices (for given incomes and prices of substitutes). Applied demand studies therefore concern themselves with alternative techniques to assess this willingness-to-pay. In *Table 14.3* I display techniques now in use or that offer possibilities for future use. Owing to the underdevelopment of theories and practices for fuelwood demand estimation, no prescribed set of approaches currently has universal acceptance.

Table 14.3 Alternative methods to study willingness-to-pay for fuelwood.

Method	*Application or context*
Market evidence	
(1) Monetary prices of fuelwood	Fuelwood sales in cities and towns; sales to rural and semirural industries
(2) Monetary prices of observed substitutes	Set implicit ranges on willingness-to-pay for fuelwood
(3) Reductions in monetary incomes	Measure sacrificed earnings opportunities due to time allocated for fuelwood production
Travel time and costs	Consumers are separated from fuelwood resources by variable distances or travel times
Hypothetical valuation	Direct observation is not possible; contrived valuations can be made realistic and relevant
Household production theory	See Section 14.4

14.3.1. Market evidence

Time series of monetary prices for fuelwood can be constructed for some urban populations (Mahamat Paba Sale, 1981) and for some geographical cross-sections at any one point in time (Bogach, 1981). Normally, the desired price data are not available in statistical reports, but must be acquired with the aid of special surveys. If the supply–demand structure can be accurately described in relation to microeconomic theory and if the familiar identification problem can be resolved, then the price information furnishes (in principle) a valid indicator of willingness-to-pay.

Prices of commercial fuelwood substitutes, such as kerosene, propane, and electricity, ordinarily are easier to obtain than prices of fuelwood itself. However, the same does not apply to extra-market substitutes, such as animal dung and crop residues. Here, price surrogates may be no more sophisticated than crude indices of residue availability (Hughart, 1979, pp 98–100), so application in demand models will be purely *ad hoc*.

Under restrictive assumptions, the analyst may be able to use monetary prices of commercial fuelwood substitutes to infer upper or lower bounds on willingness-to-pay for unpriced fuelwood. If a household is observed to buy kerosene at a price corresponding to $3 per gigajoule of thermal energy, then its willingness-to-pay for fuelwood is apparently lower than this price equivalent. Conversely, if the household is observed to use fuelwood while kerosene remains at the stated price, then its willingness-to-pay for fuelwood is evidently at least $3 per gigajoule. This opportunity–cost approach has its precursor in the Milliman range method (Sinden and Worrell, 1979, pp 265–266).

An alternative opportunity–cost method works through measures of monetary income foregone. If a family gives up $2 in alternative work opportunities because of the time they must allocate to one week's fuelwood collection, then their willingness-to-pay for that quantity of fuelwood is $2 (Gregersen and Contreras, 1979, pp 81–83). This approach suggests the possibility of using travel time and costs to value fuelwood.

14.3.2. Travel time and costs

Owing to its low value/mass ratio, fuelwood transport is costly. This is especially true for firewood (in contrast to charcoal). Gradients of distance and time frequently serve as effective fuelwood rationing devices. Accordingly, these gradients may afford opportunities to estimate shadow prices of extra-market fuelwood. To the extent that the shadow prices vary cross-sectionally or through time, they constitute a data set of potential use for constructing a demand curve.

Particularly for fuelwood demand in certain Third World settings, travel-cost methods necessarily include travel on foot. Travel cost as a price proxy for fuelwood may be expressed in units of labor hours or kilometers walked. Alternatively, time is converted into monetary equivalents at the appropriate shadow prices for labor. The latter approach requires that fuelwood collectors reveal how they would use their time if they were not collecting wood (Hyman, 1984, pp 5–7). Distinctions among men, women, and children are likely to be important in this regard (Ki-Zerbo, 1981; Stewart, 1984).

The place of travel-cost methods in the study of fuelwood demand is not yet determined, but the possibilities are intriguing. At the conceptual level, the idea that time cost (or distance cost) makes an acceptable price proxy is supported by intuitive reasoning and partial evidence. Additionally, an abundant literature on the strengths and weaknesses of travel-cost methods (e.g., Sinden and Worrell, 1979, pp 364–374) is available to guide the analyst on questions of study approach. To be weighed against these advantages is the negative aspect that most travel-cost studies have focused on recreation benefits, so much of the contextual information and integrated theory are irrelevant or even misleading.

14.3.3. Hypothetical valuation

Since fuelwood is a tangible rival in consumption, the analyst is able to select valuation methods that avail of direct empirical observations of market prices or travel costs. But methods of hypothetical valuation (i.e., contrivance of contingent and experimental markets) may be unavoidable in demand studies limited by time, budget, or other constraints. Also, hypothetical valuation is likely to be the only approach to estimate fuelwood demand among populations currently not consuming it.

The construction of contingent markets is most closely identified with the estimation of extra-market environmental benefits (Randall, 1984). Yet several of the methods based on the income compensation approach (e.g., bidding games, trade-off analyses, buy-and-sell experiments, etc.) may have application for fuelwood. Major obstacles to the use of these techniques for fuelwood valuation are the typical problems that can result from strategic, instrumental, and hypothetical bias (Hyman, 1983). These biases are particularly troublesome and difficult to overcome for fuelwood demand studies in settings of traditional culture and minimal educational attainments.

14.4. The Household Production Function

Household production models can account for the simultaneity in household consumption and production, and hence they may be quite valuable for the study of fuelwood demand. This approach can also be used to model fuelwood as a product appropriated with no money but with considerable inputs of time, and for which consumer behavior is heavily influenced by amenity values. In addition, the household production function for Third World settings often pivots on the production and consumption of food. This suitably accommodates fuelwood demand as derived from the demand for household cooking.

The general model for household production functions maximizes a household utility function subject to constraints of household labor time and budget. Different models make different assumptions regarding the degree of access to purchased inputs and the possibilities for outside earnings (Strauss, 1984a). For example, fuelwood is a commodity often produced and consumed in a Robinson Crusoe context, leading to "corner solutions" in the maximizing framework. In other cases it is a purchased input, requiring no household labor other than that for actual use.

Study of fuelwood demand through the household production function can be conceptualized from a number of different perspectives. *Figure 14.2* illustrates one possible demand structure in the case of fuelwood for cooking in Third World households. The figure suggests the complexity of the relationships and the substantial body of information needed for empirical work.

In *Figure 14.2* each fuelwood and its substitutes has sets of attributes that provide blends of satisfaction and dissatisfaction if consumed for meeting household food demand. The extent of satisfaction and dissatisfaction is determined by the tastes and preferences of the household members. However, utility is translated into actual consumption choices only with due regard for household constraints, on the one hand, and exogenous economic variables, on the other. The constraints are mainly those of budget and labor time, both of which are directly influenced by family size, skills, and capital stock. The exogenous economic variables — principally vectors of prices and wages — determine the amounts and types of household transactions with the market economy.

Aggregation over all the households in a region or over a given set of households through time leads to the final summation of demand for fuelwood and its substitute(s). This demand can be expressed as an implicit function of prices, wages, family size, or other economic and noneconomic variables. The system of equations that defines the household model will determine the dependencies and linkages.

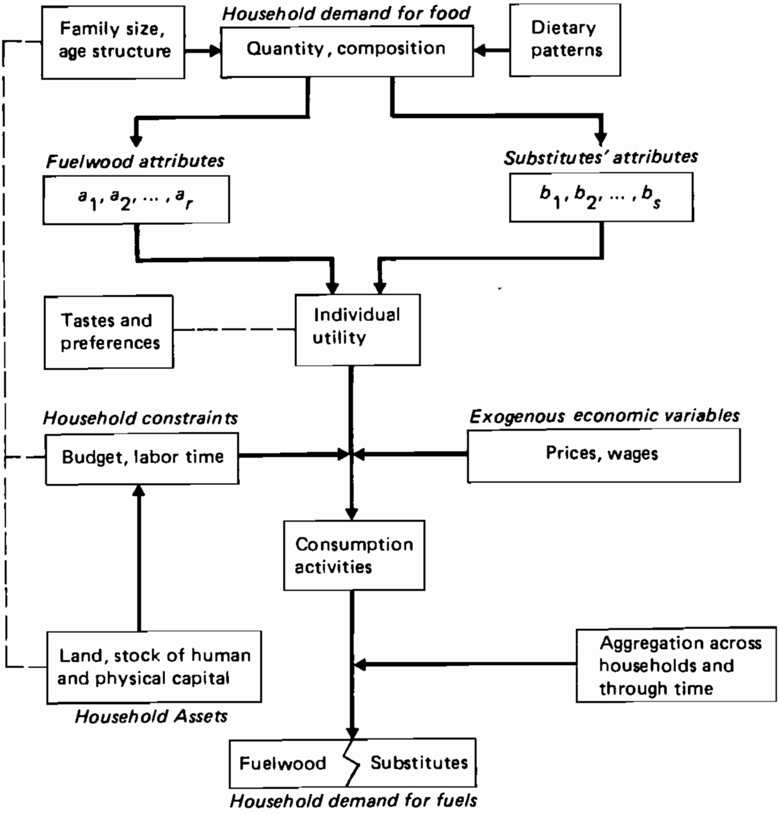

Figure 14.2 Fuelwood demand in the framework of the household production function.

These linkages must include the time or monetary expenditures for fuelwood production in relation to their respective constraints. Additional needed relationships are household utility as a function of food consumption, food consumption as a function of the joint production of food and fuelwood, and food and fuelwood production as a function of labor supply (both household and hired). Other potential model components are household consumption of leisure, purchased foods, purchased nonfoods, and purchased fuelwood. A representative framework for the possible incorporation of fuelwood aspects is given in Strauss (1984b). Interrelationships between food and fuel activities are discussed in Bajracharya (1983).

The demand for fuelwood in Western households hinges on different postulates and data requirements. Instead of demand for fuelwood as an input in household cooking, the demand in high-income households frequently shifts to fireplace wood. Also, the production process in itself may provide positive utility. But the roles of tastes and preferences, household assets, household constraints, and exogenous economic variables are likely to remain in the Western household production function.

Whether the household production function will prove to be useful for models of fuelwood demand is an untested proposition. Data needs are considerable, and many of the data must be collected through direct and expensive surveys. Applications for fuelwood need testing and validation. Despite these impediments, the approach comprises a fresh perspective in the very young science of analyzing fuelwood demand and, consequently, merits careful appraisal.

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Part IV

International Trade

CHAPTER 15

Barriers to Trade in Wood and Wood Products

A. Olechowski

As in most other product categories, international trade in wood and wood products is regulated by means of tariff and nontariff measures. While the literature on the theoretical aspects of tariff and nontariff protection is abundant, empirical studies are infrequent and — particularly those that deal with nontariff barriers — lacking in detail. This is primarily due to the noticeable scarcity of reliable information. In this chapter we describe tariff and nontariff protection in the wood sector on the basis of information drawn from the UNCTAD Data Base on Trade Measures (for further details of this Data Base, see UNCTAD, 1983, 1985).

The chapter is divided into two parts. In the first part the average tariff rates on wood and wood products in various markets are presented and analyzed. An attempt is made to evaluate the trade effects of a removal of tariffs in the developed, market economy countries (DMECs). Then, the phenomenon of tariff escalation is discussed. The second part is devoted to nontariff measures and contains empirical evidence of their extent.

15.1. Tariffs

While an uncontested feature of current protectionism is the importance of nontariff measures, tariffs still perform a major role. In particular, two aspects of tariff protection are frequently stressed: the persistently high level of tariff rates in some sectors and countries (in particular those other than DMECs) and the fact that *ad valorem* import duties tend to increase with the level of fabrication, thus adversely affecting exports of processed products. This phenomenon, called tariff escalation, is considered to be of particular importance to developing countries and their industrialization strategies.

In the following discussion, we concentrate on these two subjects. Owing to the differences in availability of relevant information, separate approaches have to be used for the DMECs, for the developing countries, and for the socialist countries.

15.1.1. Developed, market economy countries

In *Table 15.1* we provide information on the weighted, average tariff rates for wood and wood products in the major, developed market economies. The averages were calculated for rates applied before the Tokyo Round of Multilateral Trade Negotiations (concluded in 1979) as well as for the reduced, post-Tokyo Round rates. They combine the Most Favored Nation (MFN) as well as (lower) preferential tariff rates [1]. The product categories used in *Table 15.1* (as well as in other parts of this chapter) cover wood and articles of wood and furniture contained in Chapters 44 and 94 of the CCCN (Customs Co-operation Council Nomenclature, formerly Brussels Tariff Nomenclature: BTN). Specifically, they include:

Wood in the rough: CCCN 4401–4404.
Primary wood products: CCCN 4405–4419.
Secondary wood products: CCCN 4420–4428, *ex* 9401–9404.

The above groups do not include pulp and paper products.

Three major conclusions emerge from *Table 15.1*. First, while the tariff duties on rough and simply processed wood are low, those facing secondary wood products are relatively high. The average rates for all importing markets included in *Table 15.1* are 0.0% for wood in the rough; 2.4% (pre-Tokyo Round) and 1.7% (post-Tokyo Round) for primary wood products, and 7.8% and 5.7%, respectively, for secondary products. These estimates should be compared with the average rate for total imports, which, for the same markets (except Australia), was estimated to range from 4.6% (pre-Tokyo Round) to 3.6% (post-Tokyo Round) (Olechowski and Yeats, 1982). At the individual country level, particularly high rates face wood in Australia, Austria, Canada, and New Zealand. In these countries, duties on wood products are higher than the average tariff rates for all products. On the other hand, duties in the EEC, Japan, and the US are significantly lower and in line with those facing other products.

Second, in general, higher customs duties are levied on imports from the socialist countries of Eastern Europe than on imports from the DMECs. Developing countries face, in general, the lowest duties (but not in Japan and New Zealand), due to the tariff preferences that their exports benefit from. Note, however, that our averages overestimate the importance of these preferences. While the calculations assume that all imports eligible for preferences do, in fact, benefit from them, this is not correct: various limitations (e.g., quotas, ceilings, competitive criteria, etc.) and stringent rules of origin seriously restrict the actual utilization of preferences [2]. Another qualification relates to the socialist countries, which, in the case of the US market, face higher tariffs than those indicated in *Table 15.1.* While we have assumed that all socialist countries were eligible for the MFN treatment, in fact only two of them (Hungary and Romania) received this treatment, whereas all the others incurred substantially higher (so-called general) tariffs.

15.1.2. Tariff escalation

Third, the estimates in *Table 15.1* clearly indicate the existence of tariff escalation [3]. When pre-Tokyo Round tariffs are investigated, it is found that (on average) duties on secondary wood products are about 225% higher than those on primary products, and over 680% higher than duties on wood in the rough. The difference between the rates on primary products and wood in the rough is much higher than that between duties on secondary and primary products, indicating a certain bias against developing countries, for which semimanufactured, labor-intensive products are of greater importance than the more processed, capital-intensive products.

One of the stated goals of the Tokyo Round was to reduce tariff escalation and, by doing so, to facilitate the expansion of developing countries' exports of manufactures. Since most tariff cuts occurred in the industrial sectors, the overall extent of escalation was eroded. This was also, in part, the case for wood. As can be seen from *Table 15.1*, the relative difference between tariffs on secondary and primary wood products decreased in almost all cases. On the other hand, the disparity between tariffs on wood in the rough and on primary products slightly increased, from 225% to 235%. Thus, the extent of escalation in this case and the degree of bias faced by developing countries remained high.

The problem of tariff escalation was investigated in greater detail through the calculation of average rates that face individual products in two processing chains. The first chain included rough logs, squared logs, sawnwood, planed/jointed wood, and wooden furniture. The second chain

Table 15.1 Average tariff rates facing wood and wood products in major developed
UNCAD, 1983, 1985 for further details). A, wood in the rough; B, primary wood

	Imports from developing countries		*Imports from DMECs*		*Imports from socialist countries*	
	Pre-Tokyo Round	*Post-Tokyo Round*	*Pre-Tokyo Round*	*Post-Tokyo Round*	*Pre-Tokyo Round*	*Post-Tokyo Round*
Australia						
A	11.9	0.0	7.2	0.0	0.0	0.0
B	11.0	8.4	6.1	6.0	42.3	42.2
C	16.7	16.7	25.6	25.6	17.7	17.7
Austria						
A	0.1	0.1	0.3	0.3	1.0	0.7
B	0.2	0.2	8.6	7.0	2.3	2.2
C	6.8	6.8	21.4	20.5	19.2	18.6
Canada						
A	0.0	0.0	0.4	0.1	0.0	0.0
B	6.1	6.1	4.6	2.5	13.9	7.7
C	6.5	6.5	17.7	12.6	15.7	10.3
EEC						
A	0.0	0.0	0.1	0.0	0.2	0.0
B	2.5	1.9	1.0	0.8	1.1	0.8
C	2.5	1.5	2.2	1.7	4.7	3.2
Finland						
A	0.0	0.0	0.0	0.0	0.0	0.0
B	0.0	0.1	0.8	0.7	0.8	0.6
C	1.1	0.7	7.7	4.9	5.3	3.6
Japan						
A	0.0	0.0	0.0	0.0	0.0	0.0
B	8.2	7.4	0.3	0.2	2.0	1.9
C	11.1	4.8	9.6	4.3	10.4	4.6

comprised logs, veneer, and plywood. Two separate types of tariff averages were computed to account for the influence of preferences granted to developing countries. One accounted only for MFN tariffs, while the second also included the Generalized System of Preferences (GSP) and special preference rates. In both cases, the averages were unweighted in order to eliminate the influence of the current export structure of developing countries (probably distorted by the escalation).

The results confirmed our earlier observations. In the first processing chain, the MFN tariffs escalated from 0.4% rough logs to 0.2% squared logs, 0.8% sawnwood, 2.8% planed/jointed wood, and 12.0% wooden furniture. Similarly, in the second chain, MFN tariffs increased from 0.4% logs, to 6.8% veneer, and 11.8% plywood. Such large increases could influence the structure of wood imports into DMECs, but this influence is moderated country markets (from the UNCTAD Data Base on Trade measures, see products; C, secondary wood products.

	Imports from developing countries		*Imports from DMECs*		*Imports from socialist countries*	
	Pre-Tokyo Round	*Post-Tokyo Round*	*Pre-Tokyo Round*	*Post-Tokyo Round*	*Pre-Tokyo Round*	*Post-Tokyo Round*
New Zealand						
A	0.0	0.0	0.1	0.0	1.4	0.0
B	6.7	6.7	11.5	11.5	26.7	26.7
C	21.9	21.9	21.1	21.1	21.1	21.1
Norway						
A	0.0	0.0	0.0	0.0	0.0	0.0
B	0.0	0.0	1.9	1.3	1.8	1.3
C	0.0	0.0	6.9	4.8	5.6	3.8
Sweden						
A	0.0	0.0	0.0	0.0	0.0	0.0
B	0.0	0.0	1.6	1.4	1.2	1.0
C	0.0	0.0	4.0	3.0	4.9	3.7
Switzerland						
A	0.0	0.0	1.2	1.1	1.6	1.3
B	0.0	0.0	5.6	3.6	2.8	2.3
C	1.2	0.8	13.9	9.5	14.1	9.7
US						
A	0.0	0.0	0.0	0.0	0.0	0.0
B	11.0	5.6	0.8	0.4	15.4	7.3
C	3.5	1.7	4.7	2.4	3.8	2.3

by the existence of preferences. Thus, when the tariff averages account for preferential rates it is found that for the first chain, the tariff structure is 0.2% rough logs, 0.0% squared logs, 0.1% sawnwood, 0.5% planed/jointed wood, and 4.6% wooden furniture, while for the second it is 0.2% (logs), 2.6% (veneer), and 5.8% (plywood).

15.1.3. Trade effects from a removal of tariffs

As shown, tariff rates facing wood products remain relatively high, so it is important to investigate the extent to which these duties affect international trade. In other words, what is the amount of trade "lost" due to the existence of tariffs?

To answer this question a procedure developed by Olechowski and Yeats (1982) has been used. The model is similar to that employed by UNCTAD (1980) for the analysis of the results of the Tokyo Round (see Appendix 15.1 for an outline of the model).

In *Table 15.2* we summarize the results for the DMECs' imports of wood and wood products from other DMECs, from the developing countries, and from the socialist countries of Eastern Europe. Projections of trade creation for each country group are shown, as well as estimates of the range of trade losses or gains associated with a reduction of the preferential margins. *Table 15.2* also includes estimates of the overall effects expressed as a percentage of the 1976 trade base [4]. The results are presented both in total and for each of the major industrial markets.

Overall, the removal of all post-Tokyo Round tariff rates would have important trade-expansion effects for trade in wood and wood products among the DMECs. This trade is estimated to increase by about 8% over the trade base as a result of the hypothetical cuts. Austria, Canada, New Zealand, and Switzerland would experience import increases ranging from 30% to 72%. In the EEC, the overall increase would be much smaller since some of the developed country suppliers to this market would experience large trade losses from US 27×10^6 to 50×10^6, due to the erosion of the preferential margins currently enjoyed by the EFTA (European Free Trade Association) countries.

The corresponding trade effects for developing countries are estimated to amount to about 3.3%, due to the relatively low level of tariffs facing developing countries' exports and to the substantial losses associated with the removal of tariff preferences. These losses are projected to range from 5% to 28% of the 1976 trade base in the case of several industrial markets. On the other hand, developing countries would experience important increases in exports (of, mostly, processed products) to their largest markets, the EEC, the US, and Japan.

The socialist countries of Eastern Europe would also experience important increases in their exports of wood and wood products, ranging from 5.2% to 5.7% of the 1976 trade base. However, this estimate has to be qualified since the trade effects for the US market have not been included. These could influence the overall results in two contradictory directions, depending on the extent of the tariff removal; were the general tariffs to be included in the removal of tariffs, the socialist countries' gains would be substantially larger than those shown in *Table 15.2*. If, on the other hand, only MFN duties were eliminated, then the socialist countries would be priced out of the market and the overall result would be substantially lower.

Table 15.2(a) Estimated trade effects on imports from developing countries and DMECs of the removal of the post-Tokyo Round tariffs on wood and wood products[a] in the major DMECs.

		Imports from developing countries			
		Trade diversion		*Total effect*	
Importer	*Trade creation*	*Low*	*High*	*Low*	*High*
		(10^6 US$)		(% of actual imports)	
Austria	0.0	-1.2	-1.4	-7.6	-8.3
Canada	9.3	-13.6	-14.6	-6.0	-7.3
EEC (9)	45.2	15.5	25.2	3.7	4.3
Finland	0.0	-0.3	-0.4	-6.7	-9.9
Japan	49.2	-0.1	-0.2	2.7	2.7
New Zealand	0.0	-1.0	-1.5	-19.0	-27.6
Norway	0.1	-1.0	-1.3	-5.7	-7.3
Sweden	0.4	-1.7	-2.2	-6.3	-8.5
Switzerland	0.2	-1.1	-1.3	-6.7	-8.5
US	46.1	-3.4	-5.6	6.3	6.0
Total	150.6	-0.8	-3.2	3.3	3.4

		Imports from DMECs			
		Trade diversion		*Total effect*	
Importer	*Trade creation*	*Low*	*High*	*Low*	*High*
		(10^6 US$)		(% of actual imports)	
Austria	175.7	3.3	3.4	71.9	71.9
Canada	167.6	15.6	16.6	34.1	34.3
EEC (9)	78.4	-27.4	-49.8	1.5	1.0
Finland	8.5	0.5	0.7	15.3	14.9
Japan	15.4	0.3	0.6	0.8	0.8
New Zealand	2.4	1.0	1.4	30.7	34.7
Norway	48.1	2.4	2.8	17.7	17.7
Sweden	33.2	0.0	0.4	10.2	10.3
Switzerland	145.9	1.4	1.6	47.4	47.5
US	56.2	3.4	5.5	2.9	3.0
Total	731.4	0.6	-11.8	8.1	8.0

[a] Including cork and cork products.

The most important result is the overall magnitude of the estimated trade increase. If the post-Tokyo Round tariffs were to be completely removed, the DMECs' imports of wood and wood products would increase by over US 950×10^6, or 6.4% of the 1976 trade base. These figures stress the restrictive effects of tariff protection in the trade of wood and wood products.

Table 15.2(b) Estimated trade effects on imports from socialist countries of the removal of the post-Tokyo Round tariffs on wood and wood products[a] in the major DMECs.

		Imports from socialist countries			
		Trade diversion		*Total effect*	
Importer	*Trade creation*	*Low* (10^6 US$)	*High* (10^6 US$)	*Low* (% of actual imports)	*High* (% of actual imports)
Austria	6.1	0.1	0.2	12.5	12.7
Canada	1.3	-1.7	-1.7	-7.8	-9.6
EEC (9)	50.1	11.7	19.3	6.3	7.0
Finland	0.7	-0.3	-0.4	0.3	0.3
Japan	0.6	0.0	0.0	0.1	0.1
New Zealand[b]					
Norway	2.3	-1.3	-1.4	10.3	9.3
Sweden	13.5	1.8	2.0	14.1	14.3
Switzerland	4.3	-0.1	-0.1	33.6	33.7
US[c]					
Total	78.8	10.3	18.0	5.2	5.7

[a] Including cork and cork products.
[b] New Zealand imports from socialist countries are $< 10 \times 10^3$ US$.
[c] US not included due to the lack of data.

15.1.4. Developing and socialist countries

As noted earlier, the tariff data for socialist and developing countries permit only a perfunctory investigation. Specifically, unweighted tariff averages for the large sample of these countries (including 13 African, 13 American, 9 Asian, and 5 Eastern European countries) have been computed. The results are summarized in *Table 15.3* (for details, see UNIDO, 1983).

Several observations emerge from *Table 15.3*. First, the tariff rates applied in socialist countries are lower than those in developing countries and in line with duties maintained by DMECs. Second, among the developing countries, the African states seem to be the most moderate in their tariff policy (but not in other aspects of import policy, see Section 15.2.4) as the tariffs applied by these countries are substantially lower than those applied by Asian and American developing countries. Third, the phenomenon of tariff escalation is also present in the tariff schedules of developing and socialist countries. Thus, the rates for secondary wood products are higher than those for primary products, which in turn exceed those for wood in the rough. An exception occurs for the socialist countries, which apply higher rates on primary rather than on secondary wood articles.

Table 15.3 Nonweighted average tariff rates on wood and wood products in selected developing and socialist countries (from National Tariff Schedules).

Importing markets	*Wood in the rough*	*Primary wood products*	*Secondary wood products*
Africa[a]	14.4	16.2	24.1
America[b]	26.2	37.6	52.5
Asia[c]	34.1	57.8	73.1
Socialist countries of Eastern Europe[d]	7.3	14.5	9.9

[a] Uganda, Central African Republic, Chad, Liberia, Zaire, Tunisia, Morocco, Mauritius, Malawi, Egypt, Nigeria, Ivory Coast, and Ghana.

[b] Paraguay, Mexico, Brazil, Argentina, Belize, Jamaica, Bahamas, Brazil, Bolivia, Colombia, Ecuador, Peru, and Venezuela.

[c] Bangladesh, Sri Lanka, Philippines, Pakistan, India, Republic of Korea, Turkey, and Cyprus.

[d] Poland, Hungary, Bulgaria, Czechoslovakia, and Romania.

15.2. Nontariff Barriers to Trade

Since the protective effect of tariffs is frequently seen by importing countries as inadequate and since tariffs are, in any case, difficult to manipulate in a quick and efficient manner owing to legal constraints, governments often rely in their trade policies on various nontariff measures. Further obstacles are placed in the way of international trade by large, private companies operating in a manner that hinders other traders' access to the market [5].

Especially striking about the current array of nontariff measures are its wide variety and its multiplicity of objectives and effects. Some studies suggest that over 200 different types of nontariff measures exist. The UNCTAD data base on governmental trade measures (see UNCTAD, 1983, 1985) provides for 105 categories and subcategories of product-specific measures, and 106 categories and sub-categories of generalized nontariff measures. Some of these measures are designed for direct intervention in trade, while some are designed for other purposes, but can affect trade in an indirect way.

15.2.1. Direct import controls

Since not all nontariff measures (i.e., measures that have a potential to distort international trade) constitute nontariff barriers (i.e., those measures that, in fact, distort volume, price, or directions of trade) five groups of the most explicit nontariff barriers are discussed in this chapter. Specifically, we concentrate on the governmental and on the product-specific border measures that are designed for the management of the inflow of foreign goods, and for which comprehensive and internationally comparable data are available. While there is room for debate about the composition of a complete set of nontariff barriers, our selection, drawn from official definitions and based on official sources, represents a minimum list of nontariff trade policies. It comprises:

(1) *Quantitative import restrictions. Prohibitions*, i.e., embargoes on the importation of a product. A prohibition may be total, may admit exceptions, or may operate only under certain conditions. *Quotas*, i.e., ceilings (specified in value or quantitative terms) imposed for a given period of time. *Discretionary import authorizations*, i.e., permission to import granted at the discretion of the competent authorities. *Conditional import authorizations*, i.e., permission to import granted subject to the importer undertaking commitments in areas other than importation or subject to specified overall economic conditions.

(2) *"Voluntary" export restraints.* Agreements between an exporter and an importer as to the maximum amount of exports to be effected within a given period of time [6].

(3) *Measures for the enforcement of decreed prices. Variable levies*, i.e., variable charges serving to equalize the CIF import price with a decreed price. *Minimum price systems*, i.e., the setting of a minimum import price by the importing country. Actual prices below the decreed minimum may trigger the imposition of additional duty or a price investigation. *"Voluntary" export price restraints*, i.e., agreement between the exporter and the importer on the minimum price to be observed by the exporter.

(4) *Measures increasing the landed price of imports. Tariff quotas*, i.e., the application of two tariff rates, the higher rate coming into operation when the quantity of imported goods exceeds a specified level [7].

(5) *Other import management measures. Antidumping and countervailing duties*, i.e., duties levied on a product that is sold in the importing country at a lower price than in the exporting country (dumping), or to offset rebates or subsidies provided for the production or export of a good (countervailing). Although the General Agreement on Tariffs and Trade (GATT) permits the use of these duties under certain circumstances, there is evidence that they are frequently applied in lieu of safeguards, with both the intent and effect of protecting domestic industry (see Finger *et al.*, 1982). *Price investigations*, i.e., these are usually triggered by charges made by domestic producers about unfair trading practices. While an investigation is obviously necessary to

determine the facts of dumping or subsidies, there is evidence that the inquiry process itself has a protective effect, independent of the eventual findings (see Finger, 1981). Also, in some cases, price investigations were a prelude to the negotiation of "voluntary" export restraints. *Monitoring*, i.e., close surveillance of imports of sensitive products, primarily by the means of automatic and liberal licensing. Surveillance may be the precursor to restriction [8] or may inhibit trade in its own rights.

All five groups represent genuine nontariff barriers, in the sense that they serve to control or restrict either the price or the quantity of imports. In some cases the mechanism is direct — e.g., for quotas, minimum price agreements, and "voluntary" export restraints — while in others, it is more subtle. For example, price investigations and surveillance measures are necessary precursors to control and thus create uncertainty and encourage "self-restraint" among exporters, irrespective of whether explicit protective action is subsequently taken.

15.2.2. The statistical indicators and data

To investigate the effect of nontariff barriers on international trade in wood and wood products, data collected by UNCTAD within the framework of its Data Base on Trade Measures have been used (see UNCTAD, 1983, 1985). As in the case of tariffs — due to the differences in availability and quality of data — different approaches have to be employed for the DMECs and the developing countries (for the socialist countries relevant information is not available). First, the data for the developed countries are recorded at the tariff-line level (i.e., at the level at which they are applied), but for several developing countries such detailed information is not available and thus the data are recorded at the more aggregated level of the four-digit groups of the Customs Co-operation Council Nomenclature (CCCN). Second, data for the developed countries contain information on the dates of introduction and elimination (if applicable) of individual nontariff barriers, while the data for the developing countries lack this detail. Third, as already noted, much more comprehensive and detailed import statistics are available for the developed than for the developing countries.

To measure the prevalence of nontariff barriers in the developed countries two indices are used [9]. For any importer, i, and type of nontariff barrier, let $N_{qx} = 1$ if there is a nontariff barrier on (tariff-line) imports of q from exporter x, and let $N_{qx} = 0$ otherwise. For sets of commodities, Q, and exporters, X, both indices take the form:

$$I = \frac{\sum_{q \in Q} \sum_{x \in X} W_{qx} N_{qx}}{\sum_{q \in Q} \sum_{x \in X} W_{qx}}$$

The *import coverage* ratio defines W_{qx} as the value of i's actual imports of q from x. The *frequency* ratio defines W_{qx} as the presence or absence of a flow of q from x to i; thus $W_{qx} = 1$ if (tariff-line) imports of q form x are nonzero, and $W_{qx} = 0$ otherwise.

In the case of developing countries' nontariff barriers the ratio of *affected product groups* is used. This is a simple indicator defined as the share of the four-digit CCCN groups affected by nontariff barriers in the total number of the four-digit CCCN groups in a given product category. The word "affected" is used here in preference to, for example, "covered" or "restricted", as a given nontariff barrier may apply only to part of a (four-digit CCCN) product group.

The purpose of the prevalence ratio is to measure the extent to which imports are covered (or affected) by nontariff barriers and not the degree to which they are restricted. Thus, it is a more elementary concept than a tariff average. An appropriate parallel is the ratio of dutiable to total (dutiable plus duty-free) imports. A tariff rate is, by its very nature, a measure of the "intensity" of restriction, whereas nontariff measures, unfortunately, provide us with no such "natural" measure of intensity: all we have is a "Yes or No" indicator — a strictly qualitative indication of whether or not governmental, and not just normal commercial, considerations influence trade.

Each of the three indices has strengths and weaknesses. The coverage ratio is possibly the most natural in that the extent of nontariff barrier is represented by the size of the particular trade flow it affects. Its drawback is that it understates the restrictiveness of barriers because the tighter a nontariff barrier, the lower is the relevant import.

The frequency ratio avoids some of the downward bias. The extent of nontariff barriers is measured by the number of trade flows that are subject to them so that every barrier on every observed trade flow receives equal weight. The difficulties are twofold, however. First, the frequency ratio ignores the perfectly natural differences in the sizes of different trade flows and, second, it is exaggerated by the tendency of trade classifications to become more fragmented the more sensitive and restricted is a category of trade. The ratio of affected product groups is a very rough indicator and cannot be compared with the other two. Since a given nontariff barrier may (and, in fact, frequently does) restrict only part of a product group the ratio is often overestimated. However, the restrictions of part of a product group will often affect trade in other (similar) commodities in that group.

15.2.3. Results: developed, market economy countries

In *Table 15.4* we summarize results for selected DMECs, including 17 main countries. The nontariff barrier data refer to 1983 and the import data to 1981. As can be seen from *Table 15.4*, nontariff barriers as they applied in 1983 would have covered 5.2% of import flows of wood and wood products, accounting for 18.9% of the 1981 import value. In absolute terms, 3.2 $\times 10^9$ of imports have been covered by nontariff barriers. These indices are lower than those for total imports, but the coverage ratio for wood is higher than that for industrial products (i.e., other than agricultural products and raw materials).

Table 15.4 Extent of developed countries[a] nontariff barriers on imports of wood and wood products, 1983 (UNCTAD Data Base on Trade Measures, see UNCTAD, 1983, 1985).

Products	*Coverage index*	*Frequency index*
Wood in the rough	0.0	0.0
Primary wood products	29.9	13.4
Secondary wood products	0.7	0.3
All above	18.9	5.2
Total imports	27.1	12.8
Industrial imports	16.1	10.8

[a] Australia, Austria, Finland, Japan, Norway, Switzerland, the US, and the EEC (10 members).

The nontariff barriers are concentrated in trade in primary wood products. Wood in the rough is free of any nontariff controls and the secondary products face only a few barriers. Ratios for the primary products are higher than the corresponding indices for total and industrial imports. As much as 30% of primary wood product imports is subject to nontariff controls: a very high figure indeed, considerably increasing the degree of bias faced by developing countries due to — as noted earlier — escalating tariff duties.

Two markets are primarily "responsible" for this high ratio, namely the EEC and the US. Switzerland, Finland, Austria, and Japan do not apply any direct controls to imports of primary wood products. The ratios for Australia (coverage ratio 2.6) and Norway (0.7) are very low. Similarly, the ratios for Greece (0.8) and Italy (2.3) are low. However, estimates for the FRG (11.8), Ireland (13.7), the Netherlands (18.8), Denmark (19.6) and the UK, Belgium, and Luxembourg (19.9) are high, while those for France (90.4) and the US (84.4) are very high.

The index for the US is a reflection of only one measure: countervailing investigation against imports of softwood fence, shakes, and shingles, and lumber from Canada. Otherwise, the US does not apply any nontariff controls to its imports of wood. The situation is different in the EEC, where, in addition to antidumping investigations (which in 1983 involved Brazil, Czechoslovakia, USSR, Sweden, Romania, and Poland) and the resultant duties (Czechoslovakia and Poland) or "voluntary" price undertakings (Brazil, Romania, Czechoslovakia, Finland, Norway, Poland, Spain, Sweden, USSR, Bulgaria, and Hungary), a number of other measures also affect the imports of wood products. For example, at the community level several items are subject to tariff quotas; the FRG, Belgium, Luxembourg, and the Netherlands restrict certain imports from the socialist countries of Eastern Europe and Asia; France applies discretionary licensing and the so-called "intracommunity surveillance". In *Table 15.5* we summarize estimates of the application of various nontariff barriers used by the developed countries.

Table 15.5 Extent of developed countries' nontariff barriers by type of measure, 1983 (UNCTAD Data Base on Trade Measures, see UNCTAD 1983, 1985).

Type of nontariff barriers	*Coverage index*	*Frequency index*
Quantitative restrictions	0.2	0.6
"Voluntary" export restraints	0.0	0.0
Decreed prices	0.0	0.0
Monitoring measures	3.1	0.9
Antidumping and countervailing actions	11.5	1.0
Tariff type measures	4.2	2.9

One other measure should be added to those listed in *Table 15.5*, namely technical standards. Health, sanitary, and other technical regulations exist in all countries and are introduced primarily for the protection of consumers. As such, they fall into the category of nontariff measures rather than barriers. At the same time, it is well known that, in many instances, such regulations with their severe requirements and complicated procedures are used with the objective to impede imports. Indeed, this is sometimes acknowledged by the governments concerned. For example, the trade-liberalization measures introduced by Japan in 1982 were primarily designed to bring some of the Japanese technical requirements and testing procedures in line with those applied in other countries.

Unfortunately, the UNCTAD Data Base does not contain information on such standards in all countries. A guarded conclusion as to their importance for international trade in wood may be drawn from the available evidence. Thus, it appears that sanitary standards cover as much as 98.1% of imports of all wood and wood products in Australia, 83.5% in Japan, and 21% in Switzerland. The extent to which these standards actually affect or restrict imports cannot be estimated without an investigation of their exact nature and requirements.

15.2.4. Developing countries

Developing countries resort to nontariff measures even more frequently than the developed countries due to a generally higher degree of government involvement in economic activities, as well as to the necessity to regulate tightly the allocation of scarce foreign exchange. Since this latter reason appears to be a dominant one, in choosing nontariff barriers they concentrate on global (i.e., not specified in terms of origin of imports), direct controls of import volume (UNCTAD, 1985). In this they differ from the developed countries, who apply nontariff barriers in pursuance of a much wider range of goals and thus resort to more diversified measures.

In *Table 15.6* we provide estimates of the extent of selected nontariff barriers in developing countries. Note that high incidence of quantitative restrictions (including prohibition, which is rarely applied in developed countries), which, due to its frequent occurrence in developing countries, is shown in *Table 15.6* as a separate category. Similarly, a high incidence was estimated for the monitoring measures. In contrast, price and tariff-type measures (i.e., nontariff barriers most prevalent in developed countries) are not applied to the developing country's imports of wood.

When nontariff barriers are investigated in more detail it is found that (as in the case of developed markets) there are marked differences in the extent of protection afforded to individual categories of wood products. Specifically, the share for wood in the rough is 29.1%, for primary wood products it is 27.3%, and for secondary wood products it is 37.3%. Thus, while in the developed countries primary wood products appear to attract most nontariff barriers, in the developing countries imports of secondary products face the highest barriers. In general, a large part of wood items imported by developing countries is affected by nontariff barriers.

Table 15.6 Share of product groups affected by nontariff barriers in developing countries (UNCTAD Data Base on Trade Measures, see UNCTAD, 1983, 1985).[a]

Type of nontariff barrier	*Wood and wood products*[b]	*Total Imports*
Total prohibition[c]	8.8	9.9
Conditional prohibition	1.3	1.8
Other quantitative restrictions[d]	22.3	20.8
Decreed prices	0.0	1.7
Monitoring measures	26.4	37.7
Antidumping and countervailing actions	0.0	0.0
Tariff-type measures	0.0	0.0

[a] Algeria, Indonesia, Nigeria, Saudi Arabia, Venezuela, Hong Kong, Brazil, Republic of Korea, Ivory Coast, Tunisia, Turkey, Chile, United Republic of Cameroon, Guatemala, Kenya, Malawi, Pakistan, Peru, Philippines, Sri Lanka, Thailand, and Mexico.

[b] Includes cork and cork products.

[c] Includes prohibition for trade as well as other (e.g., health and sanitary) reasons.

[d] Includes quotas (with the exception of tariff quota) and discretionary licensing.

15.3. Conclusions

In spite of several rounds of multilateral tariff negotiations, the MFN tariffs that face imports of wood products into the developed countries remain relatively high. The trade effects from the removal of these tariffs are estimated to be considerable; imports would increase by over US $950 $\times 10^6$ in 1976 terms.

Another important feature of tariffs on wood products is that they increase with the level of fabrication. Evidence of the sizeable tariff escalation can be seen both in aggregated and disaggregated tariff structures. While the tariff preferences appear to moderate the extent of escalation, they, nevertheless, could exercise considerable, detrimental influence on the processed exports of developing countries. Tariffs on wood products in developing countries are even higher than in developed economies and also escalate with the level of processing.

As in most other product categories, trade in wood and wood products is also regulated by means of nontariff measures. In the major developed countries, direct import controls as applied in 1983 would have covered about 19% of 1981 imports; in addition, imports are subject to — sometimes very stringent — technical standards. In the developing countries nontariff barriers are even more frequent. Thus, the quantitative restrictions affect 29% of categories of primary and 37% of categories of secondary wood products.

Appendix 15.1: Procedure Used to Estimate Trade Effects due to the Removal of Tariff Rates

The method used can be outlined as follows. First, where the country faces MFN tariffs the estimated trade expansion that accompanies a reduction in import duties was derived from a standard partial equilibrium trade model. The basic premise behind this approach is that imports, I, equal the difference between domestic consumption, C, and production, S. From this it follows that, if P is the domestic price observed at the import level, the following condition holds concerning the change in imports relative to prices:

$$\frac{\mathrm{d}I}{\mathrm{d}P} = \frac{\mathrm{d}C}{\mathrm{d}P} - \frac{\mathrm{d}S}{\mathrm{d}P} \qquad \text{(A15.1.1)}$$

Through appropriate algebraic manipulations, equation (A15.1.1) can be restated in a general elasticity form,

$$E_{\mathrm{i}} = E_{\mathrm{d}}(C/I) - E_{\mathrm{s}}(S/I) \qquad \text{(A15.1.2)}$$

where E_{i} is the price elasticity of import demand and E_{d} and E_{s} are the corresponding domestic demand and supply elasticities. In our analysis, E_{s} is assumed equal to zero. This rules out the specific consideration of domestic supply response or stock adjustments to changed prices as the tariffs are reduced. Thus:

$$E_{\mathrm{i}} = E_{\mathrm{d}}(C/I) \qquad \text{(A15.1.3)}$$

that is, the import demand elasticity is equal to the domestic demand elasticity weighted by the ratio of consumption to imports. Finally, the percentage change in imports, $\%\mathrm{d}\,I$ is derived from:

$$\%\mathrm{d}I = E_{\mathrm{i}}(\%P)I \qquad \text{(A15.1.4)}$$

where $(\%P)$ is the estimated percentage change in the domestic price of imports resulting from the tariff change.

Aside from cuts in the applicable MFN rates, separate estimation problems occur when tariff reductions change the tariff differentials that face various suppliers. Thus, the removal of MFN duty eliminates the preferential margin enjoyed by countries eligible for GSP or special preferences. As a result, products exported by these countries become relatively less competitive and some of the existing trade is directed to other suppliers.

A two-step procedure was used to estimate trade diversion due to the erosion of preferential margins. First, total trade diversion (TD) was derived from the formula:

$$TD = T_{\mathrm{m}} E_{\mathrm{c}}\, \mathrm{d}t/(1+t) \qquad (TD \leq T_{\mathrm{b}}) \qquad \text{(A15.1.5)}$$

where T_{m} represents the value of MFN trade, t is the tariff rate, E_{c} is the cross-price elasticity between those suppliers facing MFN rates and those receiving preferences, and T_{b} is the value of imports from this second group of suppliers. Next, trade diversion from individual suppliers (TD_i) was estimated using the assumption of constant shares in total trade. Specifically, for countries that experience erosion of preferential tariff margins, the magnitude of the accompanying trade losses were approximated from

$$TD_i = S_{i\mathrm{b}} TD \qquad \text{(A15.1.6)}$$

where $S_{i\mathrm{b}}$ represents the share of a preference-receiving country in total preferential imports. These preference-receivers' losses were then allocated to individual countries facing eliminated MFN tariffs on the basis of their trade shares.

In our estimates, account was taken of ceilings or quotas on GSP trade. Specifically, if any supplier exceeded the established ceiling for a product, with the result that its imports faced the MFN rate, the GSP duty for the item was not assumed to be in effect and equation (A15.1.4) was used to estimate the trade effects. Also note that the price elasticities were matched to data at the four-digit CCCN level, a procedure that resulted in all tariff-lines within a CCCN having the same elasticity. Owing to difficulties in obtaining estimates for some smaller industrial countries, demand elasticities for other industrial nations were used as a proxy [10]. Since empirical estimates for the cross-price elasticity term were considered less reliable than those for the import demand elasticities, two different values representing high and low estimates (–2.5 and –1.5) were employed in equation (A15.1.5). This generated projections of a probable range in trade diversion [11].

While the underlying model assumes that supply can be expanded without any increase in unit costs, to the extent that costs *do* rise this would lead to an upward bias in the trade creation estimates. The projections are also static in that they only reflect the effects of tariff cuts and do not account for other factors, such as the existence of nontariff barriers or growth in import markets.

Notes

[1] In order to calculate these, the following procedure was applied. First, a tariff average for each tariff position was calculated using 1976 values and the import duties actually facing them [i.e., MFN, Generalized System of Preferences (GSP), or special preferences]. Second, the average rates for tariff positions were aggregated to the product group level, using shares of tariff positions in total imports of this product group.

[2] In the case of preferences extended by the developed countries to the developing countries within the framework of the GSP, the rate of utilization varied in 1980 between 50% to 80% (UNCTAD, 1983a, p 7).

[3] Numerous studies have demonstrated a pronounced general tendency for tariffs in industrialized countries to increase (or escalate) with the degree of product fabrication. The existence of such tariff structures has been taken as evidence of a bias against trade in processed goods. Moreover, recent

studies have argued that such a bias may exist even when tariff rates do not escalate, because the sensitivity of processed goods to a given tariff rate is generally greater than that of primary products (i.e., the import demand elasticity for processed products is normally higher than for unprocessed products; see, for example, Yeats, 1981).

[4] To condense *Table 15.2* as much as possible the 1976 trade base has not been included, but these values can easily be derived. Trade figures for 1976 have been used as a base for all projections, due to the lack of more recent, comprehensive, tariff-line import statistics.

[5] For example, it is estimated that between 30% and 40% of international trade transactions is between related parties (UNCTAD, 1983a, p 6).

[6] While voluntary export restrictions are administered by exporting countries, their imposition is the result of successful protectionist requests in importing countries.

[7] Note that tariff quotas may also provide for preferences if the lower rate is set below the applied MFN rate.

[8] Indeed, EEC regulations [e.g., *Council Regulation (EEC) 288/82*] explicitly refer to surveillance for this purpose (see the *Official Journal of the European Communities*, 1982).

[9] This analysis draws heavily on Nogués *et al.* (1985).

[10] The basic source of import demand elasticities was Stern *et al.* (1976).

[11] A similar procedure was used in a Brookings Institution study of the MFN trade effects (see Cline *et al.*, 1978). Also note that the figures (–2.5 and –1.5) are consistent with results from other empirical studies that have estimated cross-elasticities. For example, Kreinin (1967) computed an average elasticity of substitution among products of 10 advanced countries to be –2.6, while the elasticity of substitution between American and European manufactured products was estimated to be –2.5 for the period between World Wars I and II. The elasticity of substitution between socialist countries and developing country products imported by France, Italy, the FRG, and the UK has also been estimated to be –1.62, –0.39, –1.22 and –1.86, respectively.

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CHAPTER 16

Interregional Modeling

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Research on the modeling of spatial commodity markets and interregional trade has progressed dramatically during the past two decades. At the national level, increased attention to spatial models reflects the need for greater geographical specificity in management planning and policy analysis. The growing importance of international trade in virtually all industrial sectors has also spawned interest in spatial models as vehicles for analyzing trade policies, business strategies, and economic development options.

In this chapter we review the major approaches available for modeling spatial markets, describe the economic and mathematical structure of each, and evaluate their advantages and limitations. Examples of the application of each approach to the forest products sector are provided. Spatial modeling in the forest sector draws heavily on developments in agricultural and general economics. Thompson (1981) provides an excellent review of spatial modeling in agricultural markets [1]. Previous reviews of applications in the forest sector include Gallagher (1983) and Row and Roberts (1984). In the present review we build on Thompson's (1981) taxonomy of models and identify five broad classes:

(1) Two-region, nonspatial models.
(2) Multiregion, nonspatial price equilibrium models.
(3) Spatial equilibrium models.
(4) Trade flow and market share models.
(5) Transportation models.

Detailed attention is given to the the class of spatial equilibrium models in the light of the use of this form in the IIASA Forest Sector Project Global

Forest Sector Model, often called the Global Trade Model (IIASA GTM). To illustrate the mathematical structure of each model class, a common notation is used for demand and supply relations, prices, and flows:

$$D_{i,k} = D_{i,k}(P_{i,k}, P^s_{i,k}, A_{i,k}) \tag{16.1}$$

$$S_{i,k} = S_{i,k}(P_{i,k}, P^o_{i,k}, T_{i,k}) \tag{16.2}$$

are the demand and supply equations, respectively, for commodity k in region i, where $D_{i,k}$, $S_{i,k}$ are the demand and supply quantities, $P_{i,k}$ is the demand or supply region price, $P^s_{i,k}$ is the price of substitutes, $P^o_{i,k}$ is the price of other inputs, $A_{i,k}$ is a measure of end-use demand activity, $T_{i,k}$ is some measure of technology employed in production, and the product index k has the range $k = 1,\ldots,p$. Deleting the explicit representation of all the determinants of demand except prices, equation (16.1) may also be written as:

$$D_{i,k} = D_{i,k}(P_{i,1},\ldots,P_{i,p}) \tag{16.3}$$

Deleting references to input prices and technology and assuming joint production, the supply relations of equation (16.2) may also be written as:

$$S_{i,k} = S_{i,k}(P_{i,1},\ldots,P_{i,p}) \tag{16.4}$$

Trade flows between regions are denoted by $Q_{i,j,k}$, meaning the flow of commodity k from region i to region j. Transport costs and other shipping charges per unit of commodity are denoted similarly as $C_{i,j,k}$. Where it is important to distinguish between prices in demand and supply regions, prices are further indexed as P^D and P^S.

Measurement of prices in spatial models may be at the point of delivery (often termed CIF) or at the point of origin (often termed FOB), in currency of the shipping or receiving country, and in real (deflated) or nominal terms, as appropriate for the model form being used. For models in which nominal prices are employed, currency units may be transformed by means of nominal or current-period exchange rates. In other cases, where it is appropriate to deflate prices by indices specific to each country or region, a deflated or real exchange rate must be used to maintain comparability of price measures. For example, suppose that the nominal prices for some particular commodity in countries i and j in period t are given by $P_{i,t}$ and $P_{j,t}$, the general indices of prices (deflators) by $I_{i,t}$ and $I_{j,t}$, and the nominal exchange rate (i's currency per unit of j's currency) by $X_{i,j,t}$. Conversion of prices in country j to units of i's currency in *nominal* terms is accomplished by the relation:

$$P_{j,t}^{i} = P_{j,t}X_{i,j,t}$$

where $P_{j,t}^{i}$ is country j's price in units of i's currency. This same conversion in *real* terms, however, entails the expression:

$$P_{j,t}^{i,\mathrm{real}} = (P_{j,t}/I_{j,t})\ X_{i,j,t}\ (I_{j,t}/I_{i,t})$$

where $P_{j,t}^{i,\mathrm{real}}$ is country j's price in terms of real units of i's currency. The real versus nominal distinction is particularly critical in any of the equilibrium model forms where price comparisons are made across regions or countries. In the remaining discussion, it is assumed that these conversions, where necessary, have been made in the appropriate manner.

16.1. Two-Region, Nonspatial Models

The most aggregate model form, though not necessarily the simplest, involves division of the market area into two geographical units: the target country or region of interest and the "rest of the world" (denoted ROW). Depending on whether the target country is a net importer or exporter of the product under study, an excess demand (supply) function is derived as the difference between domestic demand and supply relations. A judgment must then be made as to the influence of the country's imports (exports) on market area prices. If the country is deemed a "small" element in the market, hence a price taker, trade prices may be taken as exogenous. If the country is a major element, hence has a significant influence on trade price, a complementary export supply (import demand) relation must be added for the rest of the world and the trade price made endogenous. The trade price could be defined at any of a number of reasonable geographical locations. It is most common to use the landed (CIF) or export (FOB) price in the country in question, again depending on the direction of net trade.

In terms of the general notation adopted above, models of this group can be described as follows (we assume an importing country and that the geographic boundaries of supply and demand regions are identical):

$$D_i - S_i = E_i^D \tag{16.5}$$

is country i's (excess) demand for imports;

$$\sum_{j \neq 1} (S_j - D_j) \tag{16.6}$$

is ROW export supply to country i; and

$$E_i^D = E_W^S \tag{16.7}$$

is the market balance. The summation on the left-hand side of equation (16.6) is included to emphasize that the ROW category is potentially composed of many separate countries or regions. In practice, the parameters of this relationship are commonly estimated from aggregate data rather than by actual summation of separate relations for the several components.

While this model form has been extensively used to introduce trade into otherwise closed macroeconomic models, its application in forest sector analysis has been limited. Mori (1981) presented an econometric model of the Japanese log market (all species as a composite), which included demand and supply relations for imported logs linked to supply and demand relations for domestic logs. Wiseman and Sedjo (1981) examined the effects of log export restrictions in the western US using judgmental estimates of demand and supply elasticities coupled with an explicit treatment of the vertical linkage of lumber and log markets. Adams (1974) developed "partial reduced form" relations for log export volumes and prices in the Douglas-fir region of the US based on a model using equations (16.5)-(16.7).

This model form has the advantages of focusing attention on the specific country of interest and of apparent simplicity. It may be particularly useful for countries or products where trade volumes are small or for modeling in which the principal focus is on a more detailed analysis of the domestic market and the price responsiveness of off-shore trade need be recognized only in a relatively crude fashion.

Drawbacks stem mainly from the high degree of aggregation in the ROW component. Lumping all trading partners into a ROW category precludes the identification of bilateral flows. As a consequence, the effects of tariffs or other trade barriers can only be approximated. Further, it may be difficult to give any meaningful interpretation to ROW supply or import demand elasticities, if the countries included in the ROW category are numerous or highly diverse. Specification error is also a problem in this case, since explanatory variables in equation (16.6) should include both demand- and supply-side forces in all of the supplying countries. This is also true, but often ignored, for the domestic import demand relation (16.5).

Specification error and problems of simultaneity may arise when the model is applied to only a single product category, ignoring substitute–complement and vertical–horizontal market linkages. Finally, as Thompson (1981) notes, judgment as to whether the country is a significant or minor element in market price setting is essentially arbitrary in many instances, providing a further opportunity to ignore an actual case of simultaneous price determination.

16.2. Multiregion, Nonspatial, Price Equilibrium Models

Models in this class ignore bilateral trade linkages. Excesses of demand and supply from all trading countries interact to determine a single, "global" equilibrium price. Prices in all countries are adjusted to the currency and location of a particular reference country by exchange rates and transport costs between each country and the reference country.

If country j is taken as the reference country and, again for notational convenience, assuming that demand and supply regions are identical, the price adjustment process can be described as:

$$P_i' = X_{j,i}\, P_i - C_{i,j} \tag{16.8}$$

where P_i' is the price in country i, expressed in country j's currency and adjusted for the transport cost from i to j, $X_{j,i}$ is the currency exchange rate between j and i, and $C_{i,j}$ is the transport cost from i to j in units of j's currency. Demand and supply relations are then written in terms of the adjusted prices as:

$$D_i' = D_i'\,(P_i', P_i^s, A_i) \tag{16.9}$$

$$S_i' = S_i'\,(P_i', P_i^o, T_i) \tag{16.10}$$

and excess demand or supply as:

$$E_i^S \text{ or } E_i^D = D_i' - S_i' \tag{16.11}$$

Market equilibrium requires that:

$$\sum_i E_i^D = \sum_j E_j^S \tag{16.12}$$

and

$$P' = P_1' = P_2' = \cdots = P_j = \cdots = P_n' \tag{16.13}$$

This model form has been applied to problems of both inter- and intra-country trade. Reported research varies considerably in terms of the number of supply and demand regions and their degree of geographical aggregation. Adams (1977) developed a four supply regions–one demand region model of intra-US trade in softwood lumber and plywood. Lange (1979) and Binkley and Cardellichio (1983) used variations of this model form to study US hardwood lumber markets. Flora and Vlosky (1984) examined Pacific Rim trade in low-grade softwood logs, employing six net-exporting countries and four net-importing countries.

Since this model form does not employ the highly aggregated rest of the world region, the potential specification problems of the two-region model are avoidable. Bilateral flows cannot be identified, however, nor can specific bilateral trade restrictions be represented. Thompson (1981) suggested that general tariff or quota restrictions imposed by a country on all trading partners can be represented through the appropriate adjustment of demand or supply equation coefficients or through the use of constraints in an iterative method of model solution (such as Gauss–Seidel or Newton–Raphson).

An important limitation of this model form is the assumption of a single equilibrium price in the market area. It is a common observation in importing countries that goods from certain countries of origin sell at a significant discount or premium relative to prices of the same class of goods from other countries. This may reflect the inappropriateness of the homogeneous product assumption maintained in this (and most other) model form or an actual consumer preference for goods from certain countries of origin. The model cannot, in any event, recognize such price differentials.

16.3. Spatial Equilibrium Models

Spatial equilibrium (SE) models differ from all other classes of models, save those discussed in Section 16.5, in that demand and supply quantities, prices, and bilateral trade flows are determined endogenously in the model solution process. These models also give explicit consideration to the costs of transportation and handling along each shipment route included in the market area. Solution of SE models involves the use of some direct optimization or iterative scheme to find a set of demands, supplies, prices, and trade flows that satisfies the conditions for market equilibrium for the particular market structure (either competitive or noncompetitive) under investigation.

In the competitive case, given prespecified sets of producing and consuming regions (which may have the same or different geographical boundaries), a spatial market is in equilibrium when the following conditions are satisfied (Zusman, 1969):

Regional demand and supply relations:

$$P^D_{j,k} = p^D_{j,k}\,(D_{j,1},\ldots,D_{j,P}) \qquad \text{for all } j \text{ and } k \tag{16.14}$$

$$P^S_{i,k} = p^S_{i,k}\,(S_{i,1},\ldots,S_{i,P}) \qquad \text{for all } i \text{ and } k \tag{16.15}$$

Shipments balance relations:

$$S_{i,k} \geq \sum_{j=1}^{n} Q_{i,j,k} \qquad \text{for all } i \text{ and } k \tag{16.16}$$

$$D_{j,k} \leq \sum_{i=1}^{m} Q_{i,j,k} \qquad \text{for all } j \text{ and } k \tag{16.17}$$

Zero profit condition:

$$P^D_{j,k} - C_{i,j,k} - P^S_{i,k} \leq 0 \tag{16.18}$$

$$(P^D_{j,k} - C_{i,j,k} - P^S_{i,k})Q_{i,j,k} = 0 \qquad \text{for all } i,\ j, \text{ and } k \tag{16.19}$$

Shipment nonnegativity:

$$Q_{i,j,k} \geq 0 \qquad \text{for all } i,\ j, \text{ and } k \tag{16.20}$$

These conditions require that demand and supply regions operate on their respective demand and supply functions, that supply regions produce at least as much as they ship, that demand regions consume no more than they receive, that unit profits for the kth commodity be zero in cases where bilateral flows (from i to j) are positive and nonpositive where bilateral flows are zero, and that bilateral flows must be nonnegative. The sense of the zero profit conditions follows from the competitive assumption: if a positive marginal profit were possible along some arc (i,j) arbitrage would occur so as to drive this profit to zero.

Applications of the SE model differ by the means used to attain these conditions. Following the initial work of Samuelson (1952), so-called "programming approaches" establish a formal equivalence between the equilibrium problem and an extremum problem. A function is sought such that the necessary and sufficient conditions for an extremum of this function are identical with the equilibrium conditions noted above in the competitive case (Zusman, 1969). For continuous demand and supply relations, the extremum problem can be written in general as:

$$\begin{aligned} \max \quad & \sum_{j=1}^{n} \sum_{k=1}^{p} \int_{0}^{D_{j,k}} P^{D}_{j,k}(V_{j,1},\dots,V_{j,p})\,\mathrm{d}V_{j,k} \\ & \times \sum_{i=1}^{m} \sum_{k=1}^{p} \int_{0}^{S_{i,k}} P^{S}_{i,k}(V_{i,1},\dots,V_{i,p})\,\mathrm{d}V_{i,k} \\ & \times \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} C_{i,j,k}\, Q_{i,j,k} \end{aligned} \tag{16.21}$$

subject to:

$$S_{i,k} \geq \sum_{j=1}^{m} Q_{i,j,k} \qquad \text{for } i = 1,\dots,m \text{ and } k = 1,\dots,p \tag{16.22}$$

$$D_{j,k} \leq \sum_{i=1}^{n} Q_{i,j,k} \qquad \text{for } j = 1,\dots,n \text{ and } k = 1,\dots,p \tag{16.23}$$

and $S_{i,k}$, $D_{j,k}$, $P^{S}_{i,k}$, $P^{D}_{j,k}$, and $Q_{i,j,k}$ are all nonnegative. The integrals in equation (16.21) define the areas under the demand and supply curves, respectively, for all products in all demand and supply regions. The difference between the two sums of integrals gives the sum of consumers' and producers' surpluses across all products and regions. The objective is to maximize this sum of surpluses less transportation costs — a quantity called "net social payoff" by Samuelson (1952). The Kuhn–Tucker conditions for maximization of this objective subject to constraints (16.22), (16.23), and nonnegativity are precisely those of equations (16.14)–(16.20). The objective is "artificial" and, once a market solution is obtained through its maximization, the result need have no necessary social welfare interpretation (Samuelson, 1952). Of course, welfare interpretations can be drawn and may be quite useful, as in the analysis of the distributional effects of alternative trade or development policies (see, for example, Adams and Haynes, 1981).

As Zusman (1969) and Takayama and Judge (1971) note, the integrals in equation (16.21) exist only if the demand and supply functions of equations (16.14) and (16.15) are integrable. This requires that the matrices of cross-partial derivatives of equations (16.14) and (16.15) be symmetric. When production satisfies classical competitive conditions for joint products, supply relations automatically meet these requirements. For demand relations, however, the symmetry conditions hold only under certain restrictions, e.g., if the income elasticity of demand for all analyzed commodities is zero [2]. Where demand and supply relations are estimated without restrictions or reference to a specific production structure, as is often the case, the symmetry conditions are satisfied only by chance [3].

The programming approach requires conversion of the maximum problem to some specific programming framework. The general problem of equations (16.21)–(16.23) involves maximization of a nonlinear objective function, subject to a set of linear constraints and nonnegativity conditions. While computer-based algorithms are available to solve such problems, only two frameworks have been widely employed in practice. Takayama and Judge (1971) have demonstrated the applicability of quadratic programming to the case where demand and supply are linear and the integrals in equation (16.23) are quadratic. This approach has been widely applied in the study of agricultural markets and was recently used by Buongiorno and Gilless (1984) in an analysis of the North American newsprint industry.

An alternative linear programming approach, which places no restrictions on the functional forms of the demand and supply relations, was described by Duloy and Norton (1975). In this method, the integrals in equation (16.21) are linearized by segmenting the *areas* under each demand and supply relation into a series of intervals. For example, in the case of the demand relation in region j, new activities ($w_{h,j}$) are defined, one for each interval ($h = 1,\ldots,I$), which represent the weight for (or fraction of) that interval included in the problem solution. The objective function coefficients of these activities ($A_{h,j}$) are the total area under the respective demand function up to the quantity represented by the end point of the interval ($Q_{h,j}$). The area integral in equation (16.21), for a given demand region and product, can thus be replaced by the approximating expression:

$$\sum_{h=1}^{I} w_{h,j} A_{h,j} \qquad (16.24)$$

New constraints are added, limiting the sum of the weights to a value no larger than unity and requiring that each weight be nonnegative. The regional demand quantity, D_j, is redefined as a convex combination of the interval quantities:

$$D_j = w_{1,j}\, Q_{1,j} + \cdots + w_{I,j}\, Q_{I,j} \tag{16.25}$$

Supply equations would be treated in an exactly analogous fashion.

An important modification of this approach has been demonstrated by Takayama and Judge (1964, 1971) in which the supply relations (16.15) are replaced by an activity analysis formulation. Input–output coefficients are employed to represent the requirements for both manufactured goods and raw materials in the production of a unit of some particular type of good (or of a good produced by one of several possible processes). The prices of inputs may be taken as fixed, as set by price-sensitive supply relations, or as some combination of fixed and variable components. Since the supply relations (16.15) are replaced by their constituent cost elements, the supply terms of the objective function (16.21) must be modified to include deductions of areas under the supply functions for price-sensitive inputs and for the total costs of any inputs with fixed prices. The demand–supply balance constraints (16.22) and (16.23) must also be modified to allow for the net production of raw materials and final goods, as well as for interregional flows.

Haynes (1975) described an early application of the linear programming SE approach to an analysis of the US softwood forest products sector. The linearized demand representation of Duloy and Norton (1975) was employed together with an activity analysis representation of manufacturing activities subject to capacity and resource availability constraints. Gilless and Buongiorno (1985, but see also Buongiorno and Gilless, 1983, 1984) used the linear programming SE structure to model world pulp and paper markets. Their analysis contains the most geographic detail for North America, with off-shore regions aggregated as Western Europe, Japan, and ROW. The model allows spatial flows and simultaneous price equilibrium at the pulpwood, recycled fiber, pulp, and paper and board market levels. The Duloy and Norton (1975) linearization process was used at several market levels when demand or supply relations are price sensitive. The IIASA GTM (as described in detail in Part V) is a further example of the application of this modeling approach.

A second major category of solution methods for spatial equilibrium problems is variously termed "recursive" or "reactive" programming (RP). These methods have a long history in the analysis of agricultural markets with, perhaps, the best-known approach being that devised by Tramel and

Seale (1959). In essence, RP is a *tatonnement* process in which successive approximations of the equilibrium market solution are computed. An iterative system of computations is employed, which adjusts quantities produced, consumed, and transported among regions until the equilibrium conditions (16.14)–(16.20) are satisfied.

Actual procedures vary substantially between different applications of the approach, but can be generalized as in *Table 16.1.* In effect, this process allows each producing region to "react" in turn to the revised production and shipments plans of all other regions until no producer desires, or can benefit from, a change in plan. Steps (3) and (4) insure that for any arc where $Q_{i,j,k} > 0$ the associated $R_{i,j,k} = 0$ and that if $R_{i,j,k} < 0$ then $Q_{i,j,k} = 0$. The final step insures that no $R_{i,j,k} > 0$ exists in the final solution.

Starting solutions in Step (1) may be conveniently obtained from the previous period's actual (or estimated) values. King and Ho's (1972) version of RP includes a provision for obtaining starting values of supplies and demands by simultaneous solution of the equation system, ignoring transportation costs. An initial estimate of the shipments pattern is then obtained using a transportation linear programming code. This same transportation code can also be employed at various points during the RP iterations to obtain a new set of shipments that minimize transportation costs (replacing the current $Q_{i,j,k}$ as computed by the RP calculations). Since the final equilibrium solution has the property that transportation costs are minimized given the equilibrium supply and demand quantities, this approach is thought to reduce the number of iterations required to obtain a solution. Whether such a reduction is realized appears to depend, in the author's experience, on the specific set of demand and supply relations being analyzed.

Adams and Haynes (1980) have applied RP in a model of the North American softwood lumber and plywood industries. The actual spatial model involved only a single market level, that for lumber or plywood, since raw materials (logs) were assumed not to move across regional boundaries. The model was used to examine an array of policy and cost shifts that affected intra- and inter-national trade, including tariffs and quotas on Canadian softwood lumber imports. Boyd (1983) and Boyd and Krutilla (1984) employed RP to examine the effects of US intercoastal shipping regulations on the North American lumber market and the impacts of a tariff on Canadian lumber imports to the US.

One of the major drawbacks of the RP approach has been the inability of existing algorithms to handle more than one market level in the same equilibrium solution process. In a recent study of African–European trade in tropical logs and sawnwood, Adams (1983, 1985) illustrated an iterative procedure based on the Gauss–Seidel method designed to seek

Table 16.1 Summary of the Reactive Programming algorithm.

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(1) Begin with some initial solution giving volumes produced and consumed in supply and demand regions and shipment flows. Set the supply region index $i = 1$, the demand region index $j = 1$, and the product index $k = 1$.

(2) For supply region i, treat the production and shipment patterns from all other supply regions as fixed and compute the current demand region prices and supply region costs and the change in net returns that would result from a one-unit change in shipments along the shipment path (i,j). Unit net returns for supply region i shipping product k along arc (i,j) are defined as $R_{i,j,k} = P^{D}_{j,k} - P^{S}_{i,k} - C_{i,j,k}$. The change in returns along this arc is:

$$R'_{i,j,k} = \partial R_{i,j,k}/\partial Q_{i,j,k} = P'^{D}_{i,j,k} - P'^{S}_{i,j,k} \tag{16.26}$$

Note that, in general, these derivatives are functions of both the price of the product in question and the prices of all other products.

(3) If $R_{i,j,k} > 0$ go to Step (4); if $R_{i,j,k} \leq 0$ and $Q_{i,j,k} = 0$ go to Step (5).

(4) Compute the new flow volume $Q_{i,j,k}$ using Newton's method:

$$Q^{\text{new}}_{i,j,k} = Q^{\text{old}}_{i,j,k} - R_{i,j,k}/R'_{i,j,k} \tag{16.27}$$

$Q^{\text{new}}_{i,j,k}$ must, of course, be nonnegative and no larger than the volume that would drive $R_{i,j,k}$ to zero.

(5) If all demand regions have been examined for supply region i, increment the supply region index and go to Step (2). If not, increment the demand region index j and go to Step (2). If all demand and supply regions have been examined, go to Step (6).

(6) If all the products have been examined go to Step (7), otherwise increment the product index k and go to Step (2).

(7) If the set of $Q^{\text{new}}_{i,j,k}$'s resulting from the completion of Steps (2)–(6) differ by less than some tolerance from those obtained in the preceding iteration, stop. If not, take the current solution as the starting solution and go to Step (1).

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simultaneous equilibria in both product and related factor markets. The process involves exchanging equilibrium prices between successive (independent) solutions of the market levels until prices stabilize.

One of the principal advantages of SE models for some applications is the endogenous determination of spatial flows. Practical experience with these models suggests, however, that they commonly fail to explain "minor" bilateral flows and may err substantially in predicting the size of larger flows. What is more, the predicted pattern of flows can be quite sensitive to shifts in transportation costs or in the parameters of supply and demand relations. This behavior stands in sharp contrast to the usual observation that interregional flow patterns are relatively slow to change — that is, they exhibit some "inertia".

Plausible explanations for errors in flow predictions and the volatility of flow patterns in SE models are numerous and, as Thompson (1981) points out, mostly relate to one or more failures in the underlying model assumptions. SE models ignore the heterogeneity of goods within a given commodity class, consumer preferences for goods based solely on country of origin, and the costs and time delays associated with maintaining bilateral trade links. SE models also assume perfect certainty and hence abstract from the policies of some importers of diversifying sources so as to limit the impacts of trade disruptions (e.g., from embargoes or natural disasters). Finally, SE models generally assume perfect competition in regional and world markets [4]. This is clearly in error in the case of the centrally planned economies and may also misrepresent actual behavior in the case of certain products in market economies as well.

As a final point, note that SE methods have been modified in some applications to recognize these limitations. The IIASA GTM (see Part V) and the pulp and paper model of Buongiorno and Gilless (1984) include explicit "inertia" constraints on specific bilateral flows to insure that a flow is included in the solution and to retard the speed of adjustment. These restrictions (both upper and lower bounds) can also be incorporated into RP methods. But while these limitations induce the desired model behavior, they carry with them the additional problem of explaining changes in the constraints over time in a dynamic simulation. The IIASA GTM also employs explicit models of the production and trading strategies of the centrally planned economies. This addition overcomes the most obvious problems of the competitive assumption in SE, but does not address other than competitive behavior in market economies.

16.4. Trade Flow and Market Share Models

Models in this category are characterized by their focus on individual bilateral trade flows [5]. Model forms and solution methods are varied, but in general, flows are explained by the specification of separate relationships (or submodels) for each flow of interest. For convenience of exposition, in the following discussion we divide these models into three broad groups.

16.4.1. Market share models

Some of the earliest work on international trade flows sought to explain differences in import demand characteristics depending on the country of origin or destination of the product. These studies all posit import demand or market share relationships for particular countries (or regions) and particular commodities that depend on the relative prices of imports and substitutes and, depending on the specific theory employed, on other, derived demand shifters, such as output price or a measure of activity in the end-use industry. Recent studies by Buongiorno *et al.* (1979) of US softwood lumber import demand, by Blatner (1983) of world demand for solid wood and fiber products by country of origin, by Luppold (1984) of European demand for US oak lumber imports, and by Chou and Buongiorno (1984) of EEC demand for US forest products imports all employ single equation models of demand of the general form:

$$Q_{i,j,k} = Q_{i,j,k}\,(P'_{i,k}, P'_{r,k}, P^o_j, P^{\text{output}}_j \text{ or } A_j) \tag{16.28}$$

where the primed variables are price adjusted for exchange rate and transport costs to the currency and location of the demanding region j, $P'_{i,k}$ is the price of good k imported from region i, $P'_{r,k}$ is the price of good k either from the import $(r \neq j)$ or from the destination region $(r = j)$, P^o_j is the price of other inputs in the importing region j, P^{output}_j is the price of output made from the good k in region j, and A_j is a measure of activity in end-use industries (e.g., housing, furniture, etc.) in importing region j. Demand relations of this form obtain from a general consideration of derived demand theory or from an explicit theory of cost minimization subject to technology constraints.

An alternative form based on work by Armington (1969) has been employed by Chou and Buongiorno (1983) in a study of US demand for imported hardwood plywood by country of origin:

$$Q_{i,j,k}/Q_{l,j,k} = f(P'_{i,k}/P'_{l,k}) \tag{16.29}$$

where i and l refer to two competing sources of imports in market region j. A further variant has been employed by Castillo and Laarman (1984):

$$Q_{i,j,k}/\sum_{i=1}^{m} Q_{i,j,k} = f(P'_{i,k}/P'^{0}_{j,k}) \tag{16.30}$$

where $P'^{0}_{j,k}$ refers to the volume weighted average of delivered prices (in region j) from all import sources $(i = 1,\ldots,m)$.

A third (but closely related) form of this model was employed by Cardellichio and Veltkamp (1981) to explain interregional and import shipments in the US softwood lumber and plywood markets. A typical market share relation from this study can be written as:

$$Q_{i,j,k} / \sum_{i=1}^{m} Q_{i,j,k} = f(P'_{i,k} / P'^{0}_{j,k} \, , \, Q_{j,i,k} / \sum_{j=1}^{n} Q_{j,i,k}) \tag{16.31}$$

where the final term on the right-hand side is the supplying region's share of its "home" market, which is intended as an indicator of suppliers' preference for less distant markets. One such relationship was developed for each source–destination pair.

16.4.2. Multiple-flow equilibrium models

Models in this class develop explicit demand and supply relationships for each bilateral flow of interest. For a given region, demand or supply relations may be interdependent in prices or quantities. Models may also consider more than one market level (e.g., logs and lumber). Solution of the full system of equations gives equilibrium prices and flows. A typical set of relationships for import flows from two regions, r and i, to a single demand region, j, for a single product k would include the equations:

$$\begin{array}{l} \left.\begin{array}{l} j\text{'s demand from } r \\ j\text{'s demand from } i \end{array}\right\} \begin{array}{l} \text{generally taken as interdependent} \\ \text{in import prices from } r \text{ and } i \end{array} \\ r\text{'s supply to } j \\ i\text{'s supply to } j \\ \text{balance relations for each flow, } r \text{ to } j \text{ and } i \text{ to } j \end{array} \tag{16.32}$$

Examples of applications of this model type include McKillop's (1973) study of US–Canada–Japan trade in softwood logs and lumber and studies by Nomura and Yukutake (1982) and Yukutake (1982) of the Japanese solid wood products sector.

16.4.3. Single-flow equilibrium models

Models in this class generally focus on the bilateral trade of only two regions, with considerable detail for domestic production and total demand in each region. Trade flows are determined as part of the equilibrium market solution through market balancing identities between the two regions, rather than by means of explicitly estimated excess demand–excess supply relationships. More than one market level may also be considered. A typical structure, involving two regions r and j, might appear as:

$$\begin{aligned}
&D_r = D_r\,(P_r)\\
&D_j = D_j\,(P_j)\\
&S_r = S_r\,(P_r)\\
&S_j = S_j\,(P_j)\\
&D_r + D_j = S_r + S_j\\
&P_r = P_j\,X_{r,j} + C_{j,r}
\end{aligned} \tag{16.33}$$

Examples of studies that have employed this approach include Adams' (1975) analysis of the Lake States' pulpwood trade, a model of US–Japan log and lumber trade by Gallagher (1980), a model of US–Canadian lumber trade by Adams *et al.* (1985), and an analysis of pulpwood markets in Michigan by Merz (1984). Gallagher (1983) provides an extensive theoretical examination of this general approach in the context of a regional model of North American trade in solid wood and fiber products.

Models in all three of the above subclasses generally provide better explanations of historical, bilateral flow patterns than do the SE models. As part of dynamic projections they also exhibit desirable inertia properties, particularly when the endogenous price and volume terms on the right-hand sides of relations (16.29)–(16.33) are expressed as distributed lags, as is often the case. Short-term flow stability notwithstanding, however, it is reasonable to expect that flow patterns in competitive markets will gradually approach those of the SE solutions, given sufficient time for adjustment. This cannot be guaranteed in market share or trade flow models, however, even in the face of large and persistent delivered price differentials between supplying regions, unless specific mechanisms are added to the model to insure such behavior. Models in this class are further unable to explain the emergence of bilateral flows that did not exist in the historical (estimation) data sample. They can also become quite large and complex when used to model a market area with large numbers of producers and consumers.

16.5. Transportation Models

The final category is that of transportation models in which bilateral flows are determined so as to minimize aggregate transportation costs given the volumes available at producing points and required at consuming points. This is a restrictive model form, since demand, supply, and price must be set outside of the context of flow determination. It is, of course, true that the flows observed in SE models are transport-cost minimizing for the equilibrium demand and supply quantities. Applications of the transport model have generally assumed that SE quantities and prices were exogenously identifiable and, hence, that the resultant flow patterns approximated the SE results.

The transportation model can be written as:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} C_{i,j,k}\, Q_{i,j,k} \tag{16.34}$$

subject to:

$$\sum_{i} Q_{i,j,k} \geq D_{j,k} \qquad \text{for all } j \text{ and } k,\ D_{j,k} \text{ fixed} \tag{16.35}$$

$$\sum_{j} Q_{i,j,k} \leq S_{i,k} \qquad \text{for all } i \text{ and } k,\ S_{i,k} \text{ fixed} \tag{16.36}$$

$$Q_{i,j,k} \geq 0 \qquad \text{for all } i,\ j, \text{ and } k \tag{16.37}$$

This approach has been employed, as in the case of Holland and Judge (1963), to examine the transportation efficiency of observed, market trade patterns. Holley *et al.* (1975) reported the use of a modified transportation approach to model the US softwood timber economy. Regional production and harvesting processes were linked to resource and plant capacities via activity analysis. Given estimates of demand in consuming regions, the problem was structured so as to minimize the aggregate costs of processing and transportation subject to resource and plant capacity constraints and the usual restrictions of transportation models. The static model was made dynamic by the addition of rules for expanding or contracting plant capacity, of models of resource development, and of methods for projecting demand.

16.6. Summary and Conclusions

It would be inappropriate solely on the basis of this review to offer general judgments as to the most useful approaches, since the selection of method must vary with the scope and objectives of individual research studies.

Given its use in the IIASA GTM, however, some comments on the conditions under which the SE approach is applicable may be helpful.

SE models seem particularly appropriate in analytical contexts where:

(1) A large number of products must be considered.
(2) Several market levels (for example, logs and products, or, in the case of fiber products, pulpwood, pulp, and products) must be modeled.
(3) There are a large number of individual countries or regions.
(4) Functional representations of demand and supply relations may be highly diverse, because of variations in data availability or market structures across regions.
(5) The final model must be transportable and adaptable to meet varying computational capabilities of potential users.

SE methods are also advantageous where the focus of research is on the long-term analysis of trends in the forest sector and the potential impacts of alternative policy actions. The long-term perspective implies two desirable model characteristics. First, where the regions or countries involved are predominantly market economies, the structure of interregional trade flows should gradually move toward a competitive pattern (as constrained, of course, by any trade barriers). This suggests that some historical flows may disappear in the long term while new flows may arise. Second, it must be readily possible to couple the spatial modeling method with additional model elements that explain the dynamics of demand and of supply, technological change and investment–capacity decisions being particularly important in the latter. If the model is to be used in policy analysis, then the model structure must be flexible enough to accommodate a wide range of possible simulations. Flexibility is essential since it is quite common, at the outset of modeling efforts, to be somewhat less than clear as to the full extent of policies to be examined.

The SE approach seems particularly well adapted to meet these needs and conditions because:

(1) Large numbers of products (with the attendant possibilities for price–quantity interaction in both supply and demand relations) and numerous geographic regions are readily accommodated in the SE framework, with little additional solution cost or increase in model complexity. This stands in distinct contrast to any of the other general modeling approaches.
(2) Multiple market levels, with interregional flows at all levels, are also easily admitted. This is possible only at the cost of substantially

increased model complexity in the trade flow and market share models.

(3) The SE approach can accommodate demand and supply representations, ranging from continuous functions to simple activity analysis, which enables adaptation to virtually any form of input. Solution codes (such as linear or nonlinear programming algorithms) are widely available and/or readily adaptable (in the case of RP codes) to virtually any computing environment, which ensures the transferability of the final model.

(4) The SE method yields a competitive market solution and flow structure. Addition of constraints and appropriate constraint modification routines allow the simulation of noncompetitive results in the short term with continued movement toward competitive results in the long term. This capability can be replicated in other approaches only by adding, in effect, some form of optimization procedure.

(5) The SE method is readily made dynamic by incorporation in a larger simulation controller that contains routines to modify demand and supply relations and to simulate investment and technological change. Both programming and RP approaches are efficient in such applications, since previous-period flow solutions can be used as starting bases for current-period solutions.

(6) The SE approach is certainly the most flexible framework for policy simulation or scenario analysis. This results from the ability to manipulate or modify virtually every aspect of the solution process by means of appropriate constraints and/or changes in the objective function (gradient expressions in the case of RP) to mimic the form of a given policy or scenario environment.

Notes

[1] McCarl and Spreen (1980) present a related review of price-endogenous, mathematical programming techniques for sector analysis.

[2] Paraphrasing Hurwicz (1971) and Zusman (1969), the integrability of the demand and supply functions is linked to the question of the consistency of these relations with some underlying utility and production functions. Integrability characterizes functions on which an integration process can be carried out to yield certain "integral" (indifference or isoproduction) surfaces. This integration process is possible when certain symmetry conditions, notably symmetry of the matrices of cross-partial derivatives, are satisfied by the functions. In the case of the demand functions, it is known from the generalized Slutsky equation that the price derivative of individual demand functions consists of a substitution term and an income effect term. Since the substitution terms are known to be symmetric, the condition of

symmetry of cross-partials is satisfied only if the income terms are also symmetric. This latter condition is not a general result of the Slutsky analysis. If not employed as a constraint in demand function estimation, it may be exactly satisfied if income elasticities are zero and approximately satisfied if the income effects are small relative to the substitution effects. In any case, it constitutes a significant restriction on the form and nature of the demand relations.

[3] When it can be assured that the symmetry conditions are satisfied exactly, an alternative and efficient solution algorithm, Benders decomposition, is available; see McCarl *et al.* (1984) for a discussion.

[4] SE models can be modified to consider forms of imperfect competition. See Tramel and Seale (1963) for a discussion of techniques in the case of RP and Takayama and Judge (1971) for one of quadratic programming.

[5] This is in contrast to the SE approaches, which model flows between all pairs of source and destination points in the trade matrix.

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CHAPTER 17

Ocean Shipping of Forest Products

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The influence of transportation costs on international trade in forest products and on the location of processing facilities for forest products has not been extensively investigated. The lack of attention to transportation costs as a determinant of the size and direction of forest products trade is ironic, since wood trade was cited by Ohlin as an example of a market where transportation costs have a strong influence on the size and direction of international trade (Ohlin, 1967). In this chapter we explore the role of transportation costs on forest products trade and the location of wood-processing facilities.

17.1. Literature Review

From the perspective of exporting countries, transportation costs are a barrier to trade in much the same way as tariffs. Both raise the cost of delivering the product to the potential importer and reduce the volume of trade. Empirical studies have found that the level of protection given to domestic producers by transportation costs is as significant as tariffs (Bryan, 1974a, 1974b; Sampson and Yeats, 1977, 1978; Waters, 1970; Yeats, 1977a). Sampson and Yeats found that considering imports into the US for mechanical wood products there exists a tendency for *ad valorem* transportation costs to increase with the degree of processing. The commodities, classified in terms of the Standard International Trade Classification System of the United Nations (SITC), which were included in the processing chain considered by Sampson and Yeats, were wood in the

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rough (SITC 242.2), wood simply worked (SITC 243), plywood (SITC 631.2), and wood manufactures (SITC 632). *Ad valorem* transportation costs were 2.9%, 7.3%, 25.7%, and 15.3%, respectively (Yeats, 1977b). Finger and Yeats (1976) and Gauto (1985) found that the effective protection provided to US producers of forest products by transportation costs was substantially larger than the protection provided by tariffs.

There have been few studies of the impact that transportation costs have on the forest-products trade. Buongiorno *et al.* (1980) found that distance was the most important determinant of the intensity of trade in tropical logs. McKillop (1973) stated that failure to obtain a significant predictor for the ocean freight rate variable in his Japanese–North American forest-products trade model was because he did not have available a suitable freight rate time series for logs and lumber.

Binkley and Harrer (1981) point out that transportation costs can introduce variability into the delivered prices of exported products, irrespective of shifts in commodity demand or supply, and can affect the way price changes in one region are transmitted to another. They conclude that transportation costs have an important influence on which nations trade, what products are traded, and the direction of trade. Differences in transportation costs can be one of the primary determinants of comparative advantage.

In one of the first econometric studies of ocean liner freight rates, Chinitz (1956) found that unit value was the primary determinant of the level of freight rates. Moneta (1959), in a similar study, found that ocean freight rates are positively correlated with unit value and distance.

One of the most detailed studies of the determinants of ocean freight costs was by the Economic Commission for Latin America (ECLA, 1970). The ECLA study distinguished between the *structure* and *level* of freight rates, where rate structure refers to differences among freight rates for different commodities on the same route, and rate level to differences in rates for the same commodity on different routes. ECLA's rate structure model gave quite satisfactory results. Unit value and stowage were almost always significant variables and together explained a high proportion of freight cost variation among commodities. Handling costs and risks of damage and pilferage were either statistically insignificant or of little importance. The rate level model gave much less satisfactory results. For those commodities for which the model performed satisfactorily, the number of shipping lines serving a given route, distances, and port costs were consistently the most significant explanatory variables.

Lipsey and Weiss (1974) distinguished between the commodity characteristics (i.e., structure) of freight rate and route characteristics (i.e., level). They identified the stowage factor, the possibility of using tramps rather than liners, the ease of loading and unloading, the risk of damage or deterioration and the average size or shipping weight per shipment as key commodity characteristics. Key route characteristics were distance, port loading and unloading costs, the degree of competition among shipping lines, and the imbalance of trade. Unit value and distance were the most important determinants of ocean freight rates. The existence of a tramp shipping alternative for a commodity significantly lowered the liner rate for it.

Bryan (1974b) found that the log-linear model was superior to the linear model. Unit value and stowage factor were significant for all the routes that she investigated. Freight rates generally did not vary significantly with distance; however, the distance coefficient was significant at the 5% level for Douglas-fir lumber and wood pulp. Quantity shipped was of minor importance as a determinant of differences in the rates charged for different commodities, but was a significant determinant of differences in rates among routes, except for forest products, where distance was more important.

Heaver (1973) and Shneerson (1976) found unit value and stowage factor to be the most important determinants of differences in rates among commodities. Total volume of trade was not a significant variable.

Prewo (1978) analyzed the effect of transport costs on Latin American exports using a log-linear model. He argued that in a monopolistic market, such as that for shipping services, freight rates should depend on demand elasticities. Since demand elasticity is positively correlated with unit price it should be expected that freight rates would increase with unit price. Prewo's results, in fact, tended to confirm this hypothesis. Unit value was the most important determinant of transport rates. Distance, stowage factor, and the economy of scale variables were all significant, but exhibited substantial variations among countries. Increasing distance and bulkiness generally increased transport cost, but less than proportionately.

As discussed later in this chapter some countries report imports on the basis of both landed value and value net of shipping costs. McFarland (1985) has recently analyzed these data for US imports. For the data set that he examined he observed, among other things, that shipping costs relative to product value declined by about 25% over the period from 1976 to 1983.

Several useful papers on ocean shipping of forest products were presented at a meeting entitled Conference on Transportation of Tropical Wood Products, which was sponsored by the State University of New York at Syracuse in 1971 (State University of New York, 1972). Renehan (1972) identifies several factors that affect the cost of ocean shipping in a discussion of the suitability of various types of ocean vessels to handling forest products. Frumkin (1972) reports the results of a survey of firms that produced and imported several wood products, which was intended to determine the contribution of ocean shipping costs to total landed costs of tropical wood products. Hamm (1972) discusses the way the conference system works.

Other topics relating to ocean shipping of tropical wood products included in the conference volume are warehousing, palletization, packaging, cargo documentation, insurance, transportation regulations in the US, the effect of the containerization of cargo, and the effects of transportation economics on the countries that export tropical wood products.

There have been only a few studies of the determinants of freight rates that included forest products. Doan (1983) discussed transportation factors in the shipment of forest products from the US Pacific Northwest. Hassan and Wisdom (1982) examine the role of transport costs and tariffs in modeling international trade in paper products. Wisdom (1983) and Jones (1984) analyzed both the structure and level of ocean transport rates for major exports of US forest products. Determinants of rate structure were: unit value, the quantity of the commodity shipped on the route, and stowage factor. Determinants of rate level were: distance, total volume shipped per route, and the quantity of the commodity shipped on the route. Griffin and Weeks (1984) investigated how ocean shipping costs affect the spatial location of different stages of wood processing.

Neill (1985) examined the factors that influence forest products handling charges at southern ports. The wage rate and number of sailings were both significant determinants of handling charges. Gulf ports had significantly higher handling costs than South Atlantic ports, probably due to the strong stevedoring unions on the Gulf Coast. Pulp and linerboard had the lowest handling costs, probably due to their superior packaging and handling characteristics.

17.2. The Technological and Institutional Setting

The ocean shipping system consists of both the vessel and the port, including loading and unloading equipment and temporary storage space for cargo. To these might also be added packaging equipment, which is essential to the efficient shipping of wood products, but which is not always specialized to ocean shipping. The institutional setting, including market structure, affects not only the manner and level at which freight rates are set, but also the technology of shipping.

17.2.1. Types of ships used in the forest products trade

Traditional, general purpose or break-bulk cargo ships can be used for shipping all types of forest products, including logs. These carriers are well suited to carrying shipments of sawnwood and other forest products in small lots, especially where one or both ports are small and not equipped for fast loading and unloading. Their principal advantage is that they are cheap in terms of their daily rate. Thus, they can operate in ports where stevedoring is labor intensive and so tends to be slow. Not surprisingly, they are frequently used for shipping wood products from smaller, low-volume ports in developing countries (Renehan, 1972).

Special-purpose carriers can result in transportation cost savings where volumes are large and dependable. Single-purpose chip carriers are used to ship softwood chips from North America to Japan. These ships include vibrators, chutes, and conveyors. Lumber carriers, in use for years on high-volume routes, continue to carry lumber, plywood, and veneer in large volumes. Improvements in these ships include increased size, improved cargo handling gear, and better designed holds and larger hatches to facilitate the use of forklifts and other loading equipment.

Recent developments include roll-on, roll-off ships capable, as their name implies, of allowing cargo to be rolled on and off for very rapid port turnaround times and low stevedoring costs. Side loaders are also a new design that facilitates efficient cargo handling. Another new development in ship design is the Lighter Aboard Ship (LASH) carrier, which is in use mainly in the high-volume trade among developed countries. The similar Seabee system uses barges of between 10 and 100 tones capacity. LASH ships are equipped with gantry cranes to hoist barges aboard, while the Seabee system uses elevators. In both cases the barges are carried between ports on board enormous mother ships, which pick them up and let them off at sea. The barges are specially constructed for this use, but share the properties of the ordinary barge in being able to navigate shallow ports and rivers. Also, they represent a smaller capital investment than an ocean-going ship and carry smaller loads.

For most developing countries the mobility of these barges is an important consideration, since even the small-capacity barges used in this system hold more than the average liner consignment (UNCTAD, 1970). Barges provide the opportunity to collect the goods from several locations to bring them to a deep-water port. They are, of course, used for this purpose throughout the world without the advantage of LASH/Seabee systems.

Mini-ships are small ships of shallow draft, small capacity, and slow speed, and are capable of navigating small river ports not serviced by large vessels. They are ocean-going ships with some of the advantages of the LASH/Seabee systems described above. Capacities are about 3000 tons per mini-ship, as opposed to a range of between 40 and 1000 tons for the barges used in the LASH/Seabee systems.

Two other types of ships used in the forest products trade are the geared bulk carrier and the container ship. The geared bulk carrier is a very large ship of the type formerly associated with such bulk cargoes as ore and grain, but which has been equipped for transporting other types of commodities, such as logs, lumber, and other wood products. Capacities are often in the 10^6 ft^3 range. The North America to Europe trade is often carried on board these ships, which require sophisticated port facilities and large volumes. Mini-ships are sometimes used as feeders for these geared bulk carriers.

Of considerable importance to current and future trade in forest products is the container ship. These carry their cargo in more or less homogeneous boxes. The van container comes in three lengths (20, 30, or 40 ft) and only one height and width (8 ft). These dimensions make it possible for the cargo to be transported by truck in the same container as aboard ship. It is this ability to use the same container for several or all legs of the product's journey from producer to retailer or other user that some consider to be containerization's most important feature. There are many different types of container ship. Containers may also be shipped on general-purpose ships, but in this case they do not offer the same sort of advantage as when they are used in a system designed around the container. Such systems feature large ships capable of making rapid time at sea and combine with port facilities that allow for quick turnaround.

Containerization has accounted for a rapidly increasing proportion of ocean shipping in the last two decades, a growth that has not been confined to the developed countries. In 1982, developing countries accounted for one quarter of global container-ship port traffic, a large share of which was out of Hong Kong and Singapore, together accounting for 25% of container-ship port traffic in developing countries (UNCTAD, 1983).

17.2.2. Port operations

Port facilities comprise wharfs, docks, and other means for hosting the ship, as well as equipment for unloading and loading, and temporary storage. In addition facilities must be available for customs and documentation checking, but not all these need be located physically at the shipside. It is typical now, in some places, for goods to be collected at inland facilities, where space is not so expensive, and then sent to port. Packaging and containerization costs may also be lower at an inland facility. As already mentioned, the LASH/Seabee barge-carrying ships do their loading and unloading entirely at sea. They thus comprise a floating port, at least in function. In the effort to increase turnaround time at the port, and so reduce the time the ship sits idle, this particular solution results in carrying on board elaborate loading equipment, which is itself necessarily idle most of the time.

Ship loading rates depend on the type of ship, weather, port facilities, port congestion, and the type of product. If the LASH/Seabee or roll-on, roll-off systems represent one extreme the other is often found in ships loaded at ports in developing countries, where sawnwood is loaded piece by piece. At the lower end of the spectrum, loading rates may be only a few hundred tons per day, e.g., in Indonesia log loading rates are in the range of 400–500 tons per day and are typically loaded from lighters or pulled from the water (FAO, 1978). Higher rates are exemplified by, for example, roll-on, roll-off systems, capable of loading, in the case of newsprint, 300–400 tons per hour.

17.2.3. Types of shipping services and industrial structure

Liners, tramps, and user-owned ships comprise the three types of shipping services. Liners may be independent or belong to a shipping conference, but in both cases they maintain regular schedules and accept whatever cargo is available. Tramps are usually available only to shippers who work by the shipload and may be chartered for an individual trip or for a period of time. The user-owned ship is not practical for any except the largest shippers who ship on a regular basis. Most user-owned ships carry not only the user's cargo, but also other cargo in order to improve scheduling, to keep their ships working, and to avoid empty return trips.

In general, only liner services can be said to be available to producers of forest products who ship in small quantities, and the costs of these services are correspondingly high. They are expensive in part because loading and unloading costs are high, since bulk handling equipment is usually not compatible with the break-bulk carriers used for small shipments on liners. However, with the increasing use of containers, liner services could be offered on a basis that would make available to the smaller shippers some of the economies that have previously been available only to bulk shippers. Another factor that contributes to higher freight rates for liners is that the shipping conference acts as a cartel to secure a higher price than would prevail in a competitive market. This does not, in itself, imply that conferences should be abolished since, for one thing, it is not known that a competitive liner industry is feasible. It is frequently argued that in the absence of the conference rate wars would result ultimately in the emergence of shipping monopolies. It can also be argued that the conferences have some advantages in that they tend to promote reliable rates, routes, and schedules. The reliability of shipping services may be more important for some shippers than, within limits, the level of freight rates. Some argue that the advantages of these regulated cartels in the shipping industry are overstated and assert that a competitive liner industry is feasible. Two studies of the US regulation of conferences take conflicting positions on this issue (United States Department of Justice, 1977, and Council of European and Japanese National Shipowners Association, 1978, both cited in Hansen, 1981).

As discussed earlier, there is evidence that *ad valorem* freight rates tend to increase with the degree of fabrication in a manner similar to tariff escalation. Most researchers agree, at least to the extent that unit price is a fairly good predictor, along with other variables, of conference freight rates (Prewo, 1978; Deakin and Seward, 1973). The containerization of cargo may, however, gradually erode the basis for this type of price discrimination. Unless cargo requires special handling it will be difficult for carriers to continue to justify charging different rates for different commodities. Also, all aspects of freight handling, including documentation and custom clearance, can, at least in principle, be simplified as a result of containerization. This would make it much simpler for agents and collectives to assemble large shipments and bargain with shipping conferences for lower rates. Thus, the most important impact of containerization may well be in terms of market organization rather than its technological impact on costs.

The degree of control exercised by the liner conferences varies from loose, informal associations to formal agreements with a secretariat and the ability to exercise considerable control over the members' shipping operations. Conferences that are not fully able to control the volume of shipping offered on a route are threatened with having to operate their ships with less than full loads, since freight rates are usually set at levels that result in routes being profitable even though ships are not full.

Since conferences must compete with tramps and user-owned ships, rates are affected by the perceived threat from these competitors. This is another factor which contributes to differences in rates among commodities; further, for the same commodity, rates may be much lower for full-ship lots and for shippers doing a large volume of business. These are the shippers most likely to find tramps or their own ships attractive alternatives to paying high freight rates.

Tramp services are secured both through open-market brokerages, in the case of short-term charters, and through direct contracts negotiated between principals, for long-term charters. The market tends to be highly competitive, with rates fluctuating in response to supply and demand. Contracts of affreightment, calling for the shipping of a certain quantity of goods over a specified period of time, are also typically fixed by direct negotiation. Liners sometimes use tramps to serve the scheduled routes of the line. User-owned ships provide an alternative to tramps in that they are normally operated as specialized ships hauling the owner's cargo. If they are to go out and back reasonably full, they must normally haul something besides the owner's cargo. In addition, the user-owner may make space or tonnage available to other shippers on a more or less regular basis.

17.3. Data Sources

17.3.1. Federal Maritime Commission data

A comprehensive, but relatively unknown, source of information on ocean freight rates is the conference and independent tariff schedules on file with the US Federal Maritime Commission (FMC). All conference and independent liners operating on US shipping routes were, until 1984, required to keep a current listing of services and charges on file with the FMC. Liners are no longer required by law to file their tariff schedules with the FMC, but continue to do so on a voluntary basis, at least for the time being.

In order to use the FMC data for statistical analysis of freight rate determination it is necessary to convert the various rates into common units. This is not a trivial task, but there is no other comprehensive source of data on freight rates that are charged for exports of US forest products.

The liner tariff schedules posted with FMC typically contain a range of services and charges, including quantity and container discounts, surcharges for heavy lifts or long cargoes, additional charges for out-ports, and foreign exchange. There is no industry standard for describing liner services or charges, and each liner's tariff schedule differs from others in one way or another. The measurement of forest products is particularly confusing and nonstandard, so stowage books typically devote a special chapter to alternative methods for the measurement of forest products. Freight rates are quoted in a wide variety of units, including cubic feet, cubic meters, long tons, metric tons, board feet, and linear feet.

The ocean transportation industry uses the weight/measure system (W/M) to assess rates. The measurement ton of 40 ft^3 is the unit for volume, and the long ton (2240 pounds) is the unit for weight. Since a ship has two capacity limits, volume and weight, carriers charge according to the measure that yields the greatest revenue. Most rates for forest products are quoted on a W/M basis, indicating that the liner will charge either by weight or measure, depending upon which yields the greatest revenue. Thus, in order to compare posted rates, it is necessary to have accurate information on product stowage (the relation between volume and weight), both to determine the actual rate charged by each line and to convert posted rates into common units.

An example illustrates the importance of stowage factors and the W/M system. Suppose the liner rate for softwood lumber on the US South Atlantic–Caribbean route is quoted at \$50 W/M and softwood lumber stows at 76 ft^3 per long ton (a stowage factor of $1.9 = 76/40$). The carrier calculates the two possible rates as: $\$50 \times 1 = \$50$ per weight ton, and $\$50 \times 1.9 = \$95$ for 1.9 volume tons. and so charges \$95 to ship one long ton of softwood lumber. Accurate rate conversions thus require accurate information on product stowage factors. Information on stowage factors can be obtained from books published for that purpose and liner tariff schedules often provide information on stowage for specific products.

The rates quoted in the liner tariff schedules usually include the cost of loading at the port of exit and unloading at the port of entry. Not included are the inland transportation costs, the cost of unloading from the inland carrier and transporting to alongside ship at the exit port, and the cost of transporting from alongside ship to the inland carrier (or storage) and loading onto the inland carrier at the port of entry.

17.3.2. Other data that reflect shipping charges

A few countries publish trade data that show imports by country of origin and class of commodities valued on the basis of both free on board (FOB) and cost including insurance and freight (CIF) prices. They include the US, New Zealand, the Philippines, and Brazil.

Generally, the difference between FOB and CIF prices approximates what it costs to ship the goods in international trade. In some cases the measure includes loading and unloading, as is the case for the US, where free along ship (FAS) values are compared with CIF values, whereas in others it only includes unloading. New Zealand is an instance of the latter where FOB values are used. CIF values are easier to determine and there does not seem to be much difference in the concept as reported by the above countries. One source of possible distortion in the data according to New Zealand's authorities is that there may be fluctuations in exchange rates between the time the goods are purchased by the exporter and the actual date of shipment (NZDOS, 1981). This phenomenon could, in principle, cause FOB values to be higher than CIF values in some circumstances and the data does sometimes behave this way. These data give a more precise measure of shipping charges than freight rates alone, since insurance is included. Generally, insurance is a fixed, small percentage of cargo value (typically less than 0.5%).

As far as the authors have been able to determine the degree of overall reliability of these data is unknown. Only the US data are of obviously sufficient magnitude, in terms of the number of observations and the size of the flows involved, to be really convenient for statistical analysis, although the other data sets might lend themselves to time series analysis if a sufficiently long series were available. The issue of the reliability of this data should not be confused with the reliability of the data reported by the United Nations Statistical Office (UNSO). UNSO also reports on trade flows by country of origin and commodity in terms of both CIF and FOB values. The issue with that data is somewhat different since the two figures are reported by different governments. In the UNSO data exports are valued FOB and imports are valued CIF. Apparently, the differences are not a very good indicator of shipping costs, as is observed by Kornai (this volume, Chapter 18; see also Yeats, 1978).

To return to the question of the advantages and disadvantages of the CIF-FOB data versus posted freight rates, consider the problem of the assessment of what shippers of forest products have actually paid for shipping services. Compared with an analysis of freight rate schedules there are some advantages in using trade data. First, there is usually more than one posted freight rate for a given commodity and route. These differences stem from such factors as the size of the shipment and whether it is subject to any bunker charges, delay penalties, discounts, etc. In addition, shipping firms may sometimes charge rates that are not posted, e.g., illegal discounts, rebates, and so forth. It is thus not possible to precisely determine at what rate goods were actually shipped.

A second problem is that the posted rates do not, in fact, cover the shipments made under either charter arrangements or by exporters who use their own ships. Since neither of these problems exist for the trade data, it is useful to examine the shipping costs implied by some of these data.

The data shown in *Table 17.1* and *Figure 17.1* are based on the disaggregated averages as reported in the sources cited. The indicators are measured in terms of weighted averages, which are computed as the ratio of the sum of the values over several subcategories.

Not all of the data are available for all categories. In some cases this is a limitation in the information source, but in the case of the US the limitation was due to the restricted time available to prepare the data. The observation that wood processing is a shipping cost-reducing activity is not confirmed, in the main, by these data. Only in the US data does there appear to be an unambiguous tendency for *ad valorem* shipping charges to decrease with the degree of processing. It is not possible to compare these figures directly with the data generated for the GTM (see Chapter 25), since the latter include a variable for shipping distance. It would thus be necessary to have the data disaggregated by US port of arrival to make such comparisons precise. In fact, such information is available, from the US Department of Commerce, by US Customs District and, no doubt, future research on this topic will make use of it.

Table 17.1 Ratio of transportation and insurance costs to FOB values for forest product imports of the US, Brazil, New Zealand, and the Philippines. Observations of ratios outside the range 0.05 to 0.40 are excluded, which eliminates most nonocean-based trade, for example, US imports from Canada and Mexico (US-DOC, 1983; RPNCSO, 1979, 1980, 1981; BMF, 1979; and NZDOS, 1981.)

	US 1983		*Brazil 1979*	
Product	*FOB value*	*Ratio*	*FOB value*	*Ratio*
Logs	118	0.31	4 910	0.14
Sawnwood	24 600	0.22	18	0.11
Pulp	19 900	0.16	33 100	0.12
Panels	114 000	0.13	516	0.06
Manufactures NES[a]	72 800	0.14	1 280	0.13
Paper and paper board	117 000	0.15	159 000	0.19
Paper and paper board articles	50 800	0.11	6 750	0.14
Furniture	223 000	0.12		

	New Zealand 1979–1980		*Philippines 1979–1981*	
Product	*FOB value*	*Ratio*	*FOB value*	*Ratio*
Logs			1 080	0.21
Sawnwood	4 620	0.23	1 060	0.06
Pulp	1 910	0.37	97 600	0.15
Panels	3 980	0.11	541	0.19
Manufactures NES	1 460	0.16	638	0.18
Paper and paper board	39 100	0.17	168 000	0.11
Paper and paper board articles	4 840	0.16	8 250	0.13
Furniture	947	0.17	108	0.09

[a] NES, not elsewhere specified.

17.4. Theoretical Considerations

Ocean freight rates are determined by the interaction of demand and supply for ocean transportation services. *Figure 17.2* shows the demand and supply schedules (D_A, S_A; D_B, S_B) and the corresponding excess demand and supply schedules (ED_B, ES_A) for a commodity in two countries, A and B. The excess demand and supply curves are obtained by taking, for each price, the horizontal difference between the demand and supply curves. The demand for transportation, D_t, from country A to country B is the vertical difference between the excess demand and excess supply curves.

If shipping services are supplied in a competitive market the price is determined by the intersection of supply, MC_t, and demand, D_t. In *Figure*

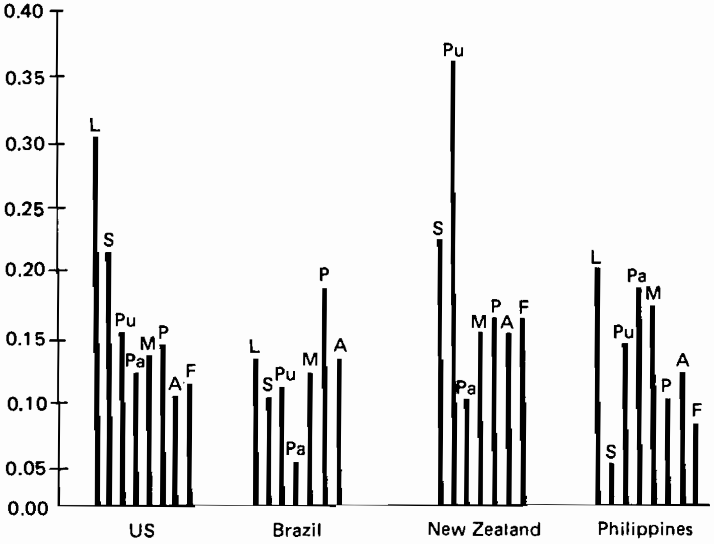

Figure 17.1 Ratio of transportation and insurance costs to FOB values for forest product imports of the US, Brazil, New Zealand, and the Philippines. Observations of ratios outside the range 0.05 to 0.4 are excluded. This eliminates most nonocean-based trade, for example, US imports from Canada and Mexico. L, Logs; S, Sawnwood; Pu, Pulp; Pa, Panels; M, Manufactures NES; P, Paper and paper board; A, Paper and paper board articles; F, Furniture.

17.2, the equilibrium freight rate is FR_t and the amount that country A exports to country B is q_{AB}. If, however, the market for transportation services is monopolistic and if the curve labeled MC_t is the monopolists' marginal cost curve, then market equilibrium occurs at the higher price FR_t' and the amount that country A exports to country B is q'_{AB}.

The specification of the complete ocean transportation model would require the explanation of the forest products markets as well as the transportation market. Our objective is more modest. We wish only to identify those factors that explain the level and structure of ocean transportation costs and to suggest how transportation costs for forest products might be estimated empirically. Forest products markets are examined in detail elsewhere in this book.

One such recent analysis (Wisdom, 1984, 1985) that relates to forest products specifies the transportation price equation as follows:

$$FR_{ij} = f(D_j, Q_{ij}, S_i, UV_i) \tag{17.1}$$

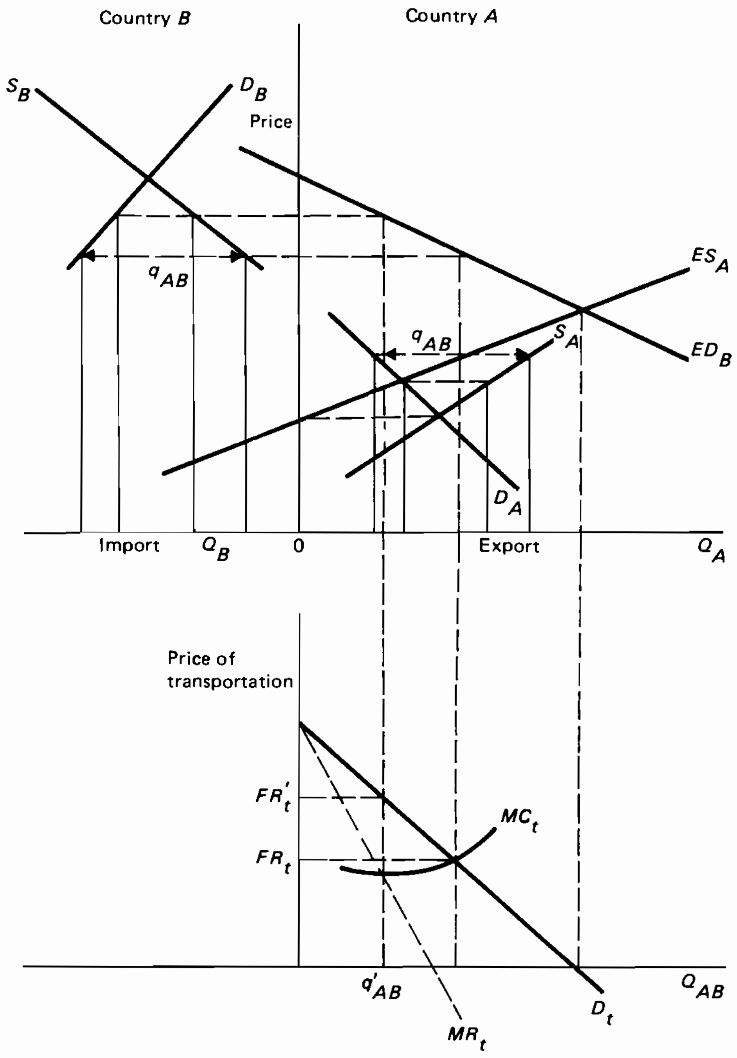

Figure 17.2 The determination of transportation prices for forest products.

where FR_{ij} is the freight rate for product i on route j (per ton), D_j is the length of route j (miles), Q_{ij} is the quantity of product i carried annually on route j (tons), S_i is the stowage factor for product i, and UV_i is the unit value of product i (per ton). The use of unit value in the equation is based on the assumption that the conferences tend to behave, at least to a degree, like monopolists and so set freight rates based on marginal revenue, which in turn means they set them higher the more inelastic is the demand. It is unlikely that the shipping conference can or would bother to make an explicit estimate of the demand elasticities for the products they carry. However, the nineteenth-century economist Alfred Marshall showed that the derived demand for an input is more inelastic the smaller is its share in total product cost. This observation is relevant in predicting freight rates. The more valuable, per unit of weight or volume, the commodity being shipped, the lower will be the share of transportation costs in the total cost of the delivered product. Thus, unit value is an indicator of demand inelasticity and so should, in principle, be relevant in estimating freight rates in a monopolistic setting.

The quantity variable may be related to stevedoring costs, since there may be scale economies in the handling of various categories of forest products. It may also, to some extent, be related to the bargaining power of shippers. Both considerations result in the tendency for freight rates to fall with increasing quantity.

For several reasons, it seems reasonable to assume a lag between a change in the demand for transportation for a commodity and the associated change in transportation price. First, it is time consuming and costly to adjust rates. The typical liner tariff schedule may include 2000–3000 items. Conferences prefer to make one-time, across-the-board adjustments in rates rather than to change each rate separately every time there is a change in demand (Bennathan and Walters, 1973). Second, a conference may not be aware that the transport demand for a particular commodity has changed until the year is over. Third, the legal requirements for rates changes and public hearings can take 3 to 6 months.

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CHAPTER 18

Historical Analysis of International Trade in Forest Products

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When international trade is represented by the bilateral trade flows, each entry in the corresponding trade matrices simultaneously represents both exports and imports, since for each product exports from country i to country j are assumed to be equal to imports of country j from country i in any given period. Originally, there were two types of such trade matrices available: the *export matrix* shows trade flows as reported by exporting countries, while the *import matrix* contains trade data of the importing countries. Needless to say, these two matrices are never the same. Previous trade and other economic analyses that were based on one or the other of these two original trade matrices have led to conclusions of a somewhat diverse and conflicting nature, reflecting mainly the specific features — and errors — of the data sets used. Thus, we need an algorithm to generate a single set of matrices that *reconciles* the data of different origins. The entries of these trade flow matrices should be close to reality. A simple reconciliation method, reported in Sections 18.1 and 18.2, produces such historically consistent trade matrices.

In Section 18.3 we summarize some basic observations about historical patterns in the international trade of forest products. A conclusion is that trade flows develop rather smoothly over time, partly due to the so-called *inertia* of the trade. A simple approach is presented to estimate trade inertia.

18.1. The Discrepancies in the Trade Flow Data

There are two somewhat independent sources of bilateral trade data on forest products. The first is the *Direction of Trade* tables published by the

Food and Agriculture Organization of the UN (FAO, 1983). The second set of bilateral trade observations is from the UN Statistical Office (UNSO, see United Nations, 1981). Besides the above two major sources, several international organizations publish "Direction of Trade" matrices, originally subsets of the UN data. The analysis in this chapter, however, is limited to a reconciliation of the FAO and UNSO data bases.

Both the UNSO and the FAO data sets include so-called *partner country* reports. In principle, all trade should be reported by both exporter and importer countries identically for all commodities traded each year or month. However, the principle that both export and import matrices constructed from trade flow reports should be equal to each other, since they represent the very same commodity flows, has so far not held true. The differences can, in fact, be large, and as the literature indicates there has, as yet, been no real breakthrough in eliminating the errors of the original data (see Morgenstern, 1963; Párniczky, 1980, 1984; Durst *et al.*, 1985; Luey, 1971; Naya, 1969; Yeats, 1978).

The UN assembles bilateral trade figures directly from the national *Trade Yearbooks* of the UN member countries. This data, previously available as a considerably summarized publication (see United Nations, 1981) or in detail as microfiche, are now available in computer-readable form (for trade since 1961). This computer data base contains all the available reports on bilateral trade.

Each edition of the *FAO Yearbook of Forest Products* (see FAO, 1983) contains a summary trade matrix for major products over the previous two years. The matrix for the earliest year in each edition includes revision of the data included in the previous edition. These data were recently made available in computer-readable form. FAO publishes matrix data reported by exporters for the years 1966–1983, while the matrices reported by importers are available only for the years 1966–1976.

The UN data cover each country that has appeared in a trade report, either as a reporter or as a partner. The FAO, however, checks, corrects, and completes the information when possible. First, national returns to the FAO questionnaires are used to complete trade data, by reference where necessary to national *Trade Yearbooks*. The UN microfiche, which is usually received by the FAO later than the national returns, is used when no national return has been received. In the event that no national data are available, information is extracted from reports of the major traders, which may show the country as a trading partner. It should be appreciated that, whether one uses national *Yearbooks* or microfiche, these methods of searching for missing data are extremely laborious. Therefore, the trade matrix published by FAO currently includes only those countries for which the total imports or exports exceed 1% of the total volume of world trade of a given product. Less significant traders are lumped together into several categories of "others". Thus, the actual dimensions of an FAO trade matrix are about 20 by 20 countries, which means that the FAO data are geographically limited. However, the economic coverage of the world by FAO is not so poor — it represents 80–90% of total trade — since international trade in forest products is rather concentrated (*cf.* Francescon *et al.*, 1983).

Similar to the large number of countries given in the UN reports, the UN covers several thousands of detailed trades in commodities. FAO, however, focuses on only 10–12 major forest products aggregated into broader categories, which correspond to the importance they play in the forest economy. Thus, some of the FAO commodities cannot be identified directly with any of the UN categories, but most may be an aggregate of the UN categories.

The UN provides the trade flow data in US dollar values, converted from the national currencies using exchange rates mostly furnished by the International Monetary Fund (IMF). When the homogeneity of the commodity allows, some quantity (volume) figures are also shown. However, there is no guarantee that all countries report in the same unit of measurement, which is suggested by the UN (e.g., metric tons). The FAO does not publish value data for the trade flows, but the volumes reported are all measured in consistent physical units that are suitable to the commodities (cubic meters for mechanical timber and wood products, metric tons for pulp and paper products).

The primary sources of UN data are official government reports, generally derived from customs records. The UN simply updates its trade data files (currency conversions, aggregation of monthly and quarterly information, summation for higher level commodity classes, etc.), but does not carry out any further checking or revision of the source data: reports are included irrespective of their quality. The FAO, however, continuously checks the sources, verifies, revises, and even estimates the data when they are missing from the questionnaires returned by national forestry authorities. The FAO experts make use of other available information (on production, consumption, processing technologies, forest resources, etc.) before publishing their trade matrices, which are frequently updated for previous years as well. These important features of the two data sources are summarized in *Table 18.1*.

In the case of the UNSO data a series of simple computations has helped us to find some characteristics of the partner country reports. A brief summary by selected products is given in *Table 18.2*. There are several studies available that analyze systematically the statistical magnitude of the discrepancies (see Durst *et al.*, 1985; Naya, 1969; Yeats, 1978). Our intention here is only to indicate the problem.

Table 18.1 Some features of UNSO and FAO trade flow statistics in 1985.

	UNSO	*FAO*
Years covered	1961–1983	Exporters' reports: 1966–1983 Importers' reports: 1966–1975
Countries covered	All reporters	"Major" reporters (1966–1977); reporters with trade $\geq$ 1 % of world exports (1978–1983)
Products covered	All products traded	Some important forest products
Measurement used	Value in US$; volume in metric tons; some countries may use other units	No values available, volume in cubic meters or in metric tons; all countries use the same unit for a given product
Primary source of data	Government reports	Questionnaires to forestry authorities revised by FAO experts and/or estimates based on other information

Table 18.2 Some features of the UNSO trade flow reports for some commodities in 1981.

Product	*Unit of measurement*[a] (10^3)	*Double reports*[b] *in % of all reports*	*World trade by importers in % of world trade by exporters*
Logs, coniferous	m^3	19	142
Logs, nonconiferous	m^3	19	186
Sawnwood, coniferous	m^3	24	287
Sawnwood, nonconiferous	m^3	21	209
Pulp	metric ton	46	93
Printing and writing paper	metric ton	31	88
Newsprint	metric ton	26	95
Paper not specified elsewhere	metric ton	45	109

[a] Units were reconverted into the indicated measurement (m^3 or metric tons) using FAO's standard conversion factors (FAO, 1983, p 61).
[b] Double reports: trade flows reported by both exporters and importers.

The basic, well-known reasons for the frequent discrepancies illustrated in *Table 18.2* are as follows (sources: Bhagwati, 1967, 1981; Darr, 1984; DeWulf, 1981; Durst *et al.*, 1985; Luey, 1971; Morgenstern, 1963; Naya, 1969; Párniczky, 1980, 1984; Richter, 1970, 1971; Simkin, 1970; Yeats, 1978):

(1) Simple, unintentional counting and recording mistakes by customs officers and other reporting officials result in errors.

(2) There is a certain shipping and recording time lag due to distance and administrative procedures. Thus, a specific period of time has a different coverage in terms of exports and imports.

(3) Origins and/or destinations of shipments may be identified incorrectly or differently by the trading partners. The "middleman" transit trade, the so-called "free-trade zones", the records based on the "country of production" principle rather than of the "country of consignment" principle are widespread sources of error.

(4) Diverse definition of commodities by the trading partners may also lead to discrepancies, as does the diversity of physical conversion factors in use.

(5) In a number of cases, trade remains simply unrecorded. Besides smuggling and deliberate falsification by one or both partners, there are several countries that make no effort to report their trade at all. A reason may be secrecy. Many countries use special systems of statistical data compilation that are difficult, or impossible, to relate to international, standard classification systems of trade. Among these countries, considering the role they play in the trade of forest products, the most important nonreporters are the socialist countries. There is basically no information available on trade among socialist countries, so bilateral trade statistics can be obtained only through the reports of their trading partners.

(6) There is an intentional (official) under- and over-invoicing of trade practiced in several countries. The basic reasons for this are to receive and/or provide advantages (e.g., price differentials, subsidies, duties, tax deductions, etc.) to domestic buyers and/or suppliers of foreign trade and to loosen or tighten quotas.

(7) Trade flows measured in value terms differ in most cases because of the so-called *free on board* (FOB) valuations of exporters versus the *cost-insurance-freight* (CIF) records of importers. However, these traditional ways of valuation may not be implemented by several countries, who use different sets of rules.

(8) Value reports may also differ due to the exchange rates used to convert local currency values into US dollars. The official rates of exchange may significantly differ from those actually used in the transaction, partly due to the time lag mentioned before and partly because of the various rules by which official rates of exchange are derived in several countries.

Reasons (1) to (6) affect both quantity and value data, while the consequences of (7) and (8) appear only in the value figures.

18.2. A Method of Trade Matrix Data Reconciliation

It is almost impossible to decompose the data so as to isolate the influence of each and every problem mentioned above, so there is no overall method available for the reconciliation of trade reports. There is no doubt that bilateral trade data should be validated somehow before one utilizes it for any serious analysis. However, the actual method chosen for reconciliation should depend on the purpose for which the data are intended.

For in-depth research of a single commodity, a manual reconciliation of the historical data is the most advantageous. One may try to identify and quantify the effects that cause the most striking discrepancies and then check and verify each individual trade flow, utilizing many pieces of microeconomic information, ranging from monthly trade data to transportation cost figures, etc. Apart from some well-known guiding principles, there cannot be a general algorithm for this type of work.

A study of general patterns of bilateral trade, however, may require masses of trade flow data to be processed without much attention being paid to any single flow. There are several such "automatic" data reconciliation methods available, each utilizing some assumed statistical or mathematical properties of the data under inspection.

According to the rather loose classification above, the scale of reconciliation methods available for historical data ranges from fully manual to fully automated procedures. The best-known automatic procedure is the biproportional method, named after its mathematical formula, the RAS, of Stone (Lecomber, 1975). Semiautomatic methods are the *entropy maximization* (Eriksson, 1983) and the *mathematical programming* approaches (Harrigan, 1983). A semimanual reconciliation procedure was suggested by Párniczky (1984).

Our deepest concern with RAS and the related limited-information procedures is that our particular problem of trade matrices is of neither the usual *biproportional* nor the *minimal information* type. Instead, we have a *data reduction problem*, with a large number of matrix elements for which there are mismatching observations. Moreover, the applications of these methods are still rather complicated and often the economic consequences of the underlying mathematical assumptions are not fully tested. For example, the biproportionality condition may fail in the real world: there is evidence that export and import totals as reported by the countries are not equally reliable and consistent economic observations (Párniczky, 1980). In fact, world trade — even in quantity terms — never adds up to the same number for exports as for imports (*cf. Table 18.2*); thus reconciliation results obtained assuming biproportionality conditions are questionable.

Partly for the reasons stated above and partly for the sake of simplicity we prefer methods that are easier to follow, such as the algorithm used to reconcile the trade matrices of six major agricultural products by Párniczky (1984). However, Párniczky's procedure is far too labor-intensive to be fruitful with such a long list of years and commodities as in our problem.

The reconciling procedure for trade matrix data that is described in this chapter is also an automatic type. It is rather straightforward and therefore somewhat more transparent than those mentioned before. Such an approach has advantages over other procedures that require strong and nonevident mathematical assumptions or that require substantial manual intervention.

The procedure produces a single, reconciled matrix, which contains the full direction of trade information. Thus, the matrices obtained are simultaneously both export and import ones, providing a full coverage of world trade. The trade flows are expressed in volume terms only to ensure full compatibility with FAO trade matrices (if they exist). The procedure may work for a rather fine commodity breakdown. In spite of the fact that the more specific the commodity definition, the bigger the relative discrepancies in the data tend to be (Yeats, 1978), forest products are homogeneous enough to allow for a detailed commodity specification.

An overall criterion applied is that the reconciled matrix should be fully consistent with the country-by-country export totals of the FAO. (That is, we make use of a single-sided proportionality only.) These export total figures published annually by FAO (FAO, 1983) are considered to be the most reliable among the trade statistics, as discussed in Section 18.1.

The reconciliation algorithm works as follows. First, the data must be given a series of simple, technical preparations. Most of these are necessary to compile four, similar, basic trade matrices for each one of the possible data reports. These preparatory steps are executed during the input of all available data to the computer. Second, we unite exporters' and importers' reports for both pairs of FAO and the UNSO matrices such that each cell of the resultant matrix contains the larger of the corresponding exporter's or importer's report. We thus reduce the number of matrices by half. Having identified the discrepancies within each data set, we merge the intermediate FAO and UNSO trade matrices, so that each entry of the resultant prereconciled matrix contains the larger of the corresponding FAO or UNSO figures. The export totals by country of this prereconciled matrix are compared with the original country export totals of FAO. The actual reconciliation is then made, on a country-by-country sequence, as follows:

(1) If the computed and the actual export totals are equal, we simply accept the figure.

(2) If the actual export total exceeds the computed figure, we introduce a new trade flow that refers to an *unspecified* importer, since we do not know the real destination of the flow.

(3) If the computed trade is larger than the actual exports, we compress each flow in the same proportion to fit the trade specified by the FAO totals.

The above procedure definitely improves the coverage of the trade matrix. However, discrepancy reasons (1) to (8) may all still have an effect. The rule of selecting the largest flow corresponding to the same cells of the intermediate and prereconciled matrices can be justified only by the results. A reason that favors this simple rule is that we will not overlook those frequent cases when there is only a single report available for a given flow. If this situation arises, FAO will not mention a minor flow, while only one of the parties reports it to UNSO.

We have tested our algorithm with several, related data reconciliation problems. Our conclusions are:

(1) The geographic coverage of the world by the reconciled trade matrix was doubled with respect to the country total export data that originally appeared in the *FAO Yearbooks* (FAO, 1983). This means that we had to extend the list of countries that appears in the *FAO Yearbook of Forest Products.*

(2) The relative difference between the world total exports in the *FAO Yearbooks* and the reconciled exports was, in fact, very minor. Even the largest differences are within a 3% range of the original FAO world totals by commodity (more than half of all cases tested resulted in a global discrepancy of less then 0.3%). In the cases of pulp and paper products and of coniferous sawnwood, in spite of doubling the number of countries with respect to the original FAO list, the trade of the newly supplemented countries was virtually negligible, while the largest discrepancies appeared for nonconiferous sawnwood.

(3) The relative discrepancies obtained in reconciliations of value data were significantly higher than those resulting from volume data. The reasons for this upward bias are rather obvious: since the CIF trade figures tend to be higher than the corresponding FOB values in most cases, the importers' reports are selected by algorithm. Then, these data are reconverted into quantities using export unit values obtained from the FAO value and volume data on export totals. The gain of having 5–15% more reports when using value data may not pay for the loss in accuracy.

(4) In the case of logs and sawnwood, about 70% of all reports in the UNSO data set had to be reconverted from metric tons into cubic

meters using the standard FAO measurement conversion factors (FAO, 1983). For pulp and paper there was virtually no need for such reconversions, since they are measured in metric tons in both data sets.

(5) Most of the actual reconciliation is done with the UNSO data, since the number of FAO reports is very low (5 to 18% of all observable flows). The relatively low number of conflicting reports on the same flows within the UN data set justify our reconciliation rule; 54 to 81% of all trade always remains unrecorded or unreported by at least one of the parties (*cf. Table 18.2*).

(6) With regard to the dynamics of the UNSO and FAO data sets in terms of geographic coverage, the improvement over time is: in 1970, 46% of all trading countries was not mentioned in the *FAO Yearbook*, in 1981 this ratio was 44%. The number of flows observed by the UN was virtually constant, while the FAO has dramatically cut the scope of observations since 1977.

(7) The tests using only UNSO's direction of trade data reveal a smaller difference than their counterparts utilizing FAO information. The reason may be that there are trade flows mentioned in the relatively small FAO data set that are not reported to the UN (e.g., trade among the socialist countries). This underlines the importance of utilizing both data sources together.

(8) One of the most important aspects is that both data sources (i.e., the *FAO Yearbooks* and the UNSO international trade statistics) imply the same conclusion: relatively speaking, the reconciled and the original world totals are virtually equal. This fact indicates that our rule on selecting the largest entry does not cause real problems — at least, in the cases tested.

No doubt, this reconciling algorithm should be further tested. The real advantages and shortcomings of the procedure can only be identified in comparison with results from other trade-matrix reconciling techniques. Such tests will give a better indication of the possible bias imposed by our simple rule.

18.3. Historical Patterns of Trade in Forest Products

The following brief overview is based entirely on quantity data published by the FAO (FAO, 1983). This approach, selected for the sake of simplicity, has several advantages and disadvantages. The fact that all the original figures are expressed in cubic meters or metric tons allows for direct intertemporal comparisons, with no bias imposed by effects such as inflation, exchange rate differences, and price changes. On the other hand, we cannot take into account the often important quality changes in the commodity mix that are reflected only in the value data.

At the world level, the physical production (consumption) of forest products has been growing annually by about 2–3% since the early 1960s (*Table 18.3*). This slow but steady growth reflects the fact that forestry is not one of the most expansive sectors, but neither is it stagnant. The fastest growing branches are the wood-based panels and paper products.

Table 18.3 World production in forest products by commodity classes (10^6 ton for pulp and paper, 10^6 m^3 otherwise).

Year	*Fuelwood*	*Industrial roundwood*	*Sawnwood*	*Wood-based panels*	*Pulp*	*Paper and board*
1963	1156	1039	355	39	68	86
1965	1188	1115	379	48	78	98
1970	1222	1259	406	70	101	128
1975	1333	1283	405	84	102	131
1980	1530	1435	441	101	126	170
1983	1633	1409	451	104	128	175
Average annual rate of growth (%)	1.66	1.46	1.15	4.78	3.06	3.44

Nearly one half of all timber production has been that of fuelwood. In spite of its 40–45% share of forestry output, it is rarely traded internationally. In 1983, total world trade of fuelwood was only 0.2% of world consumption.

Within the forest sector, the growth in consumption of panels and pulp and paper products was relatively rapid due to the introduction of new products and production technologies during the past 20 years.

In general, however, the growth of production did not lead to an expansion of international trade relative to production in forest products. The share of world trade to production of industrial roundwood has been around 7–8% for the past 20 years. A very minor increase can be observed in the trade share of sawnwood, panels, and pulp. All three commodity classes have a rather constant trade ratio of about 15%. Somewhat larger is the share of world trade in paper products, where one fifth of production is being channeled through international markets today. The only relatively dynamic expansion took place in the world market of paper products, where, besides the growth of production, a 5% increase in trade shares can be observed.

In *Table 18.4* the export earning structure of the forest sector is shown by somewhat less aggregated commodities calculated according to 1983 export unit values. We find that, for coniferous sawnwood and newsprint and pulp, the share of the total value of trade that each product has had over the past 20 years has decreased (by nearly one fifth and one fourth, respectively). On the other hand, printing and writing paper has more than doubled its contribution. Very little change is observed for the rest of the products. However, even these figures do not reveal any major or "shocking" changes.

Table 18.4 The shift in the export earning structure of the forest sector by commodities (excluding fuelwood).

	Percentage share		*Change in percentage points*
	1963	*1983*	
Pulpwood	1.9	2.3	+0.4
Particle- and fiber-boards	1.9	2.7	+0.8
Coniferous logs	2.1	4.0	+1.9
Nonconiferous sawnwood	4.1	5.6	+1.5
Printing and writing paper	4.5	11.0	+6.5
Nonconiferous logs	6.9	6.2	-0.7
Veneer and plywood	6.1	7.1	+1.0
Other paper and boards	14.5	16.8	+2.3
Newsprint	15.0	10.8	-4.2
Pulp	20.4	16.3	-4.1
Coniferous sawnwood	22.6	17.2	-5.4
	100.0	100.0	

As indicated above, the overall commodity structure of international trade in forest products has not altered dramatically in the past 20 years.

In spite of the rigidity in the commodity composition of production, consumption, and international trade, some changes can be observed in the spatial distribution of the forest sector. As shown in *Table 18.5*, North America, the largest producer, has been able to maintain its dominance. The centrally planned economies (CPEs) have generally lost some importance as a result of the emerging production in Latin America and Asia. Also, Asia has made significant percentage gains in the production of sawnwood, wood-based panels, and paper and paper board.

However, with the exception of wood-based panels, the transitions in regional distribution were rather slow and may reflect both the changes in the availability of wood raw material and the shifts in purchasing powers of the listed regions (*Table 18.6*).

Table 18.5 The regional percentage distribution of production in the forest sector.

	Industrial roundwood		*Sawnwood*		*Wood-based panels*		*Pulp*		*Paper and board*	
	1963	*1983*	*1963*	*1983*	*1963*	*1983*	*1963*	*1983*	*1963*	*1983*
North America	34	33	29	28	48	32	54	52	49	41
North Europe	7	7	5	5	6	4	16	13	7	8
West Europe	8	8	9	9	18	23	9	8	20	18
CPEs	30	25	36	29	14	11	9	10	8	8
Africa	3	4	1	2	1	1	1	2	1	1
Asia	13	15	15	20	10	18	9	9	12	18
Latin America	3	6	3	6	2	1	1	4	2	5
Others	2	2	2	1	1	10	1	2	1	1
World total	100	100	100	100	100	100	100	100	100	100

Table 18.6 The regional percentage distribution of forest product exports.

	All forest products		*Industrial roundwood*		*Sawnwood*		*Wood-based panels*		*Pulp*		*Paper and board*	
	1963	*1983*	*1963*	*1983*	*1963*	*1983*	*1963*	*1983*	*1963*	*1983*	*1963*	*1983*
North America	34	34	19	25	31	48	10	15	37	48	51	36
North Europe	29	21	8	3	21	16	32	9	45	25	34	30
West Europe	14	19	9	12	15	12	23	28	11	9	8	24
CPEs	10	8	24	21	22	12	10	10	3	5	3	3
Africa	4	2	12	5	2	1	5	2	2	3	0	1
Asia	7	12	26	24	5	8	18	31	0	1	2	3
Latin America	1	3	1	1	3	2	1	4	2	7	0	2
Others	1	1	1	9	1	1	1	1	0	2	2	1
World total	100	100	100	100	100	100	100	100	100	100	100	100

Overall, a very large proportion of trade in all forest products has come from developed countries throughout the period; over 90% in 1963, but decreasing to 84% in 1983. In contrast, the developing countries' share of exports has increased from about 10 to 16%, due to both increased trade between developing regions and increased exports to the developed world. North America and Northern Europe have been the major exporters of manufactured forest products, accounting for over one half of the world's exports. Northern Europe's share has dropped fairly steadily, together with the CPEs', while Western Europe has been continuously increasing its market share. The main exporter in the developing world is the ASEAN (Association of Southeast Asian Nations) group of countries (Indonesia, Malaysia, Philippines, Singapore, Thailand). By the mid-1970s, this group overtook the Council for Mutual Economic Assistance (CMEA) countries (Bulgaria, Czechoslovakia, the GDR, Hungary, Poland, Romania, the USSR) as the fourth largest exporter of forest products (*Table 18.7*).

Table 18.7 The regional percentage distribution of forest product imports.

	All forest products		*Industrial roundwood*		*Sawnwood*	
	1963	*1983*	*1963*	*1983*	*1963*	*1983*
North America	23	21	13	7	29	38
North Europe	1	3	6	12	0	0
West Europe	50	42	36	19	52	37
CPEs	5	4	6	3	6	4
Africa	3	4	1	1	4	5
Asia	12	23	37	58	4	12
Latin America	4	2	1	0	2	3
Others	2	1	0	0	3	1
World total	100	100	100	100	100	100

	Wood-based panels		*Pulp*		*Paper and board*	
	1963	*1983*	*1963*	*1983*	*1963*	*1983*
North America	29	35	23	19	38	24
North Europe	2	2	1	1	0	1
West Europe	55	46	60	47	39	46
CPEs	5	6	3	5	3	6
Africa	3	2	1	2	4	3
Asia	4	7	7	20	7	13
Latin America	1	1	3	4	6	5
Others	1	1	2	2	3	2
World total	100	100	100	100	100	100

Nearly half of all exports have gone to Western Europe throughout the last 20 years, while North America has decreased its imports of forest products (but has always remained a net exporter). Japan, the largest Asian importer, has remained the third major importer, with an ever-increasing share. In the case of the individual commodity aggregates in *Tables 18.4* and *18.5*, there are only a few cases, of minor importance, that are not in line with these general tendencies.

As *Table 18.8* shows, nearly 50% of world trade in forest products has occurred in three flows since 1962: namely, intraregional Western European trade, North American trade, and Western European imports from Northern Europe. While the first has almost doubled its share over the past 20 years, both the others have decreased. North American exports to Japan have also increased over the past 20 years. The overall concentration of trade flows among the six major exporting regions, as indicated by the last row of *Table 18.8* has also decreased slightly during the period.

In general, we may conclude that neither the commodity structure nor the regional distribution of the global exchange system have changed radically, at least at the level of aggregation presented above. This phenomenon of resistance to change is commonly referred to as the *inertia* of international trade. In the next section we examine the degree of this inertia in more detail.

18.4. Trade Inertia

Disregarding other factors, trading agents will choose the most profitable trade routes available. However, as the above illustrations suggest, the assumption of such free trading is not justified. From a historical point of view, trade has not been driven merely by relative price and cost differentials, but also, to a large extent, by various other factors. Examples of such effects are the existing geographical, political, cultural, and other preferences, long-term trade agreements, historical alliances, proven channels of information, costs of changing marketing channels and logistical systems, etc. Besides these trade-attracting features, there are also several prohibitive factors, such as trade barriers, tariffs, embargoes, trading, transporting, and other cartels, lack of information, etc. The joint effect of these factors is the inertia of trade.

There are several approaches available to identify the factors that explain the size of the trade flow between any pair of countries or regions. Some of these models were designed to forecast trade flows over a relatively short time horizon (Brännlund *et al.*, 1983), applying prices and costs as basic explanatory variables. Other approaches were designed to analyze

Table 18.8 Percentage shares of world trade of major bilateral flows of all forest products (Francescon *et al.*).[a]

Exporting region	*Importing region*	*1962*	*1970*	*1981*
Western Europe	Western Europe	10.0	11.8	16.9
Northern Europe	Western Europe	23.5	19.2	15.9
North America	North America	23.0	15.7	15.6
North America	Western Europe	7.6	9.0	8.1
North America	Japan	2.1	6.0	5.4
CPEs	Western Europe	6.0	4.5	2.9
North America	Latin America	1.9	2.4	2.6
ASEAN group	Japan	1.9	3.4	2.2
Africa	Western Europe	3.8	3.2	2.2
Share of trade represented above		79.8	75.2	71.8

[a] The trade shares shown here are based on aggregated value data obtained from the UNSO and, thus, are not directly compatible with the FAO *Direction of Trade* figures referred to elsewhere in this chapter.

those more or less constant, time-invariant factors, such as distances between traders, the magnitudes of their economic potential, etc., that contribute to the structural development of bilateral trade in the long run (Linnemann, 1966; Buongiorno *et al.*, 1980). More recent methodological tools are even able to combine these two basic approaches (Herman and Paelinck, 1980; Anderstig, 1983). The problem with using any of these models is their very demanding data requirements: not only should the trade flow sets by exporters and importers of a given commodity for a sequence of years be available, but also these trade matrices should be consistent with country total exports and imports. Moreover, full time series are needed for various explanatory variables that measure relative prices, competitiveness, transportation costs, tariffs, etc. As the scope of our analysis is limited, a much more simplistic and thus less data-intensive approach is satisfactory here.

A simple definition of trade inertia is the following: inertia is the extent to which the historical patterns of trade prevail over time. A more complex definition should identify all the various inertia factors (some are listed above) and to separate the magnitude of their individual contribution to rigidity.

A possible assessment of the extent to which trade inertia has existed historically is to use earlier trade patterns as the *a priori* determinant of trade shares for some later period. In other words, a simple adjustment of our earlier trade flow should predict future trade flows (*cf.* Johansson and Batten, 1983, pp 21–22). Since our intention is not to go as far as predicting trade, we may use a simple formulation of inertia:

$$e_t = I_T e_{t-T}$$

where e_t is the bilateral trade flow for a given exporter, importer, and commodity in period t (10^6 m^3 or 10^6 ton); e_{t-T} is the bilateral trade flow for the same exporter, importer and commodity, $T = 0,1,\ldots,n$ previous periods; and I_T denotes the inertia multiplier for a lag of T periods.

By definition, $I_0 = 1$, which we can use as the point of reference. The more the multiplier I departs from unity, the less inertia there is. If I decreases or increases monotonically as the time lag increases, the more likely is a positive or negative trend in the development of a given trade flow. If the inertia multiplier varies around its reference value, the more likely that *ad hoc* economic turbulences, such as sudden changes in competitiveness, play a role in shaping the short-term patterns of international trade. On the other hand, the more constant is the inertia, the more predictable is the trade.

To verify the assumed importance of inertia in trade, we can estimate directly the multipliers I by regressing through the origin, and we may easily test their stability over time.

For the systematic estimation of inertia we need time series observations on bilateral trade flows. Using the method described in the previous sections, we assessed several trade matrices. To avoid processing immense quantities of data, we limited our scope to a relatively small number of commodities and countries. Even so, we could identify over 100 major trade flows, using the 1980 flows as a point of departure. Each of the selected routes was intended to represent acurately international trade in the given forest product. Then time series of the trade flows were completed for the period from 1966 to 1983 (18 observations per flow). Because of discontinuities, we finally used 85 trade flow series for six commodities and 15 important trading countries, representing 29–68% of world trade, depending on the commodity. A summary of our trade flow data is presented in *Table 18.9*.

The given representation of trade may result in some bias in the conclusions, since even the smallest flows selected were above 1% of world trade in 1980. Large flows are more likely to experience inertia than small ones, even if several of the factors incorporated into inertia are not necessarily related to economies of scale (e.g., even a very minor flow may be based on a long tradition of partnership and cooperation). In reality, there are about 500 to 3000 historically observable trade routes every year for each commodity concerned, as was indicated by our trade data reconciliation effort. A vast number of these minor — and often rather erratic — trade connections are not represented in our data base. However, the high

Table 18.9 Summary of the trade flows selected for the analysis.[a]

	Logs		*Sawnwood*				*Number of*
Country	*C*	*NC*	*C*	*NC*	*Pulp*	*Newsprint*	*flows*
US	X,M	X	X,M	X,M	X,M	M	28
Canada	X,M	M	X,M	X,M	X	X	23
Japan	M	M	M	M	M	M	20
FRG		M	M	M	M	M	19
UK			M	M	M	M	19
Sweden			X		X	X	9
Finland			X		X	X	8
Indonesia	X	X		X			8
Brazil				X		M	8
Malaysia		X		X			8
Singapore		M		X,M			8
Philippines		X		X			5
USSR	X		X				4
China		M					2
Chile						X	1
Total share (%)	68	63	53	29	39	64	
Number of flows	6	10	15	28	12	14	

[a] C, coniferous; NC, nonconiferous; X, the country participating in trade as exporter and M, that as an importer. "Total share" refers to the share of total trade of a column in total world trade for a particular product in 1980.

volume share of the 85 flows in world trade again emphasizes the concentration of trade mentioned before.

To obtain first a set of reference values for inertia coefficients, we estimated the multiplier I for all available observations for lags $T = 1, 2,$ and 10 years using the ordinary least-square (OLS) regression method. With increasing time lag T, the following properties of trade development may be observed (see the curves marked by "All" in *Figures 18.1-18.6*):

(1) The estimated inertia multipliers are very close to unity up to lag $T = 5$ (years), increase monotonically between lags $T = 1$ to $T = 7$, then drop again to $T = 6$. The largest increase was estimated between lags $T = 9$ and $T = 10$. However, the range of the inertia figures is rather narrow. The fact that all multipliers are greater than 1 also indicates a weak, trend-like development of trade flows. (The regression statistics, which indicate that all estimated coefficients are statistically highly significant, are not given here.)

(2) The gradual decrease in explanatory power of the lagged trade flows as the lag increases obviously indicates that there are factors other than inertia that drive trade development in the longer run.

We may test several hypotheses by grouping our data according to different cross-section categories.

Is the inertia of trade significantly different for different commodities?

Testing this hypothesis for the six commodities in our sample, we found that the only decreasing inertia multiplier belongs to coniferous sawnwood (*Figure 18.1*), corresponding to the negative trend in trade and the relative decrease in the importance of this product, mentioned above (*cf. Table 18.4*). The inertias are nearly constant for coniferous logs, pulp, and nonconiferous sawnwood. The multiplier of newsprint increases relatively sharply, while the inertia of trade in nonconiferous logs is just above the average represented by the base case. Both products have experienced an upward trend in bilateral trade, while coniferous sawnwood shows a negative trend.

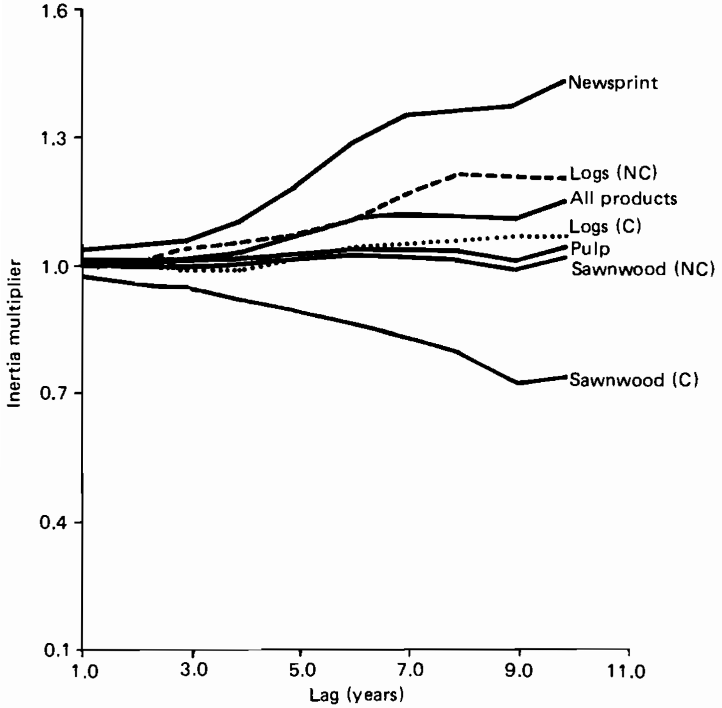

Figure 18.1 Inertia multipliers by products.

Newsprint has a mean of 2×10^6 tons per annum and per trade flow over the past 17 years. The average size of a trade flow in nonconiferous logs is less than 0.1×10^6 m^3. This shows that, while inertia depends on the commodity, once grouped by commodities the size of the trade flow does not play an important role. We discuss this point further below.

Is the inertia different by exporting countries?

The dynamics of inertia for Brazil, Chile, and the USSR are different from the up- or down-ward sloping series of other countries shown in *Figure 18.2.* Brazil is the only exporter with an inertia multiplier that fluctuates around unity, while Chile displays a steady growth following a drop for $T = 1$ and 2 years. USSR exports show a particularly strong inertia.

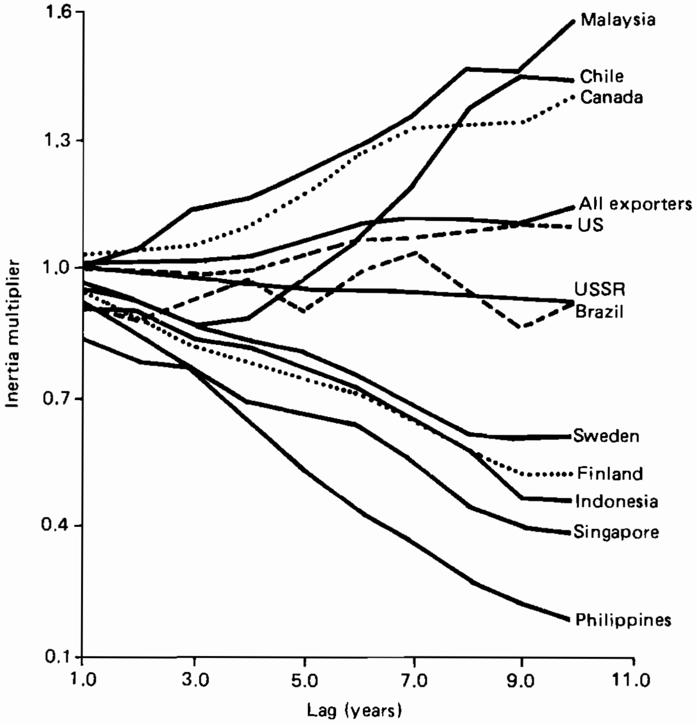

Figure 18.2 Inertia multipliers by exporters.

There are only three countries out of the 11 with a multiplier that grows faster than the all-observations base case: Malaysia, Chile, and Canada. The inertia of US exports is just above unity, while the rest of the countries — Finland, Sweden, Indonesia, Singapore, and the Philippines — display a growing propensity to change their exports over a longer period. The multiplier for Malaysia becomes as high as 1.59 for lag $T = 10$ years, while for the Philippines it decreases to below 0.19, the lowest multiplier estimated.

Is the inertia different by importing countries?

The inertias of imports (*Figure 18.3*), however, seem to be somewhat more steady than those of exports. The lowest is for Singapore, with a value of 0.33, and the highest is for China, with 1.52, both estimated for $T = 10$

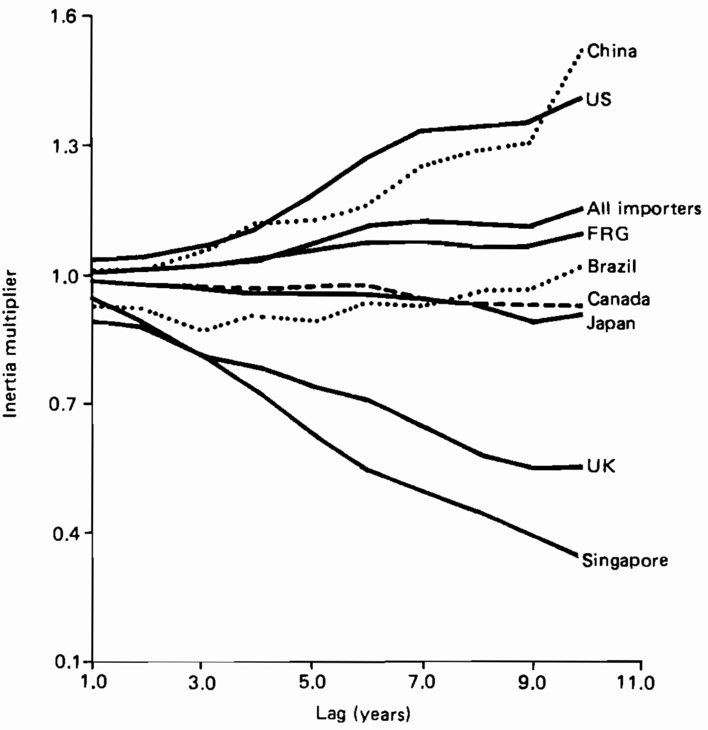

Figure 18.3 Inertia multipliers by importers.

years. Japan, Canada, the FRG, and Brazil show very little variation in their inertia multipliers, while the UK has a trade pattern that indicates more liability to changes.

Is the inertia different by countries that both export and import?

There are only four countries in our sample who participate both in export and import trade: the US, Canada, Brazil, and Singapore. As *Figure 18.4* shows, the exporting inertia of Canada and the importing multiplier for the US are virtually equal: these two countries — at least in relative terms — trade with each other exclusively. The same cannot be said about US exports and Canadian imports. The inertia of Brazilian trade indicates a

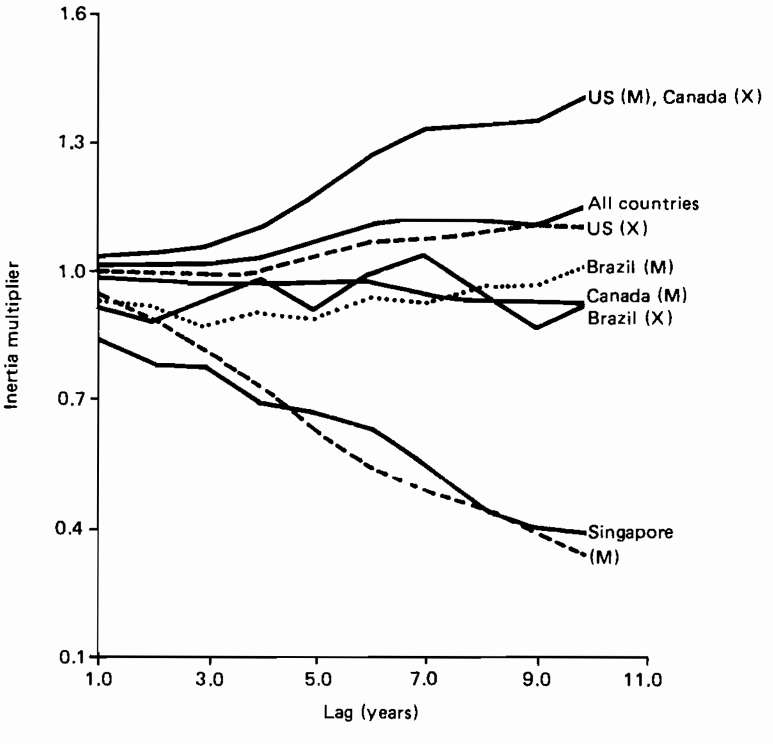

Figure 18.4 Inertia multipliers for countries that both export (X) and import (M).

rather rigid but somewhat fluctuating pattern, whereas the exporting and importing behavior of Singapore is increasingly less stable.

Is the inertia of large trade flows greater than that of the relatively small ones?

Trade inertia is heavily dependent on the size of the trade flows concerned (*Figure 18.5*). Our separation of *small* and *large* trade depended on whether a flow was smaller or larger than the mean of the *all-observations* flow. As expected, the small trade flows develop toward a more variable pattern, while the large flows are heavily influenced by inertia. This may be connected to the logistics of ocean transportation.

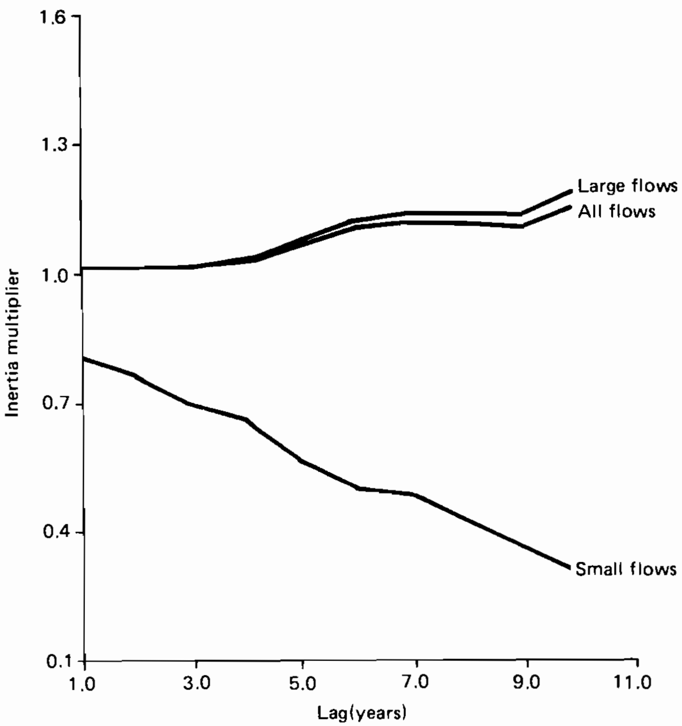

Figure 18.5 Inertia multipliers by the size of trade flows.

Is there a different degree of inertia that characterizes trade between and within the groups of developed and developing countries?

The inertia in exports of the developing countries, both to industrialized and to developing countries, is slightly decreasing. There is an upward trend in the multipliers on lagged trade between the the industrialized economies only. Overall, the inertia of world trade is not very different by economic regions — at least within our sample (*Figure 18.6*).

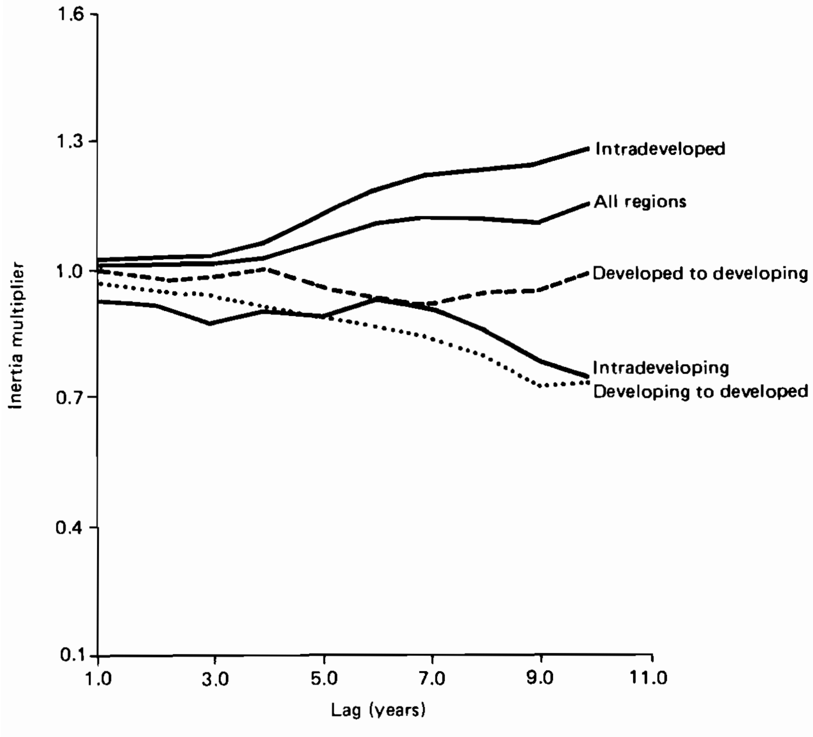

Figure 18.6 Inertia multipliers by economic regions.

As the above six simple tests indicate, a more complex approach is necessary in future work to separate the various factors now being lumped into the notion of inertia. However, it should also be obvious that any analysis of historical, bilateral trade patterns or any exercise in forecasting trade flows should not omit the issue of inertia.

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Part V

Methodology for Global Forest Sector Analysis

CHAPTER 19

Introduction to the IIASA Forest Sector Model

D.P. Dykstra and M. Kallio

The broad mission of the IIASA Forest Sector Project was to study long-term structural changes in the forest sector of the global economy. Toward this end, the Project's primary task was to develop a dynamic, global model that depicted the interactions among forest resources, wood processing, and international trade in forest products. The Project's core team was charged with responsibility for coordinating activities among the collaborating institutions, for collecting and analyzing data, for formulating, implementing and testing the model, and for making a series of demonstrative scenario runs to investigate potential long-term changes in the forest sector. Collaborating institutions assisted in the work by collecting detailed, local data on forest resources, harvesting and processing costs and capacities, and demand for forest products. Some collaborators have also been simultaneously working on specific analyses related to the overall effort and, in several cases, have developed national forest sector-models as a complement to IIASA's global effort.

The IIASA global forest sector model, which has been more commonly referred to as the Global Trade Model (GTM), is a partial market-equilibrium economic model cast in a nonlinear programming framework, with linear constraints and a partially nonlinear objective function. For any time period, t, the model finds the market-equilibrium solution for all regions and all forest products such that demand and supply are equal for each forest product in each region, given that regional material flows (including timber supply) must balance and that restrictions on productive capacity limits and interregional trade flows must be observed. The market-equilibrium solution for period t is then updated to the beginning of the subsequent five-year period, $t + 1$, by considering changes in timber supply, productive capacity, production technology and costs, demand, and trade-flow inertia. The solution for period $t + 1$ is subsequently obtained using a nonlinear programming algorithm. In this manner, sequential market-equilibrium solutions are determined for each five-year period in the planning horizon.

19.1. Structure of the Global Forest Sector Model

The GTM is a partial market-equilibrium economic model in a general framework that follows Hotelling (1932) and Samuelson (1952). The mathematical formulation is similar to that used in a model of the pulp and paper sector of North America (Buongiorno, 1981; Buongiorno and Gilless, 1983). It is also closely related to the model formulation used by Adams and Haynes (1980, 1985) to study the structure of forest products markets in North America.

In any time period the model finds the market-equilibrium solution for all forest products in all world regions, without considering any possible influence of future time periods. Thus, although the model is dynamic in the sense that it is implemented over time, it is not technically a dynamic equilibrium model. However, as is pointed out in subsequent chapters, this is not seen as a serious drawback; on the contrary, we believe that the global market equilibrium in any period is essentially independent of future market equilibria.

Figure 19.1 illustrates the dynamic structure of the model. The base year for our runs is 1980. In any dynamic run, the GTM proceeds initially to find a market-equilibrium solution for the base year. The solution thus obtained indicates the annual quantity of timber removals for the next five-year period, the quantity of harvested raw materials to be traded between regions or converted into final products within each region, the quantity of final products to be produced within each region, and the quantity of final products to be traded among the regions. The dual solution indicates the marginal prices of both raw materials and final products. For the mathematical foundations of the approach, see Chapter 20.

As illustrated in *Figure 19.1*, information from the 1980 solution is used to project timber growing stock, processing costs and capacities, and other relevant factors for the subsequent period, using an interperiod interval of five years. After the updating has been completed, the model is run for the subsequent period and a second, partial market-equilibrium solution obtained. This updating/solution sequence is repeated until the specified

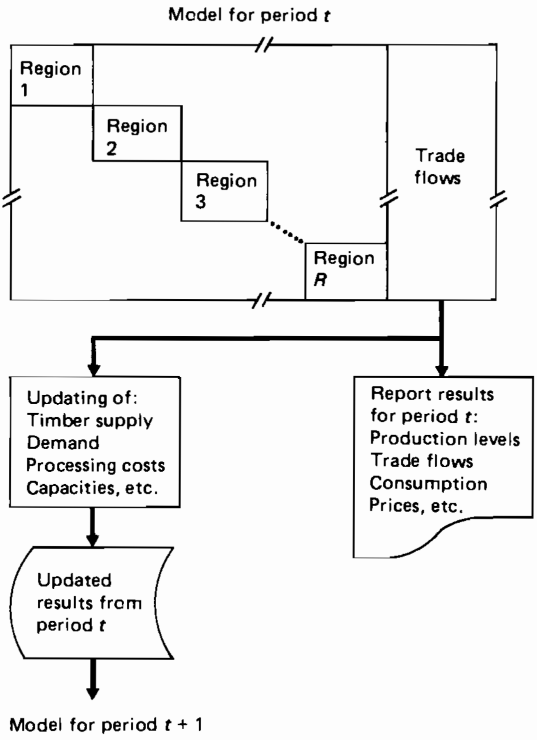

Figure 19.1 Dynamic structure of the GTM.

time horizon has been reached. The software has been designed so that after run initiation, no intervention is required by the user until the time horizon has been reached.

19.1.1. Regional and product aggregations

We have formed aggregations of regions based on a subjective evaluation of the importance of regions with respect to the global forest sector. To a certain extent, data availability was a determining factor as well. The 18 regions in the final database and GTM are:

1. Western Canada
2. Eastern Canada
3. Western US
4. Eastern US
5. Brazil
6. Chile
7. Rest of Latin America
8. Finland
9. Sweden
10. Rest of Western Europe
11. USSR
12. Eastern Europe
13. Africa
14. China
15. Japan
16. Southeast Asia
17. Australia–New Zealand
18. Rest of the World

The region called the Rest of the World includes countries from many parts of the globe, from Iceland to Tonga. Most of its population and land area, however, is centered on the Middle East and the Indian subcontinent. In this book we thus sometimes refer to this region as the Rest of Asia.

Product categories used in the GTM are listed below, together with an indication as to whether the category represents final products (F) consumed *outside* the forest sector or intermediate products (I) consumed *within* the forest sector (i.e., in the production of other intermediate or final products). In the case of the latter, small quantities may also be consumed outside the forest sector, but these quantities are considered low enough to be neglected in the model.

1. Coniferous logs (I)
2. Nonconiferous logs (I)
3. Coniferous pulpwood and chips (I)
4. Nonconiferous pulpwood and chips (I)
5. Fuelwood (F)
6. Coniferous sawnwood (F)
7. Nonconiferous sawnwood (F)
8. Veneer and plywood (F)
9. Composition panels (F)
10. Coniferous white pulp (I)
11. Nonconiferous white pulp (I)
12. Newsprint (F)
13. Printing and writing papers (F)
14. Household and sanitary papers (F)
15. Packaging paper and board (F)
16. Recycled paper (I)

In this and the following chapters we often shorten some of the names of these product categories as follows: 3. Coniferous pulpwood, 4. Nonconiferous pulpwood, 9. Particle board, 10. Coniferous pulp, 11. Nonconiferous pulp, and 13. Printing paper. Note that the term "white pulp" refers to bleached chemical pulps; other types of pulp are not considered explicitly in the model, but rather enter the paper furnish as part of "other fiber" inputs. We identify bleached pulp explicitly as a product because such pulp accounts for essentially all international trade in pulp.

19.1.2. The static model

Assume that each producer and trade agent involved in the forest sector is a profit maximizer and that each consumer purchases from the producer or trader who offers the lowest price. Given prices for each commodity in each region, profit maximization results in a certain supply of commodities in each region. If such supply equals the demand as defined by the consumption function, then the price is an ***equilibrium*** price. The solution point corresponding to the equilibrium price and consumption quantity for a particular time period can be obtained by solving a global optimization problem that is discussed in Chapter 20. The objective function of this problem represents the sum of consumers' surplus and producers' surplus. The point at which this sum is maximized defines the equilibrium point; that is, the point at which supply and demand are balanced. Constraints ensure that material balances (i.e., consumption is equal to production minus net export), limitations on available resources, and trade inertia or quotas are observed. The following subsections outline in more detail the basic concepts of the static model.

Timber supply

Growing stock in each region is segregated into four classes: large and small coniferous and large and small nonconiferous trees. Large trees can be thought of as sawtimber trees used to produce logs, pulpwood, and fuelwood; small trees can be thought of as pulpwood trees used to produce only pulpwood and fuelwood.

The marginal cost of timber removals is assumed to be a strictly increasing function of the annual removal quantity. Our practice for developing the marginal cost functions for each region was to estimate the price elasticity for stumpage supply, using published information, data provided by collaborators, or the exercise of judgment. Given independent estimates of timber costs for 1980, the other parameters for the marginal cost functions could then be calculated. For a detailed explanation of the assumptions and numerical procedures followed in the timber supply model see Chapter 21.

Final product demand

For each region and forest product, we assume that the relation between price and level of consumption is given by a consumption function. A detailed study of final product demand using the GTM product aggregations and regional definitions has been carried out and the results are discussed in Chapter 23. This study utilized data from various international sources, such as FAO (1984a).

Technological coefficients

Conversion factors that indicate the quantity of logs, pulpwood, and fuelwood produced from trees and the quantity of intermediate products required to produce a standard quantity of intermediate or final products were obtained largely from collaborators. Conversion factors for pulp and paper products were provided by Jaakko Pöyry Oy, an international forestry and forest-industry consulting company based in Finland. Where data were not available from collaborators, estimates were taken from published sources such as ECE (1982). Details on both the data and the sources are given in Chapter 22.

Cost coefficients

The model utilizes two sets of constant marginal cost coefficients for each time step: marginal production cost and unit trade cost (transportation cost plus tariffs). Production cost estimates were developed partially from data provided by collaborators and partially using a production cost model for forest products (Kirjasniemi, 1984). Unit trade costs, which include tariffs proportional to the quantity shipped (an approximation of *ad valorem* tariffs), were estimated from data provided by collaborators, from information from UNCTAD (e.g., UNIDO, 1983), and from other sources such as Wisdom (1984) and Jones (1984). For detailed discussions of processing costs see Chapter 22, for transportation costs see Chapter 25, and for tariffs, see Chapters 15 and 24.

Production capacity

Information for establishing limits to productive capacity (Chapter 22) were obtained largely from collaborators or inferred from FAO data (FAO, 1984a). For pulp and paper products we have ensured that capacity expansion through 1985 conforms to published projections (FAO, 1984b).

Trade inertia

An assumption common to most international-trade modeling work is that trade flows develop smoothly over time, thus exhibiting a kind of inertial tendency. The GTM specifies this inertia by using simple upper and lower bounds on trade flows. For 1980, we set the lower bounds equal to 50% of our reference trade quantities for that year. The upper bounds were set to 200% of the reference trade quantities. These figures are based on a statistical analysis of trade flows over a 16-year period (Chapter 24). Reference trade quantities were established by reconciling reports on forest products trade from the UN Statistical Office (UNSO) and the FAO Forestry Department (Chapter 18). Other factors considered relevant in the projection of trade inertia are changes in the market share and in the fraction of production being exported.

Centrally planned economies

Although most of the world trade in forest products passes between market economies, a significant and growing fraction of this trade is associated with centrally planned economies (CPEs). For the purposes of the GTM, two regions, the USSR and Eastern Europe, are modeled explicitly as CPEs. The People's Republic of China is modeled essentially as a market economy, because detailed information about China's plans for production and trade in forest products have not been available.

The basic differences between the regional component model of a CPE and that of a market economy are:

(1) Production levels are fixed for each (final) product according to a central plan. In the GTM this is done by assuming that future changes in the level of production will follow a trend similar to that followed during the past 20 years.

(2) Domestic consumption targets are set for each (final) product. During the past 20 years, domestic consumption of forest products in the USSR has remained essentially constant as a fraction of production and we assume that this trend will continue.

(3) We assume that the agents of the CPE will sell exports at the highest possible price, buy imports at the lowest possible price, and minimize deviations from consumption targets subject to the fixed production levels. A penalty function is employed to account for the trade-off between gains in export revenue and losses due to not meeting consumption targets. Other methods for accomplishing the same are described in Fedorov *et al.* (1984).

For a more detailed discussion of the regional component models for the CPEs, see Chapter 26.

19.1.3. Dynamic considerations

In implementing the GTM over time, numerous special considerations have to be accommodated. We have organized the GTM so that the base year is 1980 and runs of up to 50 years (i.e., to 2030) in five-year steps can be made. As the solution corresponding to each step is obtained, it is stored to permit retrieval of solution summaries after the complete run has finished. The interperiod software is then invoked to make the calculations necessary to advance from the current solution period to the subsequent period. The solution at each time period should be thought of as representing an *annual average* for the five-year time step. The following sections summarize briefly the calculations made by the interperiod software.

Timber supply

Given the level of growing stock in each timber type at the beginning of the time step and the volume of annual removals specified by the GTM solution, the timber-supply routine advances to the subsequent period by subtracting annual removals from the growing stock inventory and using simple growth models to project end-of-year growing stock levels. These calculations are made for each of the five years in the time step. Details on the procedure and its variations for special cases (such as tropical plantations) are given in Chapter 21.

Production

The GTM assumes that production capacity for any product in any region is divided into three types: old processes, modern processes, and new investments. The 1980 productive capacity has been divided into *old* and *modern* according to data received from collaborators; in 1980 there are no new investments available for production in that year.

In each time step a given percentage of the old capacity is shut down (depreciation) and another percentage of *modern* capacity is moved into the *old* category. *New* capacity created in one period is moved to the *modern* category in the following period. Cost and conversion factors are updated for *old* and *modern* capacity according to the new composition of capacity mixes.

The budget for new investments in any region for a particular time step is assumed to be a fixed percentage of annual revenues from production activities. This budget is apportioned among the various production activities according to profit levels, so that the more profitable processes receive a larger fraction of new investments.

For CPEs, a somewhat different approach is used. Recognizing that such countries operate on the basis of centrally determined production plans, we project production levels according to historical trends, or simply by production scenarios.

Demand

Following Wibe (1984), we assume that the consumption of final forest products in any region is a function of the price of the product, real income per capita and income elasticity, and a time trend (which might be due to technological development). Price is endogenously determined, but both real income per capita and the effect of the time trend are exogenous. To determine shifts in the demand curves, income elasticities with respect to demand were fitted econometrically for each final product using time-series data for the GTM regions. Estimated annual percentage changes in population and in per capita income were taken from a scenario suggested by FAO (see Wibe, 1984). Note that these estimates should be considered *scenario* parameters; they are not fixed in the GTM, but can be varied easily according to the scenario to be investigated. Income elasticities of demand as presently used in the GTM are based on estimates by Wibe (1984) and on additional estimates discussed in Chapter 13. The elasticities themselves are summarized in Chapter 23.

Exchange rates and inflation

In the GTM, exchange rates and differential inflation rates are utilized as dynamic scenario parameters. The unit of currency in the GTM is the US dollar; thus, all other currencies are expressed in terms of the dollar. In any period, marginal costs of both timber harvesting and production are adjusted for exchange rate differentials and inflation.

Tariffs

Tariffs are treated in the GTM as being proportional to the quantity traded; thus, they are simply added to transportation costs. Actual tariffs for 1980 and the post-Tokyo Round tariffs (to be implemented by 1987) have been included in the GTM. Tariffs in future periods can be either held to these levels or varied as scenario parameters.

Trade inertia

Trade flows are limited to quantities specified by the upper and lower bounds. In order to account for trade inertia, a lower bound is calculated as a given percentage (e.g., 50%) of trade during the previous time step. Similarly an upper bound is calculated to account for three factors: the actual trade flow during the previous trade period, the exporters' market share, and the share of export in production. Details of the calculation of the trade-inertia bounds are given in Chapter 24.

19.2. Implementation of the Model

The initial implementation of the GTM was on a Digital Equipment Corporation VAX 11/780 super-minicomputer using the UNIX operating system. Data base and model software are written in Fortran and a major effort has been made to ensure that all the software are compatible with the 1977 ANSI standard (Katzan, 1978). The optimization procedures make use of a nonlinear programming package called MINOS, which was developed at Stanford University (Murtagh and Saunders, 1977, 1978), and is itself written in ANSI-standard Fortran, but conforming to the 1966 standard (a subset of the 1977 standard).

A typical run involving 18 regions and 16 forest products requires somewhat under 1.3M bytes of virtual memory, of which about 350K bytes must be resident. In all of our runs, the starting basis for period t is loaded from the optimal basis for a previous solution. Tests made with a preliminary version of the model suggested that this practice reduces run times by 20–80% as compared with running from a "cold start" (i.e., with the structural variables forming the starting basis).

The size of each one-period model is small compared with many of the linear programming models used in modern forest management planning (e.g., Johnson and Scheurman, 1977), but moderate given that the objective function is partially nonlinear. A typical 18-region, 16-product model has approximately 300 linear constraint rows and 2500 columns, 225 of which are nonlinear. The density of the matrix is typically about 1.4%.

19.3. Scenario Analysis

The main idea behind the development of the GTM was to provide a tool that could be used to assess potential long-term changes in the structure of the forest sector, either within specific regions or globally. In order to demonstrate the capabilities of the model for this purpose, and to determine the sensitivity of the model to various parameters, we have made a series of runs under a variety of scenario assumptions (see Chapters 27–29). In this introductory section we briefly outline the various scenarios that we have investigated with the model; this should suggest the range of analyses that can be undertaken with such a model.

19.3.1. Base scenario

Our *base scenario* assumes that the level of economic growth globally will be slightly lower in the coming decades than it has been during the 1960s and 1970s. Moreover, population growth after the year 2000 will be reduced slightly in most regions. In addition, we assume that by 1990 currency exchange rates will have moved toward the levels that existed in 1980, as measured in US dollars; that by 1987 tariffs will have moved to the post-Tokyo Round levels; that the annual volume of timber removals in the USSR will gradually increase to a level 20% higher than the present; and that there will be no substantial change in forest growth or mortality rates due to environmental change.

Although various experts may agree or disagree with these assumptions, it should be remembered that the function of a base scenario is to provide a median scale against which other scenarios can be measured. The base scenario should *not* be thought of as our prediction of the path of development. Rather, it provides a convenient benchmark simply because none of the assumptions made for the base scenario are very remarkable.

19.3.2. Economic growth

We consider two economic growth scenarios as alternatives to the economic growth assumption of the base scenario:

(1) The *low-growth scenario* assumes that per capita income in all regions will grow at only one half the rate of the *base scenario*.

(2) The *high-growth scenario* assumes that per capita income in the industrialized regions will grow at the rates indicated in the *base scenario*, but in all developing countries it will grow at rates that are 50% higher than in the base case.

19.3.3. Trade liberalization

The *trade-liberalization scenario* is designed to measure the effect of free-trade policies on the development of the global forest sector. In this scenario we assume that by the year 2000 all tariffs on forest products will have been discontinued.

19.3.4. Acid rain

Because of strong evidence that atmospheric pollution is causing increased mortality in the forests of Central Europe, we have tested one scenario designed to illustrate the potential economic effect of such disturbances on the forest sector. In this *acid rain scenario*, we assume that only the forests of Eastern and Western Europe (excluding the USSR and Scandinavia) are effected by atmospheric pollution. The effects assumed in the scenario are of two types: an increased short-term mortality resulting in the salvage harvest of trees that would otherwise not have been considered economically ready for harvest and a long-term reduction in forest growth.

19.3.5. USSR timber exploitation

In the *USSR timber exploitation scenario*, we assume that the economically exploitable timber supply in Siberia and the Soviet Far East increases so that the average annual level of removals in the USSR eventually reaches a plateau at about 600×10^6 m^3. Because such an increase would depend largely on the development of transportation and processing infrastructure, we assume that it would be phased in gradually over time, reaching the maximum level in about the year 2010.

19.3.6. Exchange rate scenario

Some of the more sensitive parameters in the global forest sector model are the currency exchange rates. In order to measure the sensitivity of the model to variations in exchange rate assumptions, we have tested two alternative scenarios:

(1) In the *weak US dollar scenario*, we assume that by 1990 the exchange rates of all currencies as compared with the US dollar will recover and exceed the rates that existed in 1980.

(2) In the *strong US dollar scenario*, we assume that the exchange rates of all currencies as compared with the US dollar will continue at the 1985 level.

19.3.7. Climatic warming

The *climatic warming scenario* utilizes information from IIASA's Climate Project to assess the possible economic effects of climatic warming due to an increase in atmospheric carbon dioxide. Although such warming would have many diverse effects on terrestrial life, in the forest sector we assume that there would be only two significant effects: forest growth rates would increase substantially in the boreal regions represented in the GTM and the forest area would increase in these regions because the zone suitable for growing trees would be extended northward.

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CHAPTER 20

General Approach

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Over several years the Forest Sector Project at IIASA has developed a spatial equilibrium model of the global forest sector [which is often, somewhat misleadingly, also called the Global Trade Model (GTM)]. The model is designed to analyze long-term global trends in production, consumption, and world trade in forest products (see DSTG, 1982; Salo and Kallio, 1982; Buongiorno and Gilless, 1983a,b; Dobrinsky and Kallio, 1985; Dykstra, 1983; Kallio, 1983; Kirjasniemi *et al.*, 1983; Dykstra and Kallio, 1984; Fedorov *et al.*, 1984).

Most of the model-formulation work has been done for a static case, with the implicit assumption that behavior over time will be studied using the static models in a recursive manner. Some extensions into a fully dynamic formulation were also proposed (e.g., Salo and Kallio, 1982).

In this chapter we give a description of the general principles employed in the global forest sector model developed at IIASA, clarify the underlying assumptions, and give a clear interpretation of the model. An instructive way of doing this is to consider the model as constructed hierarchically by linking together the lower level, regional component modules (RCMs) with their submodules, the sectors of regional economy (hereafter also called sectoral agents). Similarly, these sectors (e.g., consumer sector, production sector, and import and export trade sectors) could be further subdivided into several subsectors. However, here we consider only three hierarchical levels: global, regional, and sectoral.

The principle of linking together sectoral agents and regions requires choosing regional and world market prices that equate demand and supply in all markets. An identical, but computationally more efficient, form of this principle can be given in a mathematical programming framework, developed from the work of Samuelson (1952). As illustrated in *Figure*

20.1, supply and demand can be equated by maximizing the area $ABCD$ between the demand and supply curves (a negative area if the supply is greater than the demand). At equilibrium this area (AED) is the sum of consumer's surplus and producer's surplus.

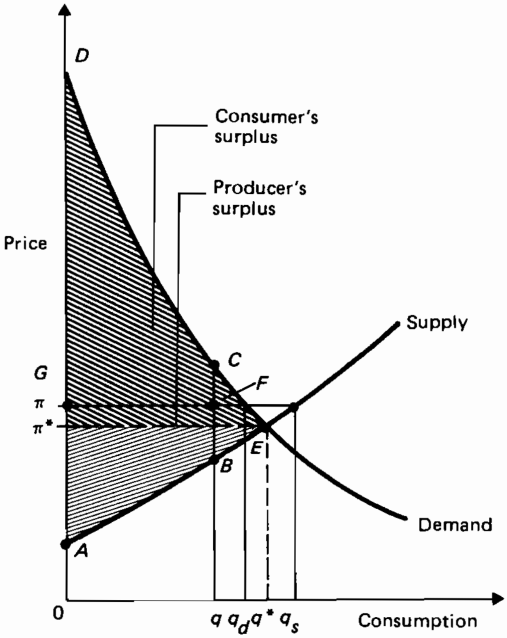

Figure 20.1 Equating supply and demand to determine the partial equilibrium price and consumption is equivalent to maximizing the area $ABCD$ between the demand and supply curves.

In the case of R regions and K products we may consider the same product in different regions as being different commodities and that exporters and importers are producers who transform only the location character of the products. Various kinds of trade inertia should also be reflected in the supply correspondences of the export–import trade agents. By doing so we have a one-region model with KR products and two sectors, the consumer and producer sectors. The notion of "the area between the demand curve and the supply curve" would then have to be constructed as a suitable line integral, which would again represent the sum of consumer's surplus and producer's surplus. However, we do not pursue this approach because various kinds of trade inertia render the supply correspondence extremely complicated. It is not practical to represent this explicitly.

We can arrive at the same, final mathematical programming model simply by constructing it hierarchically, piece by piece, starting with the sectoral models. This approach has several advantages, such as providing a simple way to prove, in a very general setting, the equivalence of the global spatial equilibrium and the optimal solution to the maximization of the sum of the consumer's surplus and the producer's surplus. As soon as one has a clear understanding of the behavior of sectoral agents represented by the sectoral models, one has a better understanding of the global model (GM) too. Our hierarchical approach demonstrates clearly the possibilities of representing different regions with different types of models. Choices of these types can be made independent of other regions. Most certainly, minor or major modifications to the present model are needed if one wants to study specific questions or to analyze the global forest sector by focusing on a certain region. The easy option is to determine the modifications needed in the sectoral models and thereby derive the modifications needed in the mathematical form of the GM.

One should be careful not to confuse a simple interpretation of the GM with its mathematical form, which is simply a computationally useful representation of the set of spatial equilibrium conditions. The mathematical formulation of our global forest sector model is similar to the pulp and paper sector model of North America (Buongiorno, 1986; Buongiorno and Gilless, 1983a). Similar formulation ideas are also employed in other sectoral studies and in theoretical papers (e.g., Hotelling, 1938; McCarl and Spreen, 1980; Plessner and Heady, 1965; Takayama and Judge, 1970).

In Section 20.2 we describe the general structure of the sectoral models, the RCMs and the GM. Once we have shown, on a general level, the role of sectoral models in the global spatial equilibrium model, we then proceed to practical specializations of them. In Section 20.3 we discuss several specializations of the general structure of RCMs in order to demonstrate their flexibility in allowing the various modeling approaches that are needed to cope with regional differences, e.g., in socioeconomic systems or in intensity in focus. The examples given in this chapter, however, do not exclude further variations suitable for the GM.

20.1. The Hierarchical Model Structure

In a modeling effort concerned with the global forest sector it is natural that different regions be linked together through different region-specific models. The reasons are many: some regions are close to a market economy, whereas others are closer to a centrally planned economy (CPE); in some regions the forest sector plays a major role in the respective economy, whereas in others it plays only a minor role; and data availability differs among regions. A basic question concerning the linkage of these models is what type of regional modules can be plugged into the GM and how.

To develop a modular and hierarchical GM, we assume that the major forces that determine trade between regions result from the willingness of the regions to exchange commodities, given the (equilibrium) prices of commodities in each region. Thus, the basic requirements for an RCM are a common product category classification in traded products over all the regions and that it can provide the GM with export supply and import demand functions [1]. Furthermore, trade must, of course, account for existing trade agreements, different kinds of trade barriers, and market inertia. These considerations are assumed to be exogenous cost factors or constraints in the model. They are also reflected in the (very complex) export supply and import demand correspondences of the regions. Then the linkage of the RCMs is merely a question of finding a trade equilibrium given these correspondences.

Each regional module receives the prices exogenously. Collectively, however, they determine the prices endogenously. The RCMs provide (implicitly) their export supply and import demand functions. Based on this information, the GM solves for equilibrium prices and trade flows. The basic structure of GM is shown in *Figure 20.2*.

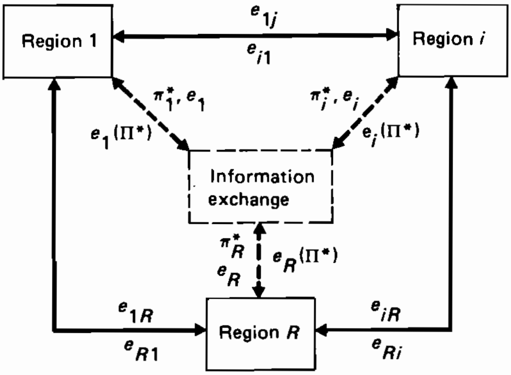

Figure 20.2 Basic structure of GM. Solid lines represent trade flows and broken lines information flows in international markets. {π_i^* is the vector of prices in region i; $\Pi^* = (\pi_1^*,\ldots,\pi_R^*)$, $e_{ij}(\Pi^*)$ is the vector of net export supply from region i to region j, $e_i(\Pi^*) = [e_{i1}(\Pi^*),\ldots,e_{iR}(\Pi^*)]$; e_{ij} is the vector of net equilibrium exports, $e_i = (e_{i1},\ldots,e_{iR})$; R is the total number of regions.}

For the RCMs, we have a basic structure that admits a wide range of possible specializations, any of which can be independently employed by each region. The simplest specialization consists only of the export supply–import demand correspondences and a trade agent. A more elaborate RCM may include several sectoral agents, such as consumers, producers, and export–import agents. It might even have a more detailed regional subdivision.

An RCM with several sectoral agents has the basic structure shown in *Figure 20.3*. The export supply–import demand correspondence of an RCM will be the sum of the demand–supply correspondences of the sectoral models.

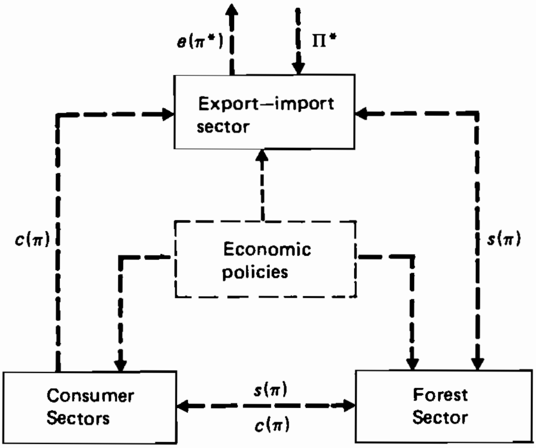

Figure 20.3 Structure of an RCM with several sectoral submodels. [π is the vector of prices in the region, Π^* is the matrix of price vectors for all regions, $c(\pi)$ is the demand for consumption, $s(\pi)$ is the supply of production, $e(\pi)$ is the export supply or import demand (depending on the sign).]

20.2. General Structure of Sectoral, Regional, and Global Models

At the ground level of the hierarchy are the specific models for the different sectoral agents. Each sectoral component is characterized by the associated resource and other constraints as well as by behavioral assumptions, such as objectives, concerning the agent. Each such module provides the relationship between demand (supply) and price, as illustrated in *Figure 20.4*, although this will be done in an implicit way.

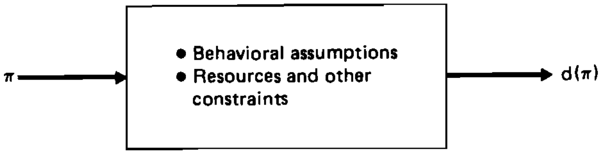

Figure 20.4 Model of an economic agent in RCM. [$d(\pi)$ is the demand–supply correspondence.]

In the following sections we discuss separately consumer, producer, and export–import sector submodules of an RCM.

20.2.1. Consumer sectors

The consumer sectors model (CSM) should generate its demand given domestic prices in the region and submit this information to the regional level of the hierarchy. Before stating our general structure of the CSM, we derive a mathematical programming formulation of it for the case of one product and a given demand function, by employing *Figure 20.1*. Let π be the product price, q the product demand, and $P(q)$ the inverse of the demand function. Given the price π, the demand q_d (*Figure 20.1*) can be determined by maximizing over q the area $GFCD$, i.e., the area under the demand curve less the corresponding area under the price line, i.e., maximizing over q:

$$\max_{q} \int_{0}^{q} P(q)\mathrm{d}q - \pi q \tag{20.1}$$

This problem is a specialization of the following one, which we adopt as the general structure of the CSM. Given prices π:

$$\max_{q} U(q) - \pi q \tag{20.2}$$

subject to:

$$q \in C \tag{20.3}$$

where q is a vector of product demands, (q_k), $k = 1,\dots,K$; π is a vector of product prices (taken as given), (π_k); C is the consumption possibility set (closed, convex, and nonempty); and U is a continuous and concave function defined over C. Following Hotelling (1938), we take $U(q)$ as a measure of total benefit to the consumer and call it the Consumer Benefit Function (CBF). Function $U(q) - \pi q$ is called the Consumer Surplus Function (CSF) (*cf.* Hotelling, 1938).

Note that the general formulation of CSM may include other endogenous decision variables too, but we have suppressed them in expressions (20.2)–(20.3). Such variables do not interfere with our general development if they are exclusively decided upon by the regional consumer sectors.

From the viewpoint of practical specification, it is important to note that any model designed to represent regional consumer sectors that can be cast in the form of a CSM can, also in this form, readily be plugged into the GM. In general, it is just a question of finding a suitable interpretation for U and C. We discuss examples of some practical specializations in Section 20.3.

20.2.2. Production sector

The production sector model (PSM) should be able to generate its supply given domestic prices in the region and submit this information to the regional level of hierarchy. As for the consumer sectors, we first derive a mathematical programming formulation of the PSM for the case of one product and given supply function, by employing *Figure 20.1.* Let z be the production and $C(z)$ the inverse of the supply function. Given the price π, the supply $z = q_s$ (*Figure 20.1*) can be determined by maximizing over q the area $ABFG$, i.e., maximizing over z:

$$\max_{z} \ \pi z - \int_{0}^{z} C(z)\mathrm{d}z \tag{20.4}$$

This problem is a specialization of the following problem, which we adopt as the general structure of the PSM. Given prices π:

$$\max_{z} \ \pi z - V(z) \tag{20.5}$$

subject to:

$$z \in Z \tag{20.6}$$

where z is a vector of product supplies, (z_k), Z is the production possibility set (closed, convex, and nonempty), and V is a continuous and convex function defined over Z. $V(z)$ can be identified as a measure of production costs and we call it the Producer's Cost Function (PCF). Function $\pi z - V(z)$ is called the Producer's Surplus Function (PSF) (*cf.* Hotelling, 1938). Note that the general formulation of PSM may include other endogenous decision variables too, but we have suppressed them in expressions (20.5)–(20.6). Such variables do not interfere with our general development if they are exclusively decided upon by the regional production sector. This option is heavily exploited in the GM, in which the regional production sectors are represented in an activity analysis framework (*cf.* Section 20.3).

From the viewpoint of practical specification it is important to note that any model cast in the form of a PSM and designed to represent the regional production sector can, in this form, readily be plugged into the GM. In general, it is just a question of finding a suitable interpretation for V and Z. We discuss examples of some practical specializations in Section 20.3.

20.2.3. Export–import sector

To conceptualize the export–import sector we assume that the producers and consumers account only for domestic prices and that the trade agents handle the allocations of exports and imports among regions. This formalization does not exclude the fact that forest industrial companies are engaged both in production and in export business.

Trade barriers, such as quotas, tariffs, and trade bans, as well as long-term agreements, inertia, etc., are dealt with by the trade sector model (TSM) of the RCM. Effectively, such additional constraints result in an equilibrium price system that may not have a unique and clear-cut interpretation. An interpretation depends on further assumptions made as to the roles of export and import agents in the exchange of products (see below).

For the moment we define the trade agents as follows. Exporters buy at domestic prices, pay for the transportation, and sell at the import prices of the importing regions. Importers buy at import prices and sell at domestic prices of the region. Note that import prices may depend on the exporting region if trade barriers are present.

A natural goal for the export–import sector is to perform trade efficiently from the economic point of view (given the various constraints above). We adopt as the TSM for region r the following. Given prices π_r and Π^*:

$$\begin{aligned}\max_{e_{rS},m_{rS}} & \sum_{sk}\Big[(\pi^*_{rsk} - \pi_{rk} - D_{rsk})e_{rsk} + (\pi_{rk} - \pi^*_{srk})m_{rsk}\Big] \\ &= \sum_{sk}\Big[(\pi^*_{rsk} - D_{rsk})e_{rsk} - \pi^*_{srk}m_{rsk}\Big] \\ &\quad - \pi_r\sum_s(e_{rs} - m_{rs})\end{aligned} \tag{20.7}$$

subject to:

$$(e_{rS},m_{rS}) \in T_r \tag{20.8}$$

where π^*_{rs} is the vector of import prices π^*_{rsk} in region s for products k from region r; Π^* is the matrix of vectors π^*_{rs}; π_r is the vector of domestic prices π_{rk} in region r, e_{rs} is the vector of exports e_{rsk} from region r to region s, m_{rs} is the vector of imports m_{rsk} to region r from region s; $e_{rS} = (e_{r1},\ldots,e_{rR})$; $m_{rS} = (m_{r1},\ldots,m_{rR})$; D_{rsk} is the unit transportation cost from region r to region s for product k, and T_r is the trade constraint set (assumed closed, convex, and nonempty).

20.2.4. Regional models

For notational convenience, let R_r be the regional constraint set defined by the expressions:

$$q_r \in C_r \tag{20.9}$$

$$z_r \in Z_r \tag{20.10}$$

$$(e_{rS},m_{rS}) \in T_r \tag{20.11}$$

and $W_r(q_r,z_r)$ is the regional benefit function (RBF) [2], where:

$$W_r(q_r,z_r) = U_r(q_r) - V_r(z_r) \tag{20.12}$$

The behavior of the sectoral agents is described above using the mathematical optimization problems CSM, PSM, and TSM. The sectoral agents are assumed to take the prices as given and otherwise behave as though their decision variables are independent of other sectors. Therefore, problems CSM, PSM, and TSM also have independent variables and independent constraints. Consequently, equivalent behavior can be described by a single, mathematical optimization problem where the sum of the sectoral objectives is maximized subject to all the constraints together, i.e., given the prices Π^* and π_r:

$$\begin{aligned}\max_{q_r,z_r,e_{rS},m_{rS}} \quad & W_r(q_r,z_r) + \sum_{sk}\left[(\pi^*_{rsk} - D_{rsk})e_{rsk} - \pi^*_{srk}m_{rsk}\right] \\ & + \pi_r\left[z_r - q_r - \sum_s(e_{rs} - m_{rs})\right]\end{aligned} \tag{20.13}$$

subject to:

$$(q_r,z_r,e_{rS},m_{rS}) \in R_r \tag{20.14}$$

W_r is a concave function as it is the difference of a concave and a convex function. R_r is a Cartesian product of C_r, Z_r, and T_r and thus a closed, convex, and nonempty set.

Define:

$$x_r = (q_r,z_r,e_{rS},m_{rS}) \tag{20.15}$$

$$h_r(x_r) = z_r - q_r - \sum_s(e_{rs} - m_{rs}) \tag{20.16}$$

As an additional assumption about R_r and h_r, let the image $h_r(R_r)$ of R_r under h_r contain an open neighborhood of null vector.

Prices π_r are exogenous for all the separate economic agents in region r, but collectively the agents define prices endogenously. At the equilibrium, product supply equals demand. For region r, $z_r - q_r$ is the vector of excess supplies available for export and:

$$\sum_{s} (e_{rs} - m_{rs})$$

is the vector of net exports. In equilibrium they are equal. For domestic equilibrium prices, π_r, the above problem is mathematically equivalent to the following problem, which we adopt as the regional model (RM) [3]. Given prices π^*:

$$\max_{x_r} W_r(q_r,z_r) + \sum_{sk}\left[(\pi^*_{rsk} - D_{rsk})e_{rsk} - \pi^*_{srk}m_{rsk}\right] \tag{20.17}$$

subject to:

$$q_r - z_r + \sum_{s}(e_{rs} - m_{rs}) = 0 \qquad (\pi_r) \tag{20.18}$$

$$x_r = (q_r,z_r,e_{rS},m_{rS}) \in R_r \tag{20.19}$$

The shadow prices π_r of the material balance equation (20.18) are domestic equilibrium prices.

20.2.5. Global model

We have shown how the behavior of a region can be represented by a mathematical optimization model RM. The sectoral agents of regions were assumed to take prices as given and otherwise behave as being independent in decision making. Therefore these regional problems (RMs) are mathematically independent, because they have independent variables and constraints. Consequently, they can be solved jointly within a single optimization problem, where the sum of the regional objective functions is maximized subject to all regional constraints. Given prices Π^*, this joint problem is to:

$$\max_{x} \sum_{r} W_r(q_r,z_r) - \sum_{rsk}D_{rsk}e_{rsk} + \sum_{rsk}\pi^*_{srk}(e_{srk} - m_{rsk}) \tag{20.20}$$

subject to:

$$q_r - z_r + \sum_s (e_{rs} - m_{rs}) = 0 \qquad \text{for all } r \qquad (\pi_r) \tag{20.21}$$

$$x_r = (q_r, z_r, e_{rS}, m_{rS}) \in R_r \qquad \text{for all } r \tag{20.22}$$

where x is the vector of decision variables (x_r). Individually, prices Π^* are exogenous for each region, but again collectively they are endogenous, resulting in values that equilibrate all markets. In the formulation above, all markets are in equilibrium if the import flow m_{rsk} of product k to region r from region s in the regional model r equals the corresponding export flow e_{srk} in the regional model s. For equilibrium prices, the above problem (20.20)–(20.22) is then mathematically equivalent [4] with problem GM1:

$$\max_x \sum_r W_r - \sum_{rsk} D_{rsk} e_{rsk} \tag{20.23}$$

subject to:

$$m_{rsk} - e_{srk} = 0 \qquad \text{for all } rsk \qquad (\pi^*_{srk}) \tag{20.24}$$

and constraints (20.20) and (20.22), with the shadow prices π^*_{srk} of the material balance equations (20.24) as the equilibrium import prices. Problem GM1 can be simplified by substituting e_{srk} for m_{rsk} for all rsk. The resultant general structure for the global model GM is to:

$$\max_{q,z,e} \sum_r U_r(q_r) - \sum_r V_r(z_r) - \sum_{rsk} D_{rsk} e_{rsk} \tag{20.25}$$

subject to:

$$q_r - z_r + \sum_s (e_{rs} - e_{sr}) = 0 \qquad \text{for all } r \quad (\pi_r) \tag{20.26}$$

$$q_r \in C_r \qquad \text{for all } r \tag{20.27}$$

$$z_r \in Z_r \qquad \text{for all } r \tag{20.28}$$

$$(e_{rS}, e_{Sr}) \in T_r \qquad \text{for all } r \tag{20.29}$$

where $e_{Sr} = (e_{1r},\ldots,e_{Rr})$, q is the vector (q_r) and z is the vector (z_r), $r = 1,\ldots,R$; e is the vector (e_{rs}), $r,s = 1,\ldots,R$. The GM is thus an optimization problem whose objective function is the sum of regional CBFs less the sum of regional PCFs less the total transportation costs and whose constraints consist of sectoral material-balance equations for all the regional consumption- and supply-constraints and of bilateral trade flow constraints. By inspection it can be easily deduced within the general framework which part of the sectoral models contribute to the GM. Note that the actual specification of sectoral models in region r is completely independent of those in other regions, except for the common product category classification in traded products.

20.2.6. Interpretation of import and export prices

The prices π^* are an interpretation of the competitive cost–insurance–freight (CIF) prices in free trade. If there are trade constraints, then the prices π^* could be interpreted as competitive CIF prices for marginal units of trade transacted on a free trade basis.

Note that the prices π^*_{srk} disappear in the transition from GM1 to GM. Therefore, the distinction between import and export agents also disappears. These prices may, however, be recovered since there is a connection between prices π^*, π, and the shadow prices for the trade flow constraints. Let us clarify the situation with a simple example. Suppose long-term agreements and trade inertia give rise to the following constraints attributed to the import flow m_{rsk}:

$$L \le m_{rsk} \le U \qquad (\delta) \tag{20.30}$$

Suppose it is the only constraint for the import flow m_{rsk} and δ is the shadow price for this constraint.

The Karush–Kuhn–Tucker conditions of optimality for GM1 imply that constraint (20.30) must be satisfied and that:

$$-\pi^*_{srk} + \pi_{rk} - \delta \le 0 \tag{20.31}$$

$$(-\pi^*_{srk} + \pi_{rk} - \delta)(m_{rsk} - L) = 0 \tag{20.32}$$

$$\delta \ge 0 \tag{20.33}$$

$$\delta(U - m_{rsk}) = 0 \tag{20.34}$$

If $m_{rsk} = L$, then the domestic price, π_{rk}, in region r may be smaller than the price, π^*_{srk}, paid for export from region s. Thus, the import agent of region r carries a loss valued at the free trade CIF prices. If $m_{rsk} = U$, then $\pi_{rs} = \pi^*_{srk} + \delta$ and the import agent makes a profit.

Next, assume that the corresponding constraints attributed to the export flow e_{srk} are nonbinding. At the equilibrium, optimality of e_{srk} requires that:

$$\pi^*_{srk} = \pi_{sk} + D_{srk} \tag{20.35}$$

i.e., the export agent of region s breaks even. If we change the assumptions so that the trade agreement and inertia constraints are attributed to the export flow e_{srk}:

$$L \leq e_{srk} \leq U \qquad (\delta) \tag{20.36}$$

and relax the constraints on m_{rsk}, then the Karush–Kuhn–Tucker optimality conditions at equilibrium stipulate that:

$$\pi^*_{srk} = \pi_{rk} \tag{20.37}$$

$$-D_{srk} + \pi^*_{srk} - \pi_{sk} - \delta \leq 0 \tag{20.38}$$

$$(-D_{srk} + \pi^*_{srk} - \pi_{sk} - \delta)(e_{srk} - L) = 0 \tag{20.39}$$

$$\delta \geq 0 \tag{20.40}$$

$$\delta(U - e_{srk}) = 0 \tag{20.41}$$

Now, the import agent breaks even, but the export agent carries a loss if $e_{srk} = L$ and makes a profit if $e_{srk} = U$.

These examples demonstrate that, due to trade barriers, trade agents may make losses or profits, allocation of which depends on the particular agreements made between the exporter and importer. Without further specification of these agreements, we are unable to make a distinction between export and import agents. Consequently, in the GM both agents are identified as one trade agent. As a second consequence the domestic prices, π_r, obtained from the GM cannot be interpreted directly as free on board (FOB) or CIF prices. We give a general interpretation of the shadow prices for trade constraints in Section 20.4.

20.3. Practical Specializations of the General Model Structure

20.3.1. Consumer sector models

Probably the most widely used approach to model demand is to employ a parameterized demand function chosen from some mathematical family of functions. Let us study the conditions under which this approach can form the basic structure of the CSM.

The separable case in which no substitution effects occur within the forest sector products is quite straightforward. Let $P_k(q_k)$ be the inverse of the kth demand function, nonnegative, and defined for nonnegative values of q_k. Assume P_k is (piecewise) continuous and nonincreasing for all k. Expanding the idea given in *Figure 20.1* and Section 20.2, it is easily deduced that the equivalent consumer behavior is represented by the problem (of the form of CSM):

$$\max_q \sum_k \int_0^{q_k} P_k(q_k) \mathrm{d} q_k - \pi q \tag{20.42}$$

subject to:

$$q \geq 0 \tag{20.43}$$

where q is the vector (q_k). In this case the CBF $U(q)$ is simply the sum of integrals in problem (20.42) and the consumption possibility set C is the nonnegative orthant.

The situation is more intricate when there are substitution effects, in which case demand is also a function of the prices of other forest products. Then, as a mathematical integrability condition, we have to assume that demand has symmetric cross-prices effects (*cf.* Hotelling, 1938), i.e.:

$$\frac{\partial q_k}{\partial \pi_j} = \frac{\partial q_j}{\partial \pi_k} \tag{20.44}$$

Practically all the demand for forest products outside the forest sector is derived from input use of other production sectors. Within the product classification used in the Forest Sector Project at IIASA (*cf.* Chapter 19) there are only a few substitution effects (e.g., substitution between panels and sawnwood) and the integrability assumption is not expected to lead to a severe bias [5].

Symmetrically, an inverse demand system (price system):

$$\pi = P(q) \tag{20.45}$$

satisfies the integrability condition when [6]:

$$\frac{\partial P_k}{\partial q_j} = \frac{\partial P_j}{\partial q_k} \quad \text{for all } j,k \tag{20.46}$$

The integrability condition (20.46) is needed in order to have a *potential function* [7] $U : R^n_+ \rightarrow R$ with the property:

$$\frac{\partial U(q)}{\partial q_k} = P_k(q) \quad \text{for all } k \tag{20.47}$$

In the simple separable case where:

$$P_k(q) = P_k(q_k) \quad \text{for all } k \tag{20.48}$$

this potential function is simply:

$$U(q) = \sum_k \int_{q_{0k}}^{q_k} P_k(q)\mathrm{d}q \tag{20.49}$$

where the starting point q_0 is arbitrarily fixed.

In the general integrable case, $U(c)$ is defined by a line integral on the gradient field defined by the price function P (*cf.* Hotelling, 1938; Apostol, 1959):

$$U(q) = \int_{q_0}^{q} \sum_k P_k(q)\mathrm{d}q_k \tag{20.50}$$

where the line integral is taken along an arbitrary path from an arbitrary starting point to the argument point q. In the separable case the line integral (20.50) reduces to the sum of ordinary integrals (20.49).

For further discussion of the nonintegrable case, see Plessner and Heady (1965) and Takayama and Judge (1971).

Assume that $P(q)$ is a continuously differentiable, nonnegative price function defined over the nonnegative orthant. Assume the Jacobian $\partial P/\partial q$ is negative semidefinite, and symmetric. Then we can define the behavior of the consumer sector as follows. Given prices $\pi = (\pi_k)$, the demand vector $q \geq 0$ satisfies conditions:

$$\pi_k \geq P_k(q) \qquad \text{for all } k \tag{20.51}$$

$$q_k \geq 0 \qquad \text{for all } k \tag{20.52}$$

$$q_k[\pi_k - P_k(q)] = 0 \qquad \text{for all } k \tag{20.53}$$

In the elastic price region conditions (20.51)–(20.53) simply imply that $\pi_k = P_k(q)$ for all k. Equivalently, given prices π, the consumer behavior can be modeled as:

$$\max\ U(q) - \pi q \tag{20.54}$$

subject to:

$$q \geq 0 \tag{20.55}$$

where U is defined by equations (20.49) or (20.50) and the path of integration is within the positive orthant. But the Karush–Kuhn–Tucker conditions, which in this case are necessary and sufficient for optimality [8], are the conditions (20.51)–(20.53). Thus, the maximization formulation (20.54)–(20.55) of consumer behavior is equivalent to the demand function formulation (20.51)–(20.53), both in the elastic price region and in its complement.

The approach discussed above is easily extended to the case where there are several different end-use demands for, e.g., product k. Let $P_{ik}(q_{ik})$ be the inverse of the demand function of end-use type i (nonincreasing, continuous, and nonnegative). Then the consumption demand for product k can be modeled as:

$$\max_{q_{ik}} \sum_i \int_0^{q_{ik}} P_{ik}(q_{ik}) \mathrm{d} q_{ik} - \pi_k q_k \tag{20.56}$$

subject to:

$$q_k = \sum_i q_{ik} \tag{20.57}$$

$$q_{ik} \geq 0 \quad \text{for all } i \tag{20.58}$$

In connection with the GM, the sum of the integrals in problem (20.56) is part of the global objective function, the sum of q_{ik} in equation (20.57) is substituted for q_k in the material balance equation of the region in question, and condition (20.58) substitutes the condition $q_k \geq 0$ as a nonnegativity constraint. In *Table 20.1* we summarize some results of the price function approach for linear and Cobb–Douglas functions.

20.3.2. Production sector models

Modeling of supply using supply functions is analogous to modeling of demand through demand functions. Let $C(z)$ be the inverse of the supply function, continuously differentiable, nonnegative, defined over the nonnegative orthant and with the positive semidefinite, symmetric Jacobian $\partial C/\partial z$. Note that for a competitive producer the price function, $C(z)$, is the same as the marginal cost function, $MC(z)$, of output z under cost-minimized production (e.g., Hotelling, 1938). Then the line integral:

$$V(z) = \int_{z_0}^{z} \sum_k C_k(z) \mathrm{d} z_k \tag{20.59}$$

which in the separable case is simply:

$$V(z) = \sum_k \int_{z_{0k}}^{z_k} C_k(z_k) \, \mathrm{d} z_k \tag{20.60}$$

Table 20.1 Price functions and corresponding potential functions.

Function type	*Price function* $P(q)$	*Potential function* $U(q)$	*Price elasticity,* σ_{kk}, σ_{kj}	*Remarks*
Linear	$P_k = a_k q_k + b_k$	$\sum_k (\frac{1}{2} a_k q_k^2 + b_k q_k)$	$\sigma_{kk}^{-1} = 1 - \frac{b_k}{P_k}$	$a_k < 0,\ b_k > 0$
			$\sigma_{kj} = 0\ ,\ j \neq k$	$0 \leq q_k \leq -\frac{b_k}{a_k}$
Cobb–Douglas	$P_k = b_k q_k^{a_k}$	$\sum_k \frac{b_k}{a_k+1} q_k^{a_k+1}$	$\sigma_{kk}^{-1} = a_k$	$-1 \neq a_k < 0,\ b_k > 0$
			$\sigma_{kj} = 0,\ j \neq k$	
Nonseparable Linear	$P = Aq + b$	$\frac{1}{2} q' Aq + b' q$	$\sigma_{kk} = \frac{A_{kk}^{-1} P_k}{q_k}$	A negative semidefinite and symmetric, $b > 0$
			$\sigma_{kj} = \frac{A_{kj}^{-1} P_j}{q_k}$	$Aq + b \geq 0$
Nonseparable Cobb–Douglas	$P_k = \frac{a_k b}{q_k} \prod_i q_i^{a_i}$	$b = \prod_i q_i^{a_i}$	$\sigma_{kk} = \frac{a_k + 1 - \sum_i a_i}{\sum_i a_i - 1}$	$a_k < 1$ for all k, $b > 0$
			$\sigma_{kj} = \frac{a_j + 1}{\sum_i a_i - 1},\ j \neq k$	$\sum_i a_i \neq 1$

can be identified as the total cost of production. Then the producer's objective function:

$$\pi z - V(z) \tag{20.61}$$

is identified as the total profit.

Note that some of the products may be used also as inputs. $z_k < 0$ then means that $-z_k$ is the input use of product k imported from some other region. The cost of this import, $-\pi_k z_k$, is included in the πz term in the profit expression $\pi z - V(z)$. Thus $V(z)$ is taken as the total production cost excluding the costs from input use of products in our product category classification. The production sector might also be thought to consist of several firms. If firm i is selling its output to firm j's input then the income from this trade to firm i is a cost to firm j and these terms cancel out in the regional total profit expression (20.61). Again we arrive at the same conclusion about $V(z)$.

In *Table 20.2* we summarize some results for the marginal cost function approach for linear and Cobb–Douglas functions.

A neoclassical profit maximization model to describe producer's behavior falls readily within the general structure of the PSM. In an activity analysis framework the production sector is thought to operate various input–output type production activities. A corresponding PSM could be the following: given prices π, choose production activity levels y_m so as to:

$$\max \pi\, z - \sum_m \int_0^{y_m} C_m(y_m)\mathrm{d}y_m \tag{20.62}$$

subject to:

$$z_k = \sum_m A_{km}\, y_m \qquad \text{for all } k \tag{20.63}$$

$$0 \le y_m \le K_m \qquad \text{for all } m \tag{20.64}$$

where y_m is the level of production for production activity m, A_{km} is the net output of product k per unit of production for process m, $C_m(y_m)$ is the marginal cost of production by process m at production level y_m, and K_m is the production capacity associated with process m. Marginal cost functions

Table 20.2 Marginal cost functions and corresponding cost functions.

Function type	*Marginal function* $C(z)$	*Cost function* $V(z)$	*Price elasticity,* σ_{kk},σ_{kj}	*Remarks*
Linear	$Q_k = a_k z_k + b_k$	$\sum_k(\frac{1}{2} a_k z_k^2 + b_k z_k)$	$\sigma_{kk}^{-1} = 1 - \frac{b_k}{Q_k}$	$a_k > 0$
			$\sigma_{kj} = 0 \, , \, j \neq k$	$z_k \geq \max\left\{- \frac{b_k}{a_k}, 0\right\}$
Cobb–Douglas	$Q_k = b_k z_k^{a_k}$	$\sum_k \frac{b_k}{a_k + 1} z_k^{a_k+1}$	$\sigma_{kk}^{-1} = a_k$	$a_k \geq 0, \, b_k > 0$
			$\sigma_{kj} = 0, \, j \neq k$	
Nonseparable Linear	$Q = Az + b$	$\frac{1}{2} z' Az + b' z$	$\sigma_{kk} = \frac{A_{kk}^{-1} Q_k}{z_k}$	A positive semidefinite and symmetric, $Az + b \geq 0$
			$\sigma_{kj} = \frac{A_{kj}^{-1} Q_j}{z_k}$	
Nonseparable Cobb–Douglas	$Q_k = \frac{a_k b}{z_k} \prod_i z_i^{ai}$	$b \prod_i z_i^{ai}$	$\sigma_{kk} = \frac{a_k + 1 - \sum_i a_i}{\sum_i a_i - 1}$	$a_k \geq 0$ for all k, $b > 0$
			$\sigma_{kj} = \frac{a_j + 1}{\sum_i a_i - 1}, \, j \neq k$	$\sum_i a_i \neq 1$

$C_m(y_m)$ are assumed to be nondecreasing functions of activity levels $y_m \geq 0$. Again, note that these marginal costs do not include the costs of input use of products in the product category classification $k = 1,\ldots,K$.

In connection with the GM, the sum of marginal cost integrals in expression (20.62) is the cost function $V(z)$ that enters the global objective function. The material balance equations, (20.63), for all k is substituted for the constraints (20.28) of the region concerned and the capacity constraints (20.64) are appended to the global constraint set.

20.3.3. Trade barriers

Treatment of *ad valorem* tariffs in our modeling framework is not simple, because the equilibrium prices enter the calculation. The equilibrium prices are determined as shadow prices for the material balance constraints and thus the calculation rule for prices in terms of primal quantities, introduced explicitly in the objective function of the GM, would be a considerable complication. However, it is expected that tariffs can be treated as being proportional to the quantity traded, in which case tariffs can be added to transportation costs to give a reasonably accurate approximation if the tariff rates are calculated according to previous time-period prices. Suppose a particular tariff rate is r times price π and the price change from a previous time period is $s\pi$. Then the error made in using previous period prices is of the order of $rs\pi$, which is expected to be very small.

Trade bans, agreements, quotas, and inertia in adjustment of trade flows can be represented by simple upper and lower bounds concerning a particular trade flow e_{rsk}, i.e.:

$$L_{rsk} \leq e_{rsk} \leq U_{rsk} \tag{20.65}$$

For detailed discussions of trade barriers see Chapters 15 and 24.

20.3.4. Centrally planned economies

An RM that represents a CPE must reflect the main features of the planned economy, such as (*cf.* Chapter 26):

(1) Consumption of forest products in the nonforest sector is specified by *target levels* and by a *penalty* for deviating from such levels. Such a penalty may be considered, for instance, as the *social cost* of not meeting the target levels.

(2) The target levels and their dynamics are generated or specified exogenously, resulting from long-term state plans or scenario assumptions.
(3) The forest industries are developed independently of world prices.
(4) Domestic prices are independent of world prices.
(5) For total imports there is an exogenously given budget and for exports there is an exogenously specified, minimum total revenue. Imports and exports also satisfy trade inertia constraints, trade agreements, quotas, and other trade policy requirements. *Efficiency* in trade is assumed to result from maximizing the *trade surplus* subject to all these constraints.

Below we derive behavioral rules for the production and trade sectors based on a central planning of the entire economy that takes the above aspects into account. To model the planning process we suppose that the central planner behaves as though solving the following optimization problem:

$$\max\ W(q_N) \tag{20.66}$$

subject to:

$$q_N + e_N + y_F - z_N = 0 \quad (p_N) \tag{20.67}$$

$$\sum_s (e_{rs} - m_{rs}) + y_N - z_F = 0 \quad (p_F) \tag{20.68}$$

$$g_N(z_N, y_N) \leq 0 \tag{20.69}$$

$$g_F(z_F, y_F) \leq 0 \tag{20.70}$$

$$e_N \in T_N \tag{20.71}$$

$$e_r \in T_{EF} \tag{20.72}$$

$$m_r \in T_{MF} \tag{20.73}$$

$$\sum_s \sum_{k \in F} \left[(\pi^*_{rsk} - D_{rsk}) e_{rsk} - \pi^*_{srk} m_{rsk} \right] + E_N(e_N) \geq 0 \quad (\psi) \tag{20.74}$$

where indices F and N refer to the forest sector and to nonforest sectors, respectively; q_N is the vector of final consumption of nonforest sector products; z is the vector of net output of production sector; y_F is the vector of input use of nonforest sector products in forest sector production; y_N is the vector of input use of forest sector products in nonforest sector production;

e_N is the net export vector of nonforest products; $e_r = (e_{r1}, \ldots, e_{rR})$; $m_r = (m_{r1}, \ldots, m_{rR})$; e_{rs}, e_{rsk}, m_{rs}, m_{rsk}, π^*_{rsk}, D_{rsk}, for $k \in F$ are as in Section 20.2, with r as the centrally planned region in question; W is the regional welfare function, assumed strictly concave; g is the vector function that defines production possibility set, assumed convex; E_N is the external value of trade in nonforest sector products; and T_N, T_{EF}, and T_{MF} are the trade constraint sets, for net exports of nonforest sector products, exports and imports of forest sector products, assumed convex. In this formulation, we have assumed that the final consumption of forest products, q_F, is negligible compared with their production input use, y_N, and therefore have not included q_F in the welfare function. Equations (20.67) and (20.68) are the material balance equations for products N and F, constraints (20.69) and (20.70) define production possibilities, constraints (20.71) and (20.73) account for trade barriers, and equation (20.74) accounts for trade balance. For specializing in forest product trade, equations (20.68) and (20.74) are discussed in more detail below.

Let p_N, p_F, and ψ be the planner's optimum shadow prices for constraints (20.67)–(20.68) and (20.74), respectively. At the optimum, constraints (20.67)–(20.68) and (20.74) may be relaxed to yield the following planning problem:

$$\begin{aligned} \max\ & W(q_N) - p_N q_N + \Big[p_N z_N - p_F y_N\Big] + \Big[p_F z_F - p_N y_F\Big] \\ & + \Big[\psi E_N - p_N e_N\Big] + \sum_s \sum_{k \in F} \Big[\psi(\pi^*_{rsk} - D_{rsk}) - p_k\Big] e_{rsk} \\ & + \sum_s \sum_{k \in F} (p_k - \psi \pi^*_{srk}) m_{rsk} \end{aligned} \tag{20.75}$$

subject to constraints (20.69)–(20.73).

From a strictly mathematical point of view, given the shadow prices p_N, p_F, and ψ, this relaxed problem separates into six independent subproblems: consumer problem in N products; production problems for sectors N and F, separately; trade problem for sectors N; export and import problems, separately, for sector F. These subproblems delegate the planning to production and trade sectors. A restricted requirement for a production sector is to produce, within the constraints of its subproblem, an output given by level z^*, which is derived from the central planning model. For the nonforest sector, this problem can be defined as:

$$\min\ p_F y_N \tag{20.76}$$

subject to:

$$g_N(z_N^*, y_N) \leq 0 \tag{20.77}$$

Under rather nonrestrictive assumptions on g_N, the optimal use of forest products, denoted by y_N, derived from problem (20.76)–(20.77) is an integrable [9], derived demand function:

$$y_N = D(p_F, z_N^*) \tag{20.78}$$

It has an inverse function:

$$p_F = P(y_N, z_N^*) \tag{20.79}$$

with potential function $U(y_n, z_N^*)$. A local approximation $U(y_N - y_N^*, z_N^*)$ in the neighborhood of y_N^* (obtained from the central plan) is called the *penalty function* for consumption of forest products. The production plan for the nonforest sector is then equivalently derived from the following problem:

$$\max \frac{1}{\psi} U(y_N - y_N^*, z_N^*) - \pi_F y_N \tag{20.80}$$

where $\psi \pi_F = p_F$ and the parameter ψ relates the planners shadow prices, p_F, to FOB prices, π^*.

At the optimum:

$$\frac{\partial U}{\partial y_N} = p(y_N, z_N^*) = p_F \tag{20.81}$$

Model (20.80) is simply a specialization of the CSM with y_N as the consumption vector q.

A similar planning problem is faced by the forest sector. As we are interested only in forest products, the optimal output z_F^* remains the only interesting figure.

An export agency trading in forest sector products is faced with the task of creating an export revenue, E^*, derived from the central plan. Given the rules and constraints to the agency, it faces the problem:

$$\max \sum_{sk} \left[\pi^*_{rsk} - D_{rsk} - \pi_k \right] e_{rsk} \tag{20.82}$$

subject to:

$$e_r \in T_{EF} \tag{20.83}$$

$$\sum_{sk} (\pi^*_{rsk} - D_{rsk})\, e_{rsk} \geq E^* \tag{20.84}$$

where we define $\psi\pi = p_F$.

Similarly, the import agency faces the problem:

$$\max \sum_{sk} (\pi_k - \pi^*_{srk})\, m_{rsk} \tag{20.85}$$

subject to:

$$m_r \in T_{MF} \tag{20.86}$$

$$\sum_{sk} \pi^*_{srk} m_{rsk} \leq M^* \tag{20.87}$$

where M^* is an import budget derived from the central plan.

Note that the export problem (20.82)–(20.84) and the import problem (20.85)–(20.87) jointly comprise a specialization of that presented in Section 20.2, with T_r defined by constraints (20.83)–(20.84) and (20.86)–(20.87).

Assume trade constraints T_{EF} to be nonbinding for the export flow e_{rsk}. Then, from the central plan:

$$p_k = \psi(\pi^*_{rsk} - D_{rsk}) = \psi\pi^*_k \tag{20.88}$$

where π^*_k is the FOB price for free trade. The penalty function U can always be normalized so that $\psi = 1$, i.e., so that central planning shadow prices p_F are the same as prices π in (20.80), (20.82), and (20.85) and same as FOB–CIF prices π^* for free trade.

Note that the import budget condition (20.87) and the export revenue condition (20.84) contain prices π^*, which leads to difficulties, described above, if treated rigorously. However, these constraints can easily be accounted for if they are only approximated by using the prices of previous periods.

Assume U is normalized so that $\psi = 1$. Then, in connection with the GM, a planned economy region could be represented as:

$$\begin{aligned} \max\ & \sum_k \int_0^{q_{rk}} P_{rk}(q)\mathrm{d}q \\ & + \text{(objectives of other regions)} \\ & - \text{(total transportation costs)} \end{aligned} \tag{20.89}$$

subject to:

$$q - A_r y_r + \sum_s (e_{rs} - e_{sr}) = 0 \tag{20.90}$$

$$z_r^0 = A_r y_r \tag{20.91}$$

$$\sum_{sk} (\pi_{sk}^* + D_{rsk}) e_{rsk} \geq E_r^* \tag{20.92}$$

$$\sum_{sk} (\pi_{sk}^* - D_{srk}) e_{srk} \leq M_r^* \tag{20.93}$$

as well as trade flow constraints for e_{rsk} and e_{srk}, and constraints on other regions, where, r is the index of region considered, $P_{rk}(q) = \partial U_r(q_r - q_r^*)/\partial q_{rk}$, q_r^* is the vector of consumption targets, q_r^* is the vector of consumption levels, z_r^0 is the vector of production output, fixed according to the production plan, $\pi_{sk}^* - D_{rsk}$ is the import price of product k of region s less transportation costs (from the previous period), $\pi_{sk}^* + D_{srk}$ is the export price of product k of region s plus transportation costs (from the previous period), and otherwise the notation is as in Sections 20.2 and 20.3.

Since the net output of the production sector is fixed according to the central plan, the cost of production may be neglected from the objective function (20.89).

20.3.5. A simplified regional model

For a region r, which is not very important at the global scale and/or is lacking detailed data, an RCM could be simplified to consider only the export supply, import demand, and efficiency of trade without further subdivision into several economic agents. Following the discussion of the

CSMs, a model of net export–import behavior may similarly be based on price function approaches. Given regional prices π_r, the net export supply–import demand behavior can then be represented by the following model:

$$\max \pi_r x_r - \sum_k \int_{\underline{x}_{rk}}^{x_{rk}} C_{rk}(x_{rk})\mathrm{d}x_{rk} \tag{20.94}$$

subject to:

$$\underline{x}_{rk} \leq x_{rk} \leq \bar{x}_{rk} \qquad \text{for all } k \tag{20.95}$$

where r is the index of the region concerned, x_r is the vector of net exports (imports if negative), $\bar{x}_r$ is the vector of upper bounds for net exports, $\underline{x}_r$ is the vector of lower bounds for net exports, and $C_{rk}(x_{rk})$ is the inverse of the net export supply function of product k. Given prices Π^*, the corresponding RCM is then:

$$\begin{aligned} \max \quad & -\sum_k \int_{\underline{x}_{rk}}^{x_{rk}} C_{rk}(x_{rk})\mathrm{d}x_{rk} \\ & + \sum_{sk}\Big[(\pi^*_{rsk} - D_{rsk})e_{rsk} - \pi^*_{srk}m_{rsk}\Big] \end{aligned} \tag{20.96}$$

subject to:

$$-x_r + \sum_s (e_{rs} - m_{rs}) = 0 \tag{20.97}$$

$$(e_{rS}, m_{rS}) \in T_r \tag{20.98}$$

In connection with the GM, the problem is to:

$$\begin{aligned} \max \quad & -\sum_k \int_{\underline{x}_{rk}}^{x_{rk}} C_{rk}(x)\mathrm{d}x \\ & + \text{(objectives of other regions)} \\ & - \text{(total transportation costs)} \end{aligned} \tag{20.99}$$

subject to:

$$\sum_j (e_{rjk} - e_{jrk}) - x_{rk} = 0 \qquad \text{for all } k \qquad (\pi_{rk}) \tag{20.100}$$

as well as trade barrier constraints for e_{rjk}, e_{jrk}, and the constraints of other regions.

20.4. Global Model Specification of IIASA

The global forest sector model developed at IIASA employs separable demand functions and an activity analysis framework for production sectors. The GM is simply the following optimization problem. Find q_i, y_i, and e_{ij}, for all i and j, to:

$$\max \left[\sum_{ik} \int_0^{q_{ik}} P_{ik}(q)\mathrm{d}q - \sum_{im} \int_0^{y_{im}} C_{im}(y)\mathrm{d}y - \sum_{ijk} D_{ijk} e_{ijk} \right] \tag{20.101}$$

subject to:

$$q_i - A_i y_i + \sum_j (e_{ij} - e_{ji}) = 0 \qquad \text{for all } i \tag{20.102}$$

$$0 \leq y_{im} \leq K_{im} \qquad \text{for all } m \text{ and } i \neq s \tag{20.103}$$

$$\sum_m h_{im} y_{im} \leq B_i \qquad \text{for all } i \neq s \tag{20.104}$$

$$L_{ijk} \leq e_{ijk} \leq U_{ijk} \qquad \text{for all } i,\ j, \text{ and } k \tag{20.105}$$

$$\sum_{j,k} (\pi^*_{jk} - D_{sjk})\ e_{sjk} = E_s \geq E^o_s \tag{20.106}$$

$$\sum_{j,k} (\pi^*_{jk} + D_{jsk})\ e_{jsk} = M_s \leq M^o_s \tag{20.107}$$

where the region index s refers to centrally planned regions. Here, the centrally planned net production, $A_s y_s = y^o_s$, is exogenously given for final products and therefore the capacity constraint (20.103), the investment budget constraint (20.104) for $i = s$, and the production costs Q_{im} in problem (20.101) are omitted. Available budget for investments is denoted by

B_i, and h_{im} stands for investment expenditure per unit of activity im. For details concerning the data for this specification see Chapters 21–26.

The price vector π^* should, in principle, be endogenous. However, such a formulation would cause major complications for the solution procedure of the model, yet the gains are likely to be minimal from the substantive point of view. Therefore, we assume that π^* is exogenously given (possibly separately for imports and exports) for the trade balance requirements (20.106)–(20.107).

The equilibrium price vectors, $\pi_i = (\pi_{ik})$, can be obtained as optimal dual solutions to constraints (20.102). For $i = s$, the interpretation of such a price vector is the vector of marginal penalties for deviate from target consumption levels. Optimality conditions are used for further analysis of the equilibrium. Let $q_i = q_i^*$, $y_i = y_i^*$, and $e_{ij} = e_{ij}^*$ be an optimal solution to problem (20.101)–(20.107) and let π_i, μ_{im}, λ_i, and δ_{ijk} be an optimal dual solution corresponding to the constraints (20.102)–(20.105). Let ξ_s and ψ_s be the dual solution for constraints (20.106) and (20.107), respectively. Defining $\xi_i = \psi_i = 0$ for $i \neq s$, the optimality conditions for problem (20.101)–(20.107) may then be stated as shown in *Table 20.3*. From the discussion in Section 20.2, we know that these conditions are also the spatial equilibrium conditions.

We now analyze the optimality conditions in more detail [10]. For the production sectors m, μ_{im} is the marginal value of capacity m. Conditions (v) and (vi) imply that $\mu_{im} = 0$ if $y_{im} < K_{im}$; in other words, the marginal value is zero if capacity is underutilized. Otherwise μ_{im} is the maximum amount that the production sector m would be willing to pay for an extra unit of similar capacity.

Note that λ_i is the imputed rent of capital in region i. Such a charge is zero if the capital budget is nonbinding. If $y_{im}^* > 0$, then conditions (iii) and (iv) imply:

$$\mu_{im} = \pi_i A_{im} - C_{im}(y_{im}^*) - \lambda_i h_{im} \tag{20.108}$$

Thus, if production activity m is employed then the marginal value of capacity is the marginal profit. Combining the above, if activity m is utilized, but not fully, then the marginal profit of production is zero.

On the other hand, if $y_{im}^* = 0$, then also $\mu_{im} = 0$ and by (iii):

$$C_{im}(0) - \pi_i A_{im} - \lambda_i h_{im} \geq 0 \tag{20.109}$$

is the minimum marginal subsidy required to activate production sector m.

Table 20.3 Equilibrium conditions of the GM.

(i)	q_i^*, y_i^*, and e_{ij}^* satisfy equations (20.102)–(20.105),	for all i,j
(ii)	$\pi_{ik} = P_{ik}(q_{ik}^*)$	for all i,k
(iii)	$\pi_i A_{im} - C_{im}(y_{im}^*) - \lambda_i h_{im} - \mu_{im} \leq 0$	for all $i \neq s,m$
(iv)	$(\pi_i A_{im} - C_{im}(y_{im}^*) - \lambda_i h_{im} - \mu_{im}) y_{im}^* = 0$	for all $i \neq s,m$
(v)	$\mu_{im} \geq 0$	for all $i \neq s,m$
(vi)	$\mu_{im}(K_{im} - y_{im}^*) = 0$	for all $i \neq s,m$
(vii)	$-D_{ijk} - \pi_{ik} + \pi_{jk} - \delta_{ijk} + \pi_k^* \xi_i - \pi_k^* \psi_j \leq 0$	for all i,j,k
(viii)	$(-D_{ijk} - \pi_{ik} + \pi_{jk} - \delta_{ijk} + \pi_k^* \xi_i - \pi_k^* \psi_j)(e_{ijk}^* - L_{ijk}) = 0$	for all i,j,k
(ix)	$\delta_{ijk} \geq 0$	for all i,j,k
(x)	$\delta_{ijk}(U_{ijk} - e_{ijk}^*) = 0$	for all i,j,k
(xi)	$\xi_s , \psi_s \geq 0$	for $i = s$
(xii)	$\xi_i = \psi_i = 0$	for $i \neq s$
(xiii)	$\lambda_i \geq 0$	for all $i \neq s$
(xiv)	$\lambda_i(\sum_m h_{im} y_{im} - B_i) = 0$	for all $i \neq s$

For the trading sector k in region $i \neq s$, δ_{ijk} is the marginal value associated with the relaxation of the trade inertia upper bound, U_{ijk}. Conditions (ix) and (x) imply that for a nonbinding upper bound, $\delta_{ijk} = 0$. Conditions (vii) and (viii) imply that if a flow, e_{ijk}^*, exceeds its lower bound, L_{ijk}, then:

$$\delta_{ijk} = \pi_{jk} - \pi'_{ik} - D_{ijk} \tag{20.110}$$

i.e., δ_{ijk} is the marginal profit from trade. This may be interpreted as the maximum tolerable tariff or as a maximum marginal cost of profitable investment for expanding market opportunities in region j. Combining the above, if a trade flow falls *between* its upper and lower bounds, then:

$$\pi_{jk} - \pi_{ik} = D_{ijk} \tag{20.111}$$

i.e., the price difference between regions i and j is the transportation cost. If the trade flow, e_{ijk}^*, is on its lower bound, L_{ijk}, then $\delta_{ijk} = 0$ and by (vii):

$$\pi_{jk} - \pi_{ik} \leq D_{ijk} \tag{20.112}$$

i.e., the price difference is *at most* equal to the transportation costs. In this case, $D_{ijk} - \pi_{jk} + \pi_{ik}$ may be interpreted as the minimum subsidy required to activate trade flow ijk. For trade involving a CPE, $i = s$, (vii) and (viii) can be rewritten as follows:

$$\pi_{jk} - \pi_{sk} \leq D_{sjk} - \pi_k^* \xi_s \qquad \text{(exports)} \tag{20.113}$$

$$\pi_{sk} - \pi_{jk} \leq D_{jsk} + \pi_k^* \psi_s \qquad \text{(imports)} \tag{20.114}$$

If trade actually takes place, but inertia constraints are nonbinding, then these hold as equalities. Thus, if the export revenue requirement is binding this region may be exporting even if the penalty π_{sk} is higher than the net revenue $\pi_{jk} - D_{sjk}$. Similarly, if the import budget is binding, this region may import even if the penalty π_{sk} of decreasing consumption is lower than the gross expenditure $\pi_{jk} + D_{jsk}$.

20.5. Dynamic Considerations

The discussion in Sections 20.1–20.4 is concerned with describing the behavior of the global forest sector model during one time period, t. During this period t, GM determines, in a myopic fashion, a global spatial equilibrium for the production, consumption, and trade of forest products. The dynamic features of GM are reflected in the way data concerning timber supply, demand, production costs, capacities, etc., are updated for period $t + 1$, based on the solution for period t; for details see Chapters 21–26.

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Notes

[1] The GM uses the inverses of these functions, i.e., price functions for export supply and import demand.

[2] This term is adopted from Hotelling (1938). Other names used are, for instance, social pay-off function (Samuelson, 1952) and quasi-welfare function (Takayama and Judge, 1970).

[3] Let:

$$L = W_r + \sum_{sk} [(\pi^*_{rsk} - D_{rsk}) e_{rsk} - \pi^*_{srk} m_{rsk}] + p_r h_r(x_r)$$

Vector $(\bar{x}_r, \bar{p}_r)$ is a *saddle point* of L if $\bar{x}_r \in R_r$ and:

$$L(\bar{x}_r, p_r) \geq L(\bar{x}_r, \bar{p}_r) \geq L(x_r, \bar{p}_r)$$

for all $x_r \in R_r$ and for all p_r. By assumption, W_r is a concave function, R_r is a convex set, and set $h_r(R_r)$ contains an open neighborhood of null vector. Then each saddle point of L defines a solution for RM and for each solution x_r for RM there are shadow prices p_r, such that x_r, p_r is a saddle point of L (see Bazaraa and Shetty, 1979). Let π_r be a vector of equilibrium prices in region r. Then any solution for problem (20.13)–(20.14) is a saddle point of L with $\bar{p}_r = \pi_r$ and thus a solution for RP. Accordingly, any saddle point of L is a solution for problem (20.13)–(20.14) with $\pi_r = p_r$.

[4] See Section 20.2 and the argument in note [3].

[5] Assume the sectors that consume forest products are competitive profit maximizers with convex production functions that have constant returns to scale. Let $\Pi(\pi_j, \pi_k)$ be the maximal profit for these sectors, given the forest product prices π_j and π_k. Assume Π to be twice continuously differentiable at prices π_j, π_k, then, according to Hotelling's Lemma (Hotelling, 1932; Diewert, 1982), $\partial\Pi/\partial\pi_i = q_i$ where q_i is the demand for forest product i and $\partial^2\Pi/\partial\pi_j\partial\pi_k = \partial q_j/\partial\pi_k = \partial q_k/\partial\pi_j$, i.e., the Jacobian $\partial q/\partial\pi$ is symmetric and the consumption demand satisfies the integrability condition.

[6] The Jacobian $\partial P/\partial q = (\partial q/\partial\pi)^{-1}$ is thereby symmetric when the demand satisfies the integratability condition.

[7] In the mathematical theory of vector functions U is called a potential function.

[8] This is true since we have assumed that the Jacobian $\partial P/\partial q$ is a negative, semidefinite matrix for all $q \geq 0$ (*cf* e.g., Bazaraa and Shetty, 1979). In the separable case $\partial P/\partial q$ is diagonal with elements $\partial P_k/\partial q_k$, which should be negative — a sound condition from the economic point of view. In the general case, these diagonal elements should be negative as well and dominate the cross-price effects strongly enough to render $\partial P/\partial q$ negative definite.

[9] This follows directly from Hotelling's Lemma (Hotelling, 1932; Diewert, 1982).

[10] In order to simplify the discussion, we assume primal nondegeneracy, in which case the dual variables indicate marginal values. If the nondegeneracy assumption does not hold, then the dual variables only yield upper bounds on marginal values.

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CHAPTER 21

Timber Supply

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Timber supply functions describe the quantity of timber that will be produced in a specified region and time period at specified prices. The Global Trade Model (GTM) uses a simple model to capture the intra- and intertemporal aspects of timber supply: short-run marginal cost curves are shifted over time in response to changes in the level of timber inventory. The upward slope of the short-run marginal cost curve (*Figure 21.1*) for a particular time period reflects the fact that higher costs must be incurred to produce larger quantities of timber. These may be thought of as the incremental costs of increasing timber harvests, for example by harvesting timber from less accessible areas, increasing the number of thinning operations in a region in order to increase the total volume harvested, or increasing the recovery of lower quality timber from harvest operations. They also include the higher price required to induce nonindustrial landowners to forego nontimber forest values and harvest more timber.

The marginal cost curves shift through time in response to changes in the inventory of standing timber in the region. Higher levels of timber inventory imply that a given level of timber removals can be achieved at a lower cost. Access costs are apt to be lower and the value of nontimber benefits less, per unit of timber output, when larger inventories of timber are available.

This approach is not explicitly based on a competitive equilibrium model of timber supply, but does capture some of the adjustments that would be expected to take place. In any particular period, an increase in price leads to a higher level of harvest. Similarly, we assume that as the level of growing stock increases, the quantity of timber removed from the forest for commercial purposes will also tend to increase. This model is simple enough to be applied to all of the GTM regions, even though data

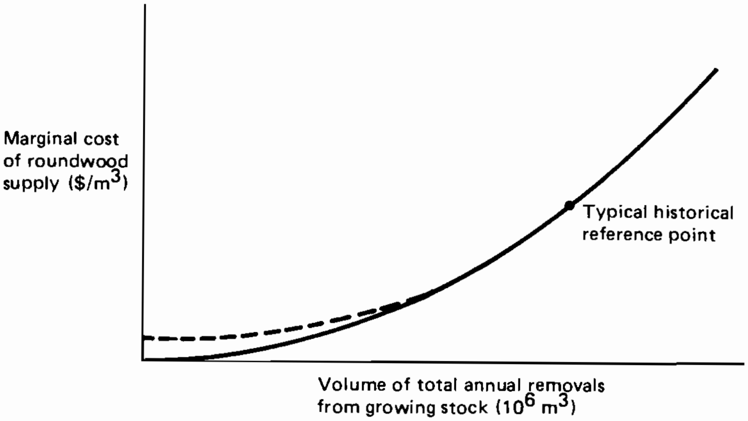

Figure 21.1 A typical short-run, marginal cost curve for roundwood supply as used in the GTM (solid line). There is one such curve for each growing-stock class in each region and each time period. Technically, the curve should intercept the vertical axis at a positive marginal cost, as shown by the dotted line, to correctly account for harvesting and transportation costs. As a practical matter, however, the total annual removals determined by the GTM solutions are far enough to the right on the curve that any error caused by passing the curve through the origin is negligible.

relating to the behavioral aspects of timber supply are unavailable for many of these regions. The same general approach has been used in several other forest sector models, including those of Adams and Haynes (1980), Data Resources (Cardellichio and Veltkamp, 1981), Lange (1983), and Binkley and Cardellichio (1985).

In this chapter we describe the present GTM implementation of this simple timber supply model. In Section 21.1 we describe how the short-run marginal cost curves were developed for the base year 1980, while in Section 21.2 we outline our procedure for shifting the supply curves over time and also detail our methods of timber inventory projection, showing that they are quite consistent with more complex approaches used in other forest sector models.

21.1. Short-Run Marginal Cost Curves

In the forest resources module of the GTM, growing stock in each region is segregated into four classes: large and small coniferous trees and large and small nonconiferous trees. Large trees can be thought of as sawtimber trees that produce logs, pulpwood, and fuelwood; small trees are pulpwood trees that produce only pulpwood and fuelwood.

The marginal cost, C_{im}, of timber removals for region i and growing stock class m is modeled as a strictly increasing function of the annual removal quantity, h_{im}, as illustrated in *Figure 21.1*. Specifically, the present formulation of the GTM assumes that:

$$C_{im} = \alpha_{im} h_{im}^{\beta_{im}} \tag{21.1}$$

This marginal cost curve is the supply curve for roundwood (logs, pulpwood, and fuelwood) delivered to the mill. Thus, $1/\beta_{im}$ is the price elasticity for roundwood supply.

In the GTM we assume that all of the β_{im} are invariant with respect to time and harvest level. Given estimates for these β_{im} and also information on the actual timber removals, h_{im}, and on the marginal costs of timber removals, C_{im}, for the base year, it is possible to calculate directly the base-year values for the position parameters, α_{im}, of the marginal cost curves. The levels of these parameters can then be varied over time to reflect the influence on timber supply of changes in growing-stock levels. Our methodology for doing this is discussed in Section 21.2. Similarly, the α_{im} can be varied to test various modifications in the scenario assumptions, as discussed in Chapters 27–29.

In *Table 21.1* we summarize, for the 18 GTM regions, data that were collected for the development of base-year marginal cost curves for timber supply. Explanations of the data categories shown in *Table 21.1* are given in the following subsections.

21.1.1. Reference volume

These are the total estimated 1980 removals from growing stock in each of the growing stock classes, in 10^6 m^3 measured inside bark. Sources for these data are given in *Table 21.1*. In general, such data had not been segregated according to our growing-stock classes, so we made the segregations in a largely subjective way using yield tables supplied by collaborators. For a few regions (Canada, the US, Brazil, Chile, Finland, Sweden, and Australia–New Zealand), detailed information from collaborators or from publications permitted us to make this type of segregation directly.

21.1.2. Reference price

The 1980 reference price levels shown in *Table 21.1* were established as follows. First, for each region reference prices were estimated for the five roundwood products in the model, as described in Chapter 19. Note that these prices are interpreted as trade prices rather than domestic prices. Then, given estimates for the input–output coefficients that represent the conversion of standing trees into logs, pulpwood, and fuelwood, it was possible to calculate directly the 1980 reference prices for timber.

To illustrate this procedure, consider the calculation of the reference price for large coniferous trees in the Western US. Input–output data in the GTM suggest that, for every 1 m^3 of large coniferous trees removed from growing stock in this region, the following quantities of unprocessed products are produced: 0.80 m^3 of coniferous logs, 0.15 m^3 of coniferous pulpwood, and 0.05 m^3 of fuelwood. The 1980 reference prices for these three products in the Western US are \$44/m^3, \$21/m^3, and \$10/m^3, respectively. These input–output coefficients and product prices imply the following timber price:

$$(0.80)(44) + (0.15)(21) + (0.05)(10) = \$38.9/\ m^3$$

This is the value shown in *Table 21.1* that corresponds to large coniferous trees in the Western US.

21.1.3. Short-run roundwood supply elasticity, $1/\beta$

The parameters in *Table 21.1* that have been the most difficult to verify, and must therefore be considered highly suspect, are the shape parameters of the marginal cost curves, designated β_{im} in equation (21.1). In our timber supply model, $1/\beta_{im}$ is the price elasticity for roundwood supply from growing stock class m in region i. For two countries, the US and Sweden, we were able to obtain independent estimates of these elasticities (Adams and Haynes, 1980; Hultkrantz, 1985). For all other countries we based our estimates of the β_{im} on these estimates and on our own judgment, coupled with advice from collaborators, as to whether stumpage supply in a particular region tends to be more or less elastic than in North America or Scandinavia.

One can also derive timber supply elasticities from access cost models [Williams and Morrison (1985) have applied this kind of model to British Columbia]. An access cost model assumes that harvest and delivery costs are the principal costs associated with the supply of timber. As long as the

Table 21.1 Reference values and β parameters used in the short-run marginal cost

		1980 reference values		
Region	*Growing-stock class*[a]	*Volume*[b] (10^6 m^3)	*Price*[c] (US\$/m^3)	β^k
Western Canada[d]	L,C	75.0	38.3	3.0
	S,C	1.5	15.0	3.0
	L,N	6.0	19.5	2.0
	S,N	4.2	15.0	2.0
Eastern Canada[d]	L,C	40.1	33.7	2.5
	S,C	15.2	16.0	2.5
	L,N	5.2	20.3	2.0
	S,N	4.3	15.0	2.0
Western US[e,f]	L,C	112.8	38.9	3.9
	S,C	0.2	20.5	2.5
	L,N	1.6	22.5	2.5
	S,N	0.5	14.8	2.0
Eastern US[e,f]	L,C	90.9	30.2	2.5
	S,C	34.4	17.4	2.5
	L,N	45.2	25.3	1.6
	S,N	28.4	13.8	1.6
Brazil[e]	L,C	17.7	29.6	2.0
	S,C	6.8	10.4	2.0
	L,N	33.7	35.5	2.0
	S,N	16.2	12.7	2.0
Chile[e]	L,C	7.3	34.5	2.0
	S,C	1.7	19.0	2.0
	L,N	1.6	30.0	2.0
	S,N	0.4	10.0	2.0
Rest of Latin America[g]	L,C	11.4	30.6	2.5
	S,C	0.9	18.0	2.0
	L,N	22.3	29.8	2.0
	S,N	67.0	10.0	2.0
Finland[e,h]	L,C	29.6	54.2	2.5
	S,C	7.9	37.2	1.4
	L,N	2.6	46.2	1.7
	S,N	4.1	34.8	1.4

[a] Growing stock classes are: L, large trees (yielding logs, pulpwood, and fuelwood); S, small trees (yielding only pulpwood and fuelwood); C, coniferous trees; N, nonconiferous trees; All, all trees (no segregation by species or size; this has been done for the USSR, Eastern Europe, and China).

[b] Measured inside bark.

[c] Calculated from product prices, estimated as outlined in Chapter 19.

functions for timber supply.

		1980 reference values		
Region	*Growing-stock class*[a]	*Volume*[b] $(10^6\ m^3)$	*Price*[c] (US\$/m^3)	β[k]
Sweden[e,h]	L,C	28.9	56.5	2.5
	S,C	11.7	43.0	1.4
	L,N	4.4	36.2	1.7
	S,N	3.8	19.0	1.4
Rest of Western Europe[e,h]	L,C	69.6	56.0	3.0
	S,C	18.5	44.2	1.2
	L,N	31.6	46.6	3.0
	S,N	15.5	33.0	1.0
USSR[e,h]	All	356.6	22.6	–
Eastern Europe[e,h]	All	91.4	35.8	–
Africa[i]	L,C	5.9	30.5	2.0
	S,C	3.5	18.0	2.0
	L,N	33.3	34.0	2.0
	S,N	368.0	10.0	2.0
China[g]	All	194.2	18.8	2.5
Japan[e,j]	L,C	19.7	72.5	3.0
	S,C	1.3	34.9	3.0
	L,N	5.7	55.0	3.0
	S,N	7.1	40.0	3.0
Southeast Asia[g]	L,C	1.5	37.5	3.0
	S,C	1.4	12.2	3.0
	L,N	86.5	35.0	3.0
	S,N	158.0	9.8	2.0
Australia–New Zealand[e]	L,C	10.5	53.1	2.0
	S,C	6.6	22.6	2.0
	L,N	8.0	44.3	2.0
	S,N	0.5	11.4	2.0
Rest of the World[g]	L,C	29.9	50.0	3.0
	S,C	4.9	17.6	3.0
	L,N	47.1	31.2	3.0
	S,N	305.5	10.0	3.0

[d-j] These footnotes refer to sources of data on timber removals, as follows: d, Bonnor (1982); e, collaborators' reports; f, USDA Forest Service (1982); g, UNIDO (1983); h, ECE (1976) and Peck (1985); i, Viitanen (1984); j, Japan Forestry Agency (1981).

[k] There are no β parameters for the USSR and Eastern Europe. For Eastern Europe, timber removals are held constant at the 1980 level throughout the planning horizon. For the USSR the volume of timber removals is treated as a scenario parameter (see Chapters 27–29).

price received for timber at the mill exceeds the cost of harvesting timber from a certain area and transporting it to the mill, the timber from that area will comprise part of the supply curve. The supply curve can thus be regarded as the cumulative distribution function for access costs.

A simple access cost model can give some insight into the magnitude of supply elasticities that might be expected from this approach. Assume that transportation costs vary linearly with distance and that the road system in the region of interest has been adequately developed so that straight-line distance is a good proxy for actual road distance. Assume also that transportation cost is the only variable cost of supply and that harvesting costs are constant per unit volume, irrespective of the location of the timber. Finally, assume that the density of the forest is uniform across the region (in Chapter 5 we suggest why this last assumption may not hold).

With these assumptions, it is easy to compute a timber supply curve based on access costs for simple geometric shapes. A linear region has a β_{im} value equal to 1.0, whereas a circular region with inelastic supply at each point in the region has a β_{im} of 0.5. A circular region with elastic supply at each point in the region has a β_{im} of the order of 0.3. It would be interesting to complicate the transportation and harvesting cost models used in these calculations and observe how the elasticity estimates change.

Since most of the β_{im} parameters in *Table 21.1* are based on subjective judgment, there is no question but that they are likely to be in error. It is somewhat surprising, however, that the econometrically fitted estimates of β_{im} (e.g., Adams and Haynes, 1980) are so much larger (all $\gg 1.0$) than those derived from simple transportation cost models (all ≤ 1.0). The estimation of price elasticities for stumpage supply is clearly an activity that would benefit from empirical work by forest economists in nearly all regions of the world.

21.1.4. Timber supply with an inelastic component

In some regions or situations it can be argued that at least part of the timber supply is inelastic; that is, a certain volume of timber will be harvested annually regardless of stumpage price levels. This situation might arise for several reasons. For example, in some countries (e.g., the US), law or custom requires public forestry agencies to provide a certain quantity of timber irrespective of market conditions. As another example, certain circumstances might dictate that forests be harvested with little or no consideration of market conditions. Two such cases are particularly relevant for our work:

(1) Salvage harvests as a result of major environmental catastrophes, such as mortality induced by atmospheric pollution.
(2) Deforestation to make way for agriculture in developing countries, particularly those in the tropics.

Whether or not the inelastic component of timber supply is important depends on the quantity of fixed removals relative to the quantity of price-responsive removals.

To model timber supply when it includes both elastic and inelastic components, we proceed as follows. Suppose, for clarity of exposition, that the inelastic component of timber supply arises from public timber sales, whereas the supply of timber coming from private forests responds to changes in the level of timber prices. First, we compute the parameters of the price-responsive portion of the supply curve using the methods outlined above. In this case the reference volume used in the calculation of α_{im} is that for private timber sales alone.

At any price, the volume of timber supplied is the sum of public and private supply. Let h_p refer to private supply and h_g refer to the inelastic supply component. The inverse private supply curve is as follows (the i and m subscripts have been omitted for clarity):

$$C = \alpha h_p^{\beta} \tag{21.2}$$

To add public timber supply to this private component we first invert equation (21.2):

$$h_p = (C/\alpha)^{1/\beta} \tag{21.3}$$

Total supply h is the sum of public and private supply, so:

$$h = h_g + h_p = h_g + (C/\alpha)^{1/\beta} \tag{21.4}$$

In collecting data for the GTM we have been able to obtain reliable information on the inelastic portion of timber removals only for the US. It seems clear that in the US, timber removals from publicly owned timberlands are not significantly influenced by stumpage prices (Adams and Haynes, 1980). These removals account for a considerable fraction of the total annual timber harvest in the Western US (about 48% at current levels) and a smaller, but still significant, fraction in the East (about 9%). For the US we assume that all timber removals from private lands (both industrial and nonindustrial) are influenced by stumpage prices. Removals from all government properties, on the other hand, are held constant throughout the model's planning horizon at the average annual level of removals observed during the 1970s. *Table 21.2* summarizes our data for both regions of the US with respect to the segregation of growing stock and to removals as used in the GTM.

Table 21.2 Segregation of growing stock and removals for the US regions according to private and government ownerships. Data are for the GTM base year, 1980 (USDA Forest Service, 1982, and collaborators' data).

	Coniferous		*Nonconiferous*	
	Private	*Government*	*Private*	*Government*
Western US				
Growing stock (10^6 m^3)	2085.8	6699.2	304.5	294.8
Annual removals (10^6 m^3)				
Large trees	58.5	54.3	1.2	0.4
Small trees	0.2	0.0	0.5	0.0
Eastern USA				
Growing stock (10^6 m^3)	3614.7	612.4	5872.8	1044.9
Annual removals (10^6 m^3)				
Large trees	82.6	8.3	41.5	3.7
Small trees	31.3	3.1	26.1	2.3

21.2. Timber Supply Dynamics

The dynamics of timber supply are modeled in the GTM in two parts. The first is a procedure for shifting the short-run supply curve in any region (i.e., the marginal cost curve for timber supply) in response to changes in the volume of growing stock in that region. The second is a procedure for projecting the amount of timber inventory in each region. The level of this inventory changes in response to both endogenous factors, such as the annual volume of removals from growing stock, and exogenous factors, such as changes in the forest land base.

21.2.1. Shifting the timber supply curve

To shift the short-run timber supply curves through time, we assume that the elasticity of timber supply with respect to inventory level is 1.0. This means that, all else being equal, an increase in the timber inventory level will lead to an equivalent percentage increase in the level of harvest (the rationale for this assumption is discussed in Chapter 5).

In terms of the GTM, this procedure was implemented as follows. Suppose the timber inventory changes from I to I', then the timber supply curve retains the same price elasticity, but its position shifts. The change in the location parameter of the timber supply equation may be determined by imposing two conditions that define a unitary inventory elasticity of supply:

$$h' = h\frac{I'}{I} \tag{21.5}$$

and

$$C' = \alpha' h'^{\beta} = C = \alpha h^{\beta} \tag{21.6}$$

Substituting equation (21.5) into equation (21.6) and rearranging gives:

$$\alpha' = \frac{\alpha}{(I'/I)^{\beta}} \tag{21.7}$$

The consequence of shifting α in this way as the inventory of growing stock changes is illustrated in *Figure 21.2*. C^* is a reference marginal cost for roundwood delivered to the mill and h^* is the reference harvest level. In the reference year, the inventory of growing stock is equal to I (so that the relationship between h and C is given by $C = \alpha h^{\beta}$). At some other point in time, the level of growing stock inventory increases to I', so that $C' = \alpha' h'^{\beta}$. Because the timber inventory has increased, a larger volume of timber can be harvested at the same marginal cost as before.

Given the base-year estimates for α and β, a method of projecting changes in the timber inventory — finding I' given I and h — completes the GTM timber supply specification.

21.2.2. Timber inventory projection

The timber-inventory projection system begins with an identity that expresses the conservation of mass:

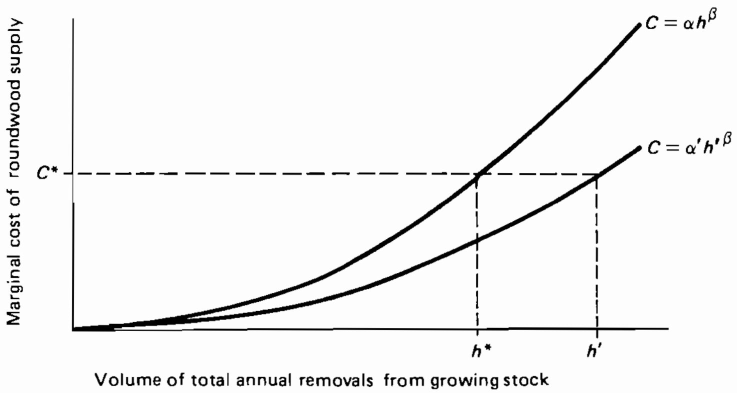

Figure 21.2 Shifting the short-run roundwood supply curve as a result of a change in the level of growing stock inventory.

$$I_{t+1} = I_t - h_t + g_t \tag{21.8}$$

The starting inventory level, I_0, is an initial condition of the model and the harvest level, h_t, is part of the GTM solution for period t. To complete the inventory model, timber growth, g_t, is the only variable that remains to be specified. In this section we begin by discussing the general theory of modeling g_t and then describe our methods for estimating timber growth for each of the regions in the GTM.

General theory of timber growth

Timber growth depends on numerous edaphic and genetic factors that are exogenous to the GTM. The principal endogenous factor is the level of growing stock per unit area, denoted as $x = I/area$. *Figure 21.3* shows Smith's (1962) summary of the relationship between timber growth per unit area, $\dot{x}$, and stocking per unit area, x. At $x = 0$, $\dot{x}$ also is zero because no timber growth can take place in the absence of trees. There also exists some maximum level of stocking above which mortality exceeds productivity, so net growth ceases.

It is well known that any arbitrary function can be approximated with a power series, so:

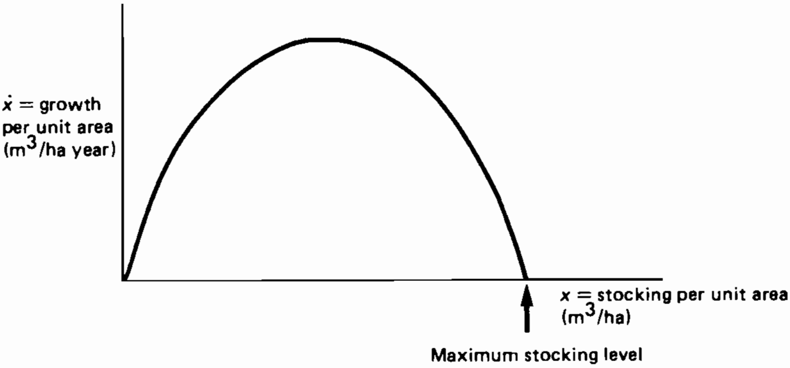

Figure 21.3 The general relationship between forest growth per unit area and level of stocking per unit area (adapted from Smith, 1962).

$$\dot{x} = b_0 x + b_1 x^2 + b_2 x^3 + \cdots \tag{21.9}$$

Note that this relationship is constrained to go through the origin on the $(x,\dot{x})$ plane.

Dividing equation (21.9) by x expresses growth on a percentage basis:

$$\frac{\dot{x}}{x} = b_0 + b_1 x + b_2 x^2 + \cdots \tag{21.10}$$

The forest growth model for the GTM was estimated in the form of equation (21.10) because many decision makers and policy analysts in the forest sector think of growth on a percentage rather than on an absolute basis. In estimating the forest growth model for each region and timber type (coniferous and nonconiferous), we restricted equation (21.10) to three terms. Depending on the growth and inventory data available to us and on the results of statistical analyses made with these data, the functions fitted to the form of equation (21.10) were thus either constant, linear, or quadratic. In *Table 21.3* we summarize the three growth models that result from these three types of functions.

In the first case, timber inventory grows exponentially without bound. While this is not biologically plausible over a long time period, this specification is used in situations where a species group in a particular region is relatively unimportant (such as nonconiferous timber in the Western US) and no better information is available. Even though growth is exponential, if annual removals balance annual growth there will be no net change in forest inventory over time.

Table 21.3 Summary of growth model specifications used in the GTM.

Case	b_0	b_1	b_2	$\dot{x} = 0$
Exponential ($\dot{x}/x$ is constant)	> 0	$= 0$	$= 0$	$x = 0$
Logistic ($\dot{x}/x$ is linear)	> 0	< 0	$= 0$	$x = 0, (b_0/-b_1)$
($\dot{x}/x$ is quadratic)	$= 0$	> 0	< 0	$x = 0, (b_1/-b_2)$

In the second case, the development of the timber inventory over time follows a logistic curve with a maximum level of growing stock equal to $(b_0/-b_1)$. The logistic curve is the simplest specification that shows the biologically expected phenomenon of saturation — that is, the rate of growth is reduced as the level of stocking increases. Most of the growth functions used in the GTM are of this type.

In two cases — coniferous and nonconiferous timber in the US East — the data suggest that the third type of function is most appropriate. In this case, the percentage growth rate drops more rapidly as the maximum stocking level at $(b_1/-b_2)$ is approached.

The term "stocking per unit area" is used in an unusual way in the GTM. In *Table 21.4* we provide data that help to clarify our use of this term. Shown are data on the total exploitable forest area, growing stock, and net annual increment in each GTM region as of 1980. We interpret "exploitable forest" as including all forest land in which industrial cuttings have occurred or could occur periodically under the current level of technical and economic development in the region in question (ECE, 1976). Forests that are excluded from this category in any region would include those in which industrial cutting is prohibited or severely restricted by law or in which physical productivity is too low or delivered wood costs to the nearest market are too high to warrant periodic industrial harvests.

Many foresters will be surprised by the way we use the information in *Table 21.4* to calculate the levels of coniferous and nonconiferous stocking per unit area. To do this, we simply divide each of the two growing stock values for a region by the area of exploitable forest in the region. As an example, for Western Canada the calculated stocking level of coniferous timber is 9480×10^6 m^3/92.5×10^6 ha = 102.5 m^3, and for nonconiferous timber, 1618×10^6 m^3/92.5×10^6 ha = 17.5 m^3/ha.

Table 21.4 Exploitable forest area, growing stock, and net annual increment in the GTM regions for the base year 1980.

		Growing stock (GS) and net annual increment (NAI) on exploitable forest (10^6 m^3)			
		Coniferous		*Nonconiferous*	
Region	*Exploitable forest area* (10^6 ha)	*(GS)*	*(NAI)*	*(GS)*	*(NAI)*
Western Canada[a]	92.5	9480	162.1	1618	35.3
Eastern Canada[a]	98.6	6090	104.1	2456	53.5
Western US[b,c]	51.9	8785	140.6	599	16.8
Eastern US[b,c]	143.3	4227	234.6	6918	263.3
Brazil[c,d]	301.0	2500	64.2	44600	940.0
Chile[c,d]	4.0	63	4.0	455	6.8
Rest of Latin America[d]	225.0	960	22.8	32524	715.0
Finland[c,e]	19.4	1290	48.1	278	13.8
Sweden[c,e]	22.2	1934	55.3	330	11.6
Rest of Western Europe[c,e]	49.9	3541	134.3	2376	75.9
USSR[c,e]	534.5	54669	601.5	12327	148.8
Eastern Europe[c,e]	35.6	2885	67.9	2665	66.5
Africa[f]	162.3	66	4.2	38723	486.0
China[d]	122.0	5300	159.0	4200	105.0
Japan[c,g]	25.3	1224	34.3	962	21.3
Southeast Asia[d]	151.9	78	3.0	27575	280.0
Australia–New Zealand[c]	38.6	416	18.7	2071	31.1
Rest of the World[d]	67.1	1844	38.7	4768	71.5

[a–g] Sources for the data in this table are as follows: a, Bonnor (1982); b, USDA Forest Service (1982); c, collaborators' reports; d, UNIDO (1983); e, ECE (1976) and Peck (1985); f, Viitanen (1984); g, Japan Forestry Agency (1981).

As this example shows, we have expressed the stocking per unit area for each type of timber (coniferous and nonconiferous) in terms of the *total* exploitable forest area in Western Canada, rather than the area occupied principally by either coniferous or nonconiferous trees. The reason for this is a practical one: in most regions, it is impossible to segregate the exploitable forest area into coniferous and nonconiferous components. In Canada, for example, we have used data from an excellent and recent nationwide forest inventory (Bonnor, 1982). Although this inventory provides estimates of growing-stock volume for both coniferous and nonconiferous timber, it classifies the exploitable forest area into three categories: coniferous, nonconiferous, and mixed. Rather than make assumptions, which might be unsupportable, about the mixed forests, we have decided to base our growth model on a stocking per unit area that is derived from the total exploitable forest area in each region.

Application to the GTM regions

In *Table 21.5* we summarize the parameter estimates for the two species groups in each of the GTM regions, except for several regions with very high rates of plantation establishment, discussed in a separate section below. For all of the growth functions shown in *Table 21.5*, large and small trees are grown as a single inventory. We assume that the ratio of large to small trees will remain constant at the level observed in the late 1970s. Two different methods were used to obtain the estimates presented in *Table 21.5*, as discussed in the following two sections.

Table 21.5 Parameter estimates for the forest growth model as currently used in the GTM.

Region	*Type*[a]	b_0	b_1	b_2
Western Canada	C	0.0458	–0.2803e–3	0.0
	N	0.0220	0.0	0.0
Eastern Canada	All	0.0300	–0.1500e–3	0.0
Western US	C	0.0625	–0.2803e–3	0.0
	N	0.0303	0.0	0.0
Eastern US	C	0.0	0.4931e–2	–0.1059e–3
	N	0.0	0.1799e–2	–0.2122e–4
Brazil	See section on Emerging Regions			
Chile	See section on Emerging Regions			
Rest of Latin America	All	0.0422	–0.1360e–3	0.0
Finland	All	0.0700	–0.4000e–3	0.0
Sweden	All	0.0700	–0.4000e–3	0.0
Rest of Western Europe	All	0.0830	–0.4000e–3	0.0
USSR	All	0.0300	–0.1500e–3	0.0
Eastern Europe	All	0.0860	–0.4000e–3	0.0
Africa	C	0.0708	–0.0174	0.0
	N	0.0450	–0.1360e–3	0.0
China	All	0.0600	–0.4000e–3	0.0
Japan	All	0.0600	–0.4000e–3	0.0
Southeast Asia	All	0.0350	–0.1360e–3	0.0
Australia–New Zealand	See section on Emerging Regions			
Rest of the World	C	0.0210	0.0	0.0
	N	0.0150	0.0	0.0

[a] C, coniferous; N, nonconiferous; All, both coniferous and nonconiferous.

US and Western Canada. For the Eastern and Western US, the data were adequate to permit the direct estimation of the growth function parameters. In *Table 21.6* we give statistical information on the fitted equations, calculated using an iterative, generalized least-squares procedure to correct for lag-one serial correlation among the residuals. For the Eastern US growth functions, the model was estimated using data on all ownerships taken together. In the Western US, public lands contain a much higher average level of stocking per unit area than do privately held lands. For this reason the two time series, for private and for public lands, were pooled. The data on Western US public forests prior to 1970 showed very anomalous behavior and were therefore eliminated from the analysis. Also, for the Western US the intercept term was adjusted so that the growth curve passed through the 1980 levels of stocking and percent growth. The growth model for coniferous timber in Western Canada was assumed to have the same slope coefficient, b_1, as in the corresponding model for the Western US, but the intercept was adjusted so that the model fitted the 1980 levels of stocking and percent growth in Western Canada.

Table 21.6 Summary of statistically fitted parameters for the growth models.[a]

Region	b_0	b_1	b_2	R^2	F	n
Western US and Western Canada						
coniferous	0.0614 (17.4)	-0.2803e-3 (-12.3)	–	0.794	150	41
Eastern US						
coniferous	–	0.4931e-2 (93.8)	-0.1059e-3 (-48.2)	0.996	37304	31
nonconiferous	–	0.1795e-2 (78.9)	-0.2122e-4 (-37.2)	0.997	44812	31
Tropical						
hardwoods	0.0379 (3.6)	-0.1360e-3 (-2.3)	–	0.630	5	5

[a] Numbers in parentheses are t-statistics for the null hypothesis that $b_i = 0$.

Although the data for the US purport to reflect estimates of annual growth, removals, and growing stock levels for the period 1952–1980, in fact, they refer only to linear interpolations of four "data" points: 1952, 1962, 1970, and 1977. Furthermore, the estimates made for these years are not data in the usual sense of the word, but rather estimates made by the USDA Forest Service on the basis of field measurements, which in any year may be as much as 10 years out of date for some areas in the US. Because the "data" used to estimate the growth model have been smoothed, the results reported in *Table 21.6* overstate to some unknown, but probably large, degree the actual statistical fit of the model.

Other Regions. To estimate growth function parameters for the remaining GTM regions, for which results are shown in *Table 21.5*, data were pooled by groups of regions identified on the basis of roughly similar timber types.

The groupings thus established were Europe (including Finland, Sweden, Western Europe, and Eastern Europe), China–Japan, USSR–Eastern Canada, Rest of the World, and the region of native tropical hardwoods (Brazil, Chile, Rest of Latin America, Asia, and Africa). Growth rates of coniferous timber in Africa were analyzed separately.

For Europe, estimates of growth and stocking in 1970 and 1980 from ECE (1976) and Peck (1985) were used to estimate the slope parameter b_1 (see *Table 21.5*). Using this slope parameter, region-specific intercepts were then calculated to force the curve for each region in the "Europe" group through the 1980 growth–stocking point reported for that region.

Similar methods were used for the other groups of regions. For the China–Japan group, data on growth and stocking were from the Japan Forestry Agency (1981) and collaborators' reports on Japan only. For the USSR–Eastern Canada group, data were pooled from ECE (1976), Peck (1985), and Bonner (1982). The region Rest of the World includes primarily Western Asia and the Middle East. Data for this group were from FAO (1982) and UNIDO (1983). Since forest land is scarce in much of this region, we assumed that growth rates would remain constant at the observed 1980 rates. For the region of tropical hardwoods, data came from collaborators' reports and from FAO (1982) and UNIDO (1983). Note that data on tropical hardwood growth and stocking for Brazil and Chile were included in this group, even though these two countries are treated in the GTM as emerging regions. This was done in order to increase the number of observations used in the statistical analysis. The parameters for tropical hardwoods shown in *Table 21.6* were estimated using ordinary least-squares regression.

Parameter estimates for the growth rate of coniferous timber in Africa were calculated separately, as follows. In 1980 the total area of coniferous plantations in Africa was approximately 10^6 ha (Viitanen, 1984). Using data on the yield of coniferous timber in Tanzania (Adegbehin and Philip, 1979) as a guide, we estimated that the maximum average stocking attainable on coniferous plantations in Africa as a whole would be about 650 m^3/ha. This gives a maximum total coniferous volume for 10^6 ha of about 650×10^6 m^3, or a maximum average stocking on the 162.3×10^6 ha (*Table 21.4*) of total exploitable African forest land of 4.0 m^3/ha. Since this is the estimated maximum attainable average stocking on total hectares, it corresponds to a growth rate of 0%. The observed 1980 average growth rate of 6.4% at an average stocking of 0.4 m^3/ha (*Table 21.4*) provides a second point and the parameters shown in *Table 21.5* were then calculated from these two point estimates.

For most of the GTM regions, a single growth function is used for both coniferous and nonconiferous timber (the exceptions are Western Canada, Western and Eastern US, Africa, and Rest of the World; see *Table*

21.5). In these single-function regions, the timber inventory is projected over time as a whole and then split into coniferous and nonconiferous components on the basis of the 1980 ratio for each region. As long as the ratio of coniferous to nonconiferous volume does not change appreciably this procedure gives a reasonable approximation to the actual development of the timber inventory. The same assumption was made with respect to the fraction of large trees (yielding logs, pulpwood, and fuelwood) and small trees (yielding only pulpwood and fuelwood) for each species category.

Emerging Regions. In several regions, particularly Brazil, Chile, and Australia–New Zealand, plantations of fast-growing, short-rotation species are being established at a rate that will significantly affect growing-stock inventories in these regions over the next several decades, especially of coniferous timber. For these regions, which Sedjo (1983) has called "emerging regions" in the context of timber supply, it is not sensible to simply extrapolate past growth rates, because the plantation area and the character of the growing stock are both changing rapidly. Instead, for these regions the GTM utilizes an entirely different kind of methodology to determine the volume of timber available for harvest in any period and to shift the short-run timber supply curves. This methodology was suggested by Morales (1985) and details of the data and methods were established together with collaborators from each of the regions.

We do not use explicit growth functions for Brazil, Chile, and Australia–New Zealand, nor do we directly make use of data on forest area and growing stock, as we do for the other regions. Instead, we utilize estimates from collaborators as to the volume of timber that is expected to be available for harvest during each period within the GTM planning horizon. These estimates are summarized in *Table 21.7.*

The GTM utilizes the information in *Table 21.7* as follows. The volumes of coniferous and nonconiferous timber potentially available to be harvested in period t are used to determine *upper limits* on removals in period t. Suppose one of these upper limits is designated U_t. If the volume of removals, R_t, determined by the GTM solution for period t, is less than U_t, then the difference, $D_t = U_t - R_t$, is carried over into the subsequent period, $t + 1$. Thus, if T_{t+1} is the volume potentially available in period $t + 1$ according to *Table 21.7*, the upper limit on removals in period $t + 1$ would be $U_{t+1} = T_{t+1} + D_t$. This is probably not a completely realistic treatment, since some of the volume carried over might be lost through mortality or degradation, or the growth on the volume carried over might be sufficient to increase the carryover even further. The residual volumes carried over in this way are usually quite small, however, and the method therefore seems acceptable.

Table 21.7 Estimated volumes of timber potentially available for harvest (10^6 m^3/year) in the emerging regions, 1980–2030. These estimates are for both plantations and natural forests (Iusem, 1985; Larsen, 1985; Manley, 1985; Morales, 1985).[a]

	Brazil		*Chile*		*Australia–New Zealand*	
Year	*C*	*N*	*C*	*N*	*C*	*N*
1980	24.5	49.9	9.9	1.4	13.1	11.6
1985	25.5	64.9	11.2	2.3	17.4	10.5
1990	34.9	76.6	12.3	3.0	21.0	10.2
1995	57.2	66.4	18.5	4.2	29.2	10.0
2000	60.6	80.4	28.9	5.7	36.8	9.8
2005	53.6	84.9	30.0	7.5	42.0	9.7
2010	68.5	85.6	30.0	9.7	46.5	9.4
2015	68.5	85.6	30.0	12.7	48.0	9.2
2020	68.5	85.6	30.0	16.5	48.0	8.5
2025	68.5	85.6	30.0	21.5	48.0	8.5
2030	68.5	85.6	30.0	28.0	48.0	8.5

[a] C, coniferous; N, nonconiferous.

Since the GTM does not explicitly utilize data on growing-stock inventories for the emerging regions, equation (21.7) cannot be used to shift the short-run timber supply curves through time. Instead, we shift these curves according to the upper bounds on removals, U. Thus, if the upper bound on removals changes from U to U', the position parameter of the short-run timber supply curve, α, would shift to α':

$$\alpha' = \frac{\alpha}{(U'/U)^{\beta}} \tag{21.11}$$

This is consistent with the methodology discussed in Section 21.2.1.

Exogenous changes to forest area and growing stock

Important changes are underway in several regions that will significantly influence the forest area and growing stock of industrial timber in those regions. These changes include both afforestation and deforestation.

Afforestation may result either from plantation activities or from natural evolutionary processes. An example of the latter is the unplanned afforestation of abandoned farms that has occurred since World War II in the Southern US.

Worldwide, deforestation most commonly results from the clearance of forest land for agricultural purposes, particularly in areas where shifting agriculture is practiced (OTA, 1984). Lesser, but still important, factors that contribute to deforestation include livestock grazing, fuelwood gathering, and logging. In the context of the removal of forest areas and growing stock from the industrial timber-supply base, we should also consider such factors as encroaching urbanization and the setting aside of forests as designated natural preserves` in which commercial forestry is prohibited or severely restricted.

In the GTM, afforestation and deforestation are treated as exogenous increases or decreases in forest area and growing stock. Although the GTM software has been organized so that it is possible to explicitly recognize such changes for any region, the model runs reported in this book include estimates of future afforestation and deforestation only for the regions of tropical forests, where these changes are likely to be most significant in the coming decades. Because the three emerging regions of Brazil, Chile, and Australia-New Zealand have been treated in a different way, as discussed in the preceding section, we do not explicitly consider afforestation or deforestation in these regions.

Afforestation. Based on an analysis of data both from collaborators and from published accounts, it appears that important afforestation efforts are underway in three regions: Rest of Latin America, Africa, and Southeast Asia. For each of these regions we have estimated the average annual additions to forest area and growing stock that are projected to result from plantations now being established or planned. These estimates are based largely on data from FAO (1982), McGaughey and Gregersen (1983), UNIDO (1983), and Viitanen (1984), and are summarized in *Table 21.8.*

Deforestation. The subject of deforestation and forest resource degradation, particularly in the tropics, has become one of the most newsworthy topics of recent years (OTA, 1984). In spite of this it is very difficult to find reliable data on current levels of deforestation and degradation, let alone estimates of future trends. For this study we decided to rely entirely on estimates of deforestation levels made in connection with a recent global inventory of tropical forests (FAO, 1982). In doing so we have not attempted to distinguish between deforestation and forest-resource degradation. In the GTM scenario runs reported in this book we assume that bp once an area has been deforested it is lost to the forest resource land base for the remainder of the model's 50-year planning horizon.

In *Table 21.9* we summarize data on deforestation for the four GTM regions that seem likely to experience substantial losses of forest area and growing stock during the next 50 years. Because of the way they are

Table 21.8 Estimated average annual additions to forest area and growing stock, 1980–2030, for three GTM regions in which substantial new areas of plantations are anticipated (FAO, 1982; McGaughey and Gregersen, 1983; UNIDO, 1983; Viitanen, 1984).[a]

	Forest area (10^6 ha/year)		*Growing stock* (10^6 m^3/year)	
Region	*C*	*N*	*C*	*N*
Rest of Latin America	0.07	0.04	0.40	0.30
Africa	0.01	0.01	0.05	0.08
Southeast Asia	0.07	0.15	0.30	1.20

[a] C, coniferous; N, nonconiferous.

Table 21.9 Estimated average annual deforestation of exploitable forests in four GTM regions, averaged over the period 1981–85 (10^6 ha/year) (FAO, 1982; and the subsidiary reports FAO, 1981a–c).

Region	*Undisturbed forests*	*Logged-over forests*	*Total deforestation*
Rest of Latin America			
coniferous	0.02	0.14	0.16
nonconiferous	1.20	0.70	1.90
total	1.22	0.84	2.06
Africa[a]	0.22	1.03	1.25
Southeast Asia[a]	0.32	1.08	1.40
Rest of the World[a]	0.06	0.18	0.24

[a] Coniferous forests in these regions are small and are primarily plantations; all of the deforestation is thus assumed to take place in nonconiferous forests.

treated as emerging regions, Brazil and Chile are not included in this list. The exogenous estimates of potential, future timber removals for these two countries (see *Table 21.7*) have already been adjusted for projected deforestation.

Analysis of the data in *Table 21.9* together with forest resources data in *Table 21.4* suggests that the annual deforestation rates for these four regions during the early 1980s were 0.9% (Rest of Latin America), 0.8% (Africa), 0.9% (Southeast Asia), and 0.35% (Rest of the World). However, not all of the deforestation occurs in previously undisturbed forest. In Latin America, only 14% of the deforested coniferous area and 63% of the deforested nonconiferous area are classified as undisturbed forest land. In the GTM scenario runs reported in this book, we assume that no measurable timber volume is lost when logged-over lands are deforested; the only effect is that the forest land base is reduced (i.e., hectares are lost). When a hectare of undisturbed forest land is deforested, however, we assume that a volume equal to the average stocking per hectare is lost. For 1980 this is based on *Table 21.4*, but the averages will change over time due to growth, removals, and exogenous changes in the forest land area and growing-stock inventory.

In *Table 21.10* we summarize our estimates of average annual losses in forest area and growing stock for the four GTM regions that seem likely to experience significant deforestation during the coming decades. In making these estimates, we have assumed that deforestation *rates* will continue at approximately the average rates reported for the early 1980s by FAO (1982). There is little agreement on how to project deforestation rates. Myers (1980) has projected *total* deforestation linearly, implying that the fraction of forest land being deforested each year will increase over time. Palo (1984) has also concluded that the rate of deforestation will tend to increase in the future because of intensifying population pressures. On the other hand, Sedjo and Clawson (1983) have argued that deforestation rates will tend to decline as the management of tropical forests improves, income levels in developing countries increase, and governments take vigorous action to reduce deforestation. Clearly, there is no broad consensus of expert opinion on what constitutes a reasonable assumption with respect to deforestation. We have taken a moderate view, holding deforestation rates

Table 21.10 Estimated average annual deforestation, showing losses in forest area (10^6 ha/year) and growing-stock volume (10^6 m^3/year) for four GTM regions, 1980–2030. These losses assume that deforestation *rates* will remain approximately constant at the levels estimated by FAO (1982) for the early 1980s.[a]

	Rest of Latin America		*Africa*		*Southeast Asia*		*Rest of the World*	
Period	*Area*	*Volume*	*Area*	*Volume*	*Area*	*Volume*	*Area*	*Volume*
1980–1985	1.99	166.63	1.28	54.88	1.34	56.06	0.23	4.14
1985–1990	1.90	162.36	1.23	54.49	1.28	55.49	0.23	4.13
1990–1995	1.82	158.20	1.18	54.10	1.23	54.93	0.23	4.11
1995–2000	1.74	154.15	1.13	53.72	1.17	54.37	0.22	4.09
2000–2005	1.66	150.20	1.09	53.34	1.12	53.82	0.22	4.07
2005–2010	1.59	146.36	1.05	52.96	1.07	53.27	0.21	4.05
2010–2015	1.52	142.61	1.00	52.58	1.02	52.73	0.21	4.04
2015–2020	1.45	138.95	0.97	52.21	0.98	52.19	0.21	4.02
2020–2025	1.39	135.39	0.93	51.84	0.94	51.66	0.20	4.00
2025–2030	1.32	131.92	0.89	51.47	0.89	51.14	0.20	3.98

[a] All volumes shown are for nonconiferous growing stock. Only in the Rest of Latin America region is coniferous growing stock subject to significant deforestation. The estimated loss of coniferous volume in that region is 0.09 × 10^6 m^3/year, which remains approximately constant throughout the GTM planning horizon.

constant so that the number of hectares deforested annually will decline over time.

21.2.3. Validation of the GTM growth model

Forest growth and development is an extraordinarily complex process. A reasonable question to ask about the GTM forest resources model is whether the simple growth functions we have used are capable of projecting the actual patterns of inventory development that might be expected over time. This question can be partially answered by comparing the performance of the GTM growth models with results from the much more elaborate growth models that are used for forest sector planning in some countries. Because the level of timber inventory is used to shift the short-run timber supply curves, it is more important to portray future inventory levels than timber growth *per se*.

In *Table 21.11* we compare timber inventory projections made with the GTM and those made by agencies charged with estimating future forest inventories in two countries, the US and Finland. These countries were chosen because they support comparatively sophisticated forest sector planning and cover the range of growth-model specifications discussed above.

Table 21.11 Comparison of timber inventory projections made with the GTM versus independent projections for Finland and the US made using more elaborate forest growth models.

Timber type and region	*Percent deviation*[a]				
	1990	*2000*	*2010*	*2020*	*2030*
Coniferous					
Finland	5.6	9.5	10.9	11.1	–
Western US	3.6	3.9	2.6	0.7	–1.3
Eastern US	0.6	–1.5	3.6	–3.1	0.2
Nonconiferous					
Finland	5.7	8.1	8.0	6.7	–
Eastern US	3.4	5.6	6.1	6.4	7.5

[a] Percentage deviation = $([GTM - est]/est)(100\%)$, where GTM is the inventory of timber growing stock for the time period indicated, estimated by using the GTM inventory and growth model, and est is the corresponding timber inventory levels projected with the more elaborate forest growth models of Kuusela (1983) in Finland and USDA Forest Service (1982) in the US. Projections for Finland are only to 2020.

The GTM growth model for Finland treats coniferous and nonconiferous timber together and was estimated using data pooled for all of the regions in Europe. The growth models for the Western US treat the coniferous volume separately from the nonconiferous volume. The nonconiferous model for the Western US is not included in this analysis because this volume is very small and it is economically unimportant compared with the coniferous volume. The two Eastern US models also separate coniferous from nonconiferous volume, but have the added complexity of a quadratic term in equation (21.10). The other two test cases, Finland and the Western US, use logistic growth functions.

Table 21.11 was constructed using the appropriate GTM growth model to project current timber inventories into the future. Removals were trended exponentially between the decadal values reported by Kuusela (1983) for Finland and in Table 8.5 of USDA Forest Service (1982) for the US cases.

In all cases the inventory levels projected by the GTM are reasonably close to those projected by the responsible national authorities. The largest deviations occur with the projection of coniferous volumes for Finland. Even here, though, the GTM overstates the inventory by only 11% after 40 years, or an average deviation of about 0.25% per year. For coniferous timber in the Western US, USDA Forest Service (1982) projects slight increases in timber volume over the 50-year period, whereas the GTM procedure gives a slight decline. The differences are small, however, never exceeding 4%. For coniferous volume in Eastern US, the two projections show the same pattern of a temporary increase in inventory followed by a decline. The GTM projection peaks in the same decade as the USDA Forest Service (1982) projection, but shows a more rapid initial decline. By 2030 the two projections are nearly identical.

The GTM procedures overstate nonconiferous timber inventories in both Finland and the Eastern US, although the magnitudes of the differences are not large, amounting to 0.16% per year for Finland and 0.15% per year for the Eastern US, averaged over 40 years for Finland and 50 years for the US.

This analysis is admittedly not comprehensive, as it is restricted to only three of the 18 GTM regions. Furthermore, we recognize the possibility that neither the GTM nor the timber inventory projection models used in Finland or in the US may be correct. The important conclusion, however, is that both the GTM and the more elaborate timber inventory projection models used in these two countries simulate similar patterns of timber inventory development over time. At the very least this suggests that the GTM forest resources model is reasonably satisfactory for the purpose of sectoral-level forest policy analysis.

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CHAPTER 22

Forest Industry Modules

M. Kallio

In this chapter we discuss the supply of forest products, i.e., sawnwood, wood-based panels, pulp, and paper. The basic topics to be covered are the material input–output characteristics of wood processing, production costs, productive capacity, and investments. The structure of the forest industry module of the GTM is identical for 15 of the GTM regions, differing only for the three planned economy regions, the USSR, Eastern Europe, and China. We discuss the general structure here, along with some differences for the planned economies. A more detailed explanation of the planned economy models is given in Chapter 26.

The static version of the industry module, which applies to any single time step of the GTM, is discussed first, followed by a discussion of the data for the base year 1980, and, finally, a description of the procedures for dynamically updating the modules.

22.1. The Static Model

22.1.1. General description

For each time step and each region the general structure of the industry module is:

$$cx = z \tag{22.1}$$

$$Ax = y \tag{22.2}$$

$$hx \leq B \tag{22.3}$$

$$L \leq x \leq U \tag{22.4}$$

Here $x = (x_i) \in R^n$ is the vector of production quantities, one component for each production activity i; $c = (c_i) \in R^n$ is the vector of marginal production costs, excluding timber and wood fiber costs, and z is the total nonwood variable cost of production associated with output level x. The matrix $A = (a_i) \in R^{m \times n}$ is the matrix of conversion coefficients, each column a_i referring to a production activity and each row of A referring to one of the 16 products of the GTM. Component a_{ji}, row j of column a_i, measures the output of product j per unit of activity i. If the primary purpose of activity i is to produce product k, we define $a_{ki} = 1$, i.e., at a unit level of activity i one unit of k results. Other elements of a_i may be positive, negative, or zero, a positive figure indicating a side product or residual (e.g., pulpwood residues from sawmilling) and a negative one indicating an input (e.g., log input for sawmilling). Vector $y = Ax \in R^m$ thus indicates the net output given activity level x. Typically, the first four elements of y are negative, referring to net input of logs and pulpwood, coniferous, and nonconiferous separately. Vector $h = (h_i) \in R^n$ is a vector of investment expenditures associated with production activity i and B is the available investment budget. Vectors $L = (L_i)$ and $U = (U_i)$ in R^n are bounds on the production level x. The lower bound L_i typically is equal to zero, but not always. The upper limit U_i is normally the capacity limit.

We assume that profit maximization is the basic principle that determines activity levels x. Given a price vector $\pi \in R^m$ for all products, the profit maximization problem is:

$$\max \pi y - z \tag{22.5}$$

subject to equations (22.1)–(22.4). If $\pi = \pi^*$ is an equilibrium price vector and $x = x^* = (x_i^*)$ is the corresponding vector of equilibrium production, then x^* is an optimal solution for problem (22.5). Denote by λ^* the corresponding, optimal dual multiplier for investment budget constraint (22.3). Applying λ^* for investment expenditures, then x_i^* is an optimal production level for the profit-maximization problem of the production unit consisting of activity i alone:

$$\begin{aligned} &\max\ (\pi a_i - c_i)x_i - \lambda^* h_i \\ &L_i \leq x_i \leq U_i \end{aligned} \tag{22.6}$$

Therefore, the equilibrium solution x_i^* is optimal for problem (22.6) for all i as well.

Consequently, we may conclude that despite the assumption in production behavior implied by the aggregate regional problem (22.5), the equilibrium solution does not assume nor exclude centralized decision making in the region. In fact, one can use a similar argument to show that the equilibrium solution is a profit-maximizing solution for each individual production unit in a set of independent units, which jointly comprise the entire production capacity in the region. We may think of the set of forest industry enterprises in the region as representing such independent units.

22.1.2. Production activities

The vector x of production is decomposed into the following components:

(1) Three components (except for planned economies, which have only one) for each forest industrial product, e.g., coniferous sawnwood, particle board, bleached coniferous pulp, newsprint, etc.
(2) One component for paper recycling.
(3) Two technical components, one to enable the conversion of logs into pulpwood and the other to enable the conversion of pulpwood into fuelwood.

The three components per product refer to the alternative technologies that are available for producing this product: two of these technologies subdivide the present capacity, created before the current time step (to which the static model refers), into *old* and *modern*, or *inefficient* and *efficient* capacity, and the third one, the *new* technology, refers to the capacity that is created during the current time step through investments.

For existing capacity, i, either old or modern, the marginal cost, c_i, includes only nonwood costs that are created if capacity i is activated for production. Such costs include labor, chemicals, energy, nonwood fiber (e.g., bagasse), and maintenance costs. Capital costs are excluded for existing capacity (since they are then sunk costs) but included for new capacity. Production costs, c_i, as well as conversion vectors, a_i, are typically dependent on technology. In addition to new capacity, existing capacity may also consume some of the investment budget because of maintenance or repair investments.

Upper bounds on activities that correspond to existing technologies are determined by capacity and an upper bound that corresponds to new technology is set in order to prevent excess investments in a single product line (see Section 22.3). Lower bounds are sometimes employed in order to meet production or other targets or to include investments that are known to be made, but are not yet implemented (for examples of such investments, see *Table 22.14*). Joint capacity constraints for several production activities have not been included in this version of the GTM. This could be a relevant future development for sawmilling and for white pulp production. The ability to shift capacity from one product line to another (involving minor investments) is not included in the present model, either. In practice, however, newsprint capacity, for example, is sometimes "upgraded" to produce higher quality printing paper.

For the single activity i of recycled paper, the cost c_i of production includes both recovery and processing costs. No investment or other inputs are assumed. The upper limit U_i is determined by the recovery rate and paper consumption in the region.

The two technical activities for converting logs into pulpwood and pulpwood into fuelwood are needed to add flexibility. For example, the model might have an excess of logs, but a shortage of pulpwood at the same time; permitting logs to be used as pulpwood would relieve this imbalance without allowing the pulpwood price to exceed the price of logs. There are no conversion costs or material losses involved. Through the possibility of converting pulpwood into fuelwood, the fuelwood price thus sets a lower bound on the pulpwood price (see also fuelwood demand in Chapter 23).

22.2. Base-Year Data

We now discuss some of the data for 1980, which are used in the scenario runs of Part VI and are associated with equations (22.1)–(22.4), i.e., the cost vector, c, capital expenditure vector, h, investment budget, B, conversion coefficients, A, and the bounds, L and U.

The basic pulp and paper data, excluding that for the planned economies, were obtained from the Finnish consulting company Jaakko Pöyry Oy. Much of the rest were provided directly by collaborators of the Forest Sector Project. If no sources were available, then the data were estimated on the basis of judgment (by using, for example, the same data from other regions). We make no claim that the data are flawless; this is the first attempt to assemble such data on a global basis, so there remains much room for future improvement.

One of our general principles during the collection of data was that there ought to be a certain uniformity of data for the regions. For example, in order to avoid problems due to different interpretations of model parameters, we sometimes rejected a figure from a collaborator in order to make the parameter value more comparable with values from other regions.

Another principle we followed was to obtain consistency both in material flows and in cost and price structures. In order to check material flows, we used 1980 production figures, denoted by x^0, which are obtained primarily from FAO statistics, to compute from equation (22.2) the net output vector, $y = Ax^0$. For timber-consumption components of y, the absolute value of this vector should equal domestic timber production plus net imports. Similarly, for final forest products the net production component of y should equal domestic consumption plus net exports. To check the cost structures we calculated the profit share of price as $(\pi^0 a_i - c_i)/\pi_i^0$, where π^0 is the vector of 1980 reference prices (see Chapters 21 and 23) and π_i^0 is the price of the primary product produced by activity i. This share should conform with the capital cost share of the production value. Both of these cross-checks produced a number of changes, both in the conversion coefficient matrix A and in the cost coefficient vector c.

Tables 22.1–22.5 show the conversion coefficients for 1980. Output coefficients, which are equal to one by definition, are omitted.

Paper recycling in 1980, both in terms of tons of recycled paper consumed by the paper industry and as a share of paper consumption, i.e., recovery rate, is given in *Table 22.6* for each region.

The investment expenditures, at the 1980 cost level, for new forest-industry processing capacity are summarized in *Tables 22.7* and *22.8*. In order to take into account investment expenditures related to repair investments for existing old and modern capacity, it was assumed that such costs are proportional to the cost of new capacity. The factor that determines the share depends on the age of the capacity, so values of 18.7% for old capacity and 8.3% for modern capacity are used in the current model version.

The marginal production cost coefficients, c_i, for activities i in 1980 are given in *Tables 22.9* and *22.10*, for old and modern technologies. For new investments, the corresponding cost coefficients were obtained by adding a capital cost, amounting to 15% of investment cost (*Tables 22.7* and *22.8*), to the marginal cost of modern capacity. For the planned economies, production levels are exogenously given and the marginal costs were thus set to zero.

Production capacities in 1980 by region are given in *Tables 22.11* and *22.12*. For sawnwood, only the total capacities for old and modern technologies and for total coniferous and nonconiferous wood are indicated. In the model runs this was subdivided by product according to the actual 1980 production and the resultant capacity was further subdivided equally between the two technologies. The latter applies also to veneer and plywood and to particle board. No capacity expansion was allowed for 1980. As a result, the 1980 investment budget B in equation (23.3) was set to zero.

Table 22.1 Conversion coefficients per m^3 of sawnwood production: log consumption, pulpwood residuals, fuelwood residuals, and loss. Technologies: T_1 = old, T_2 = modern, T_3 = new capacity.

		Coniferous sawnwood				*Nonconiferous sawnwood*			
Region	*Technology*	*Logs*	*Pulpwood*	*Fuelwood*	*Loss*	*Logs*	*Pulpwood*	*Fuelwood*	*Loss*
Western Canada	T_1,T_2	2.40	0.90	0.10	0.40	2.31	1.00	0.20	0.11
	T_3	1.80	0.50	0.10	0.20	2.10	0.80	0.10	0.20
Eastern Canada	T_1,T_2	2.40	0.90	0.10	0.40	2.31	1.00	0.20	0.11
	T_3	1.80	0.50	0.10	0.20	2.10	0.80	0.10	0.20
Western US	T_1,T_2	1.90	0.55	0.30	0.05	2.03	0.90	0.10	0.03
	T_3	1.90	0.65	0.20	0.05	1.83	0.70	0.10	0.03
Eastern US	T_1,T_2	2.52	1.45	0.06	0.00	2.03	0.40	0.60	0.03
	T_3	1.90	0.65	0.20	0.05	1.83	0.70	0.10	0.03
Brazil	T_1,T_2	2.90	0.00	1.90	0.00	3.00	0.00	2.00	0.00
	T_3	2.00	0.50	0.50	0.00	3.00	0.80	1.20	0.00
Chile	T_1,T_2	2.20	0.52	0.00	0.68	2.40	0.00	1.00	0.40
	T_3	1.80	0.70	0.00	0.10	2.00	0.00	1.00	0.00
Rest of Latin America	T_1,T_2	2.00	0.70	0.10	0.20	1.85	0.00	0.20	0.65
	T_3	2.00	0.50	0.50	0.00	3.00	0.80	1.20	0.00
Finland	T_1,T_2	2.00	0.61	0.17	0.22	2.00	0.83	0.00	0.17
	T_3	1.80	0.75	0.00	0.05	1.80	0.75	0.00	0.05
Sweden	T_1,T_2	2.04	0.84	0.09	0.11	2.00	0.86	0.09	0.05
	T_3	2.08	0.97	0.09	0.02	2.08	0.97	0.09	0.02
Western Europe	T_1,T_2	1.54	0.30	0.10	0.14	1.79	0.30	0.10	0.39
	T_3	1.54	0.30	0.10	0.14	2.10	0.80	0.10	0.20
USSR	T_1	1.38	0.18	0.10	0.10	1.58	0.18	0.30	0.10
Eastern Europe	T_1	1.66	0.30	0.15	0.21	2.30	0.30	0.90	0.10
Africa	T_1,T_2	2.07	0.30	0.10	0.67	2.10	0.14	0.20	0.76
	T_3	1.80	0.30	0.30	0.20	2.10	0.40	0.50	0.20
China	T_1	1.69	0.31	0.10	0.28	1.90	0.17	0.20	0.53
Japan	T_1,T_2	1.25	0.05	0.00	0.20	1.57	0.50	0.00	0.07
	T_3	1.25	0.05	0.00	0.20	1.57	0.50	0.00	0.07
Southeast Asia	T_1,T_2	2.20	0.30	0.10	0.80	2.50	0.00	0.20	1.30
	T_3	1.80	0.30	0.10	0.40	2.10	0.80	0.10	0.20
Australia–New Zealand	T_1,T_2	2.30	1.20	0.08	0.02	2.58	0.30	0.20	1.08
	T_3	2.00	0.80	0.08	0.12	2.10	0.80	0.10	0.20
Rest of the World	T_1,T_2	2.00	0.00	0.80	0.20	2.30	0.00	1.00	0.30
	T_3	1.80	0.30	0.30	0.20	2.10	0.40	0.50	0.20

Table 22.2 Conversion coefficients per m^3 produced of veneer and plywood: coniferous (C) and nonconiferous (N) logs input, C and N pulpwood residuals, fuelwood residuals, and loss. Technologies: T_1 = old, T_2 = modern, T_3 = new capacity.

Region	*Technology*	*Logs*		*Pulpwood*		*Fuelwood*	*Loss*
		C	*N*	*C*	*N*		
Western Canada	T_1,T_2	1.62	1.00	0.80	0.60	0.01	0.21
	T_3	1.50	1.00	0.70	0.60	0.01	0.19
Eastern Canada	T_1,T_2	1.62	1.00	0.80	0.70	0.01	0.11
	T_3	1.50	1.00	0.70	0.60	0.01	0.19
Western US	T_1,T_2	1.82	0.00	0.65	0.00	0.15	0.02
	T_3	1.80	0.00	0.70	0.00	0.01	0.09
Eastern US	T_1,T_2	2.00	0.22	0.90	0.05	0.25	0.01
	T_3	1.90	0.20	0.90	0.10	0.01	0.09
Brazil	T_1,T_2	2.26	0.10	0.05	0.01	1.00	0.30
	T_3	2.16	0.10	1.00	0.01	0.01	0.24
Chile	T_1,T_2	0.38	2.00	0.00	0.00	1.00	0.38
	T_3	0.84	1.30	0.00	0.00	1.00	0.14
Rest of Latin America	T_1,T_2	0.38	1.63	0.00	0.04	0.20	0.77
	T_3	0.50	1.50	0.20	0.60	0.10	0.10
Finland	T_1,T_2	1.00	1.83	0.60	1.20	0.00	0.03
	T_3	1.00	1.00	0.50	0.50	0.00	0.00
Sweden	T_1,T_2	2.08	0.00	0.05	0.00	0.02	1.00
	T_3	2.08	0.00	0.80	0.00	0.01	0.27
Western Europe	T_1,T_2	0.00	2.40	0.00	1.00	0.01	0.39
	T_3	0.00	2.40	0.00	1.00	0.10	0.30
USSR	T_1	2.26	0.10	0.05	0.05	0.01	1.25
Eastern Europe	T_1	2.18	0.10	0.05	0.01	0.01	1.21
Africa	T_1,T_2	0.00	2.30	0.00	0.01	0.01	1.28
	T_3	0.00	2.30	0.00	1.00	0.10	0.20
China	T_1	0.00	2.09	0.00	0.37	0.01	0.71
Japan	T_1,T_2	0.00	1.65	0.00	0.60	0.00	0.05
	T_3	0.00	1.65	0.00	0.60	0.00	0.05
Southeast Asia	T_1,T_2	0.00	2.30	0.00	0.01	0.01	1.28
	T_3	0.00	2.30	0.00	1.10	0.10	0.10
Australia–New Zealand	T_1,T_2	0.00	2.44	0.00	0.00	0.13	1.31
	T_3	0.00	2.44	0.00	1.10	0.00	0.34
Rest of the World	T_1,T_2	2.28	0.10	0.00	0.00	0.80	0.58
	T_3	2.18	0.10	1.00	0.00	0.01	0.27

22.3. Dynamics of the Industry Modules

The dynamics of the industrial components of the GTM are defined by changes in the model equations (22.1)–(22.4) over time. We discuss the changes for the general case in four sections: investments in productive capacity, capital depreciation, changes in technology, changes in paper recycling, and cost changes due to developments in exchange rates and inflation. Specific differences for planned economies are discussed in Chapter 26.

22.3.1. Investments in productive capacity

A number of aspects must be kept in mind while considering investment alternatives:

(1) *Profitability.* What is the return on investment?
(2) *Uncertainty.* How does profitability depend on future uncertainties concerning demand, prices, and costs?
(3) *Time preferences.* When are the profits realized?
(4) *Liquidity.* How can the investment expenditures be covered?
(5) *Economic impacts.* What are the effects on employment and GNP?
(6) *Environmental impacts.* What are the effects on air and water quality, as well as on the forest ecosystem?

For investments, we employ a very simple rule which, to a certain extent, can accommodate the above considerations. Formally stated, the rule is: capacity expansion follows the equilibrium principle; however, the capacity in a single product line cannot be increased by more than a given percentage in one time step and total investment expenditures in a region must conform to constraint (22.3). In the following we discuss this rule in detail.

Let π be a price vector in a given region for all 16 products of the GTM and let the production schedule x be determined as an optimal solution to the profit maximization problem (22.5). Note that due to alternative optimal solutions for problem (22.5), x may not be unique. Let us concentrate on one of the industrial products j (e.g., a solid wood product, white pulp, or a grade of paper), and let $i = 1$, 2, and 3 be three activities i, referring to the old, modern, and new technologies, respectively, for producing j. Thus, $x_1 + x_2 + x_3$ is the gross production of j in the region.

Table 22.3 Conversion coefficients per m^3 produced of particle board: coniferous Technologies: T_1 = old, T_2 = modern, T_3 = new capacity.

		Particle board		*White pulp*	
Region	*Technology*	*C*	*N*	*C*	*N*
Western Canada	T_1	1.18	0.40	5.70	4.72
	T_2	1.18	0.40	5.50	4.56
	T_3	1.00	0.50	5.50	4.40
Eastern Canada	T_1	1.18	0.40	5.70	4.56
	T_2	1.18	0.40	5.40	4.32
	T_3	1.00	0.50	5.20	4.16
Western US	T_1	1.00	1.16	5.80	4.64
	T_2	1.00	1.16	5.50	4.40
	T_3	1.00	0.60	5.50	4.40
Eastern US	T_1	0.50	0.67	4.05	3.60
	T_2	0.50	0.67	4.02	3.36
	T_3	0.70	0.90	4.00	3.36
Brazil	T_1	0.85	1.50	5.00	4.34
	T_2	0.85	1.50	4.00	3.80
	T_3	0.76	1.22	4.20	3.80
Chile	T_1	1.80	0.00	5.50	–
	T_2	1.80	0.00	5.30	–
	T_3	1.70	0.00	5.00	–
Rest of Latin America	T_1	1.67	0.29	4.40	3.52
	T_2	1.67	0.29	4.20	3.36
	T_3	1.60	0.30	4.20	3.36
Finland	T_1	1.17	0.20	5.20	4.16
	T_2	1.17	0.20	4.80	3.84
	T_3	1.10	0.20	4.70	3.76

We define the *supply function* of j for this region to be the optimal production quantity of j as a function of price, π_j, while keeping all other prices, π_k, $k \neq j$, constant. Such a function, of course, is defined separately for each combination of prices π_k.

An example of this production function is given in *Figure 22.1*. Quantities U_1 and U_2 refer to capacity limits for old and modern capacity, respectively. Price $\pi_j^1 = c_2$ is the level at which marginal costs for efficient capacity can be covered. At this price any production quantity x_2, such that $0 \leq x_2 \leq U_2$, is optimal for problem (22.5). In order to employ the

(C) and nonconiferous (N) pulpwood input per ton produced of C and N pulp.

		Particle board		*White pulp*	
Region	*Technology*	*C*	*N*	*C*	*N*
Sweden	T_1	1.22	0.21	5.20	4.00
	T_2	1.22	0.21	4.80	3.70
	T_3	1.22	0.21	4.65	3.72
Western Europe	T_1	0.63	0.97	4.80	3.84
	T_2	0.63	0.97	4.60	3.68
	T_3	0.78	0.79	4.50	3.60
USSR	T_1	0.63	0.61	5.17	4.14
Eastern Europe	T_1	0.71	0.61	5.17	4.14
Africa	T_1	1.80	0.10	4.50	3.60
	T_2	1.80	0.10	4.40	3.52
	T_3	1.60	0.10	4.30	3.44
China	T_1	0.42	2.13	5.17	4.14
Japan	T_1	0.34	1.40	4.70	3.76
	T_2	0.34	1.40	4.20	3.36
	T_3	0.79	0.77	4.00	3.20
Southeast Asia	T_1	0.49	2.03	4.50	3.60
	T_2	0.49	2.03	4.35	3.48
	T_3	0.44	1.65	4.20	3.36
Australia–New Zealand	T_1	0.00	1.49	5.20	4.16
	T_2	0.00	1.49	5.00	4.00
	T_3	0.70	0.70	4.80	3.84
Rest of the World	T_1	1.53	0.62	4.50	3.72
	T_2	1.53	0.62	4.30	3.44
	T_3	1.36	0.42	4.20	3.36

old capacity as well, the price has to increase to level c_1, the marginal costs of old technology. For production to increase beyond the existing capacity, the price of j should increase to c_3, the level at which all marginal costs, including capital costs, can be covered for new capacity. We indicate an upper bound U_3 for new capacity as well; its role is discussed later.

We define the *demand function*, which faces the industry in this particular region, as the quantity of product j purchased from this industry as a function of price π_j. There are four examples of demand functions in *Figure 22.1*. Such demand depends both on domestic and export demand

Table 22.4 Coniferous pulpwood input (m^3), coniferous (C) and nonconiferous (N) for newsprint and other printing paper. Technologies: T_1 = old, T_2 = modern,

		Newsprint				*Other printing paper*			
Region	*Technology*	*Pulpwood*	*C pulp*	*N pulp*	*Recycled paper*	*Pulpwood*	*C pulp*	*N pulp*	*Recycled paper*
Western Canada	T_1	2.00	0.24	0.00	0.00	0.75	0.60	0.07	0.00
	T_2	2.10	0.21	0.00	0.00	0.75	0.59	0.07	0.00
	T_3	2.20	0.11	0.00	0.00	0.80	0.58	0.06	0.00
Eastern Canada	T_1	2.38	0.18	0.00	0.00	0.75	0.34	0.34	0.00
	T_2	2.20	0.19	0.00	0.00	0.75	0.34	0.33	0.00
	T_3	2.20	0.11	0.00	0.00	0.80	0.43	0.21	0.00
Western US	T_1	1.75	0.20	0.00	0.16	0.00	0.45	0.40	0.00
	T_2	1.80	0.13	0.00	0.20	0.00	0.42	0.38	0.00
	T_3	1.80	0.13	0.00	0.20	0.20	0.36	0.36	0.00
Eastern US	T_1	1.00	0.13	0.00	0.52	0.15	0.25	0.44	0.11
	T_2	1.71	0.20	0.00	0.07	0.22	0.24	0.43	0.10
	T_3	1.60	0.25	0.00	0.10	0.35	0.30	0.30	0.10
Brazil	T_1	2.00	0.11	0.11	0.00	0.30	0.04	0.70	0.00
	T_2	2.00	0.09	0.09	0.00	0.30	0.04	0.69	0.00
	T_3	2.00	0.17	0.00	0.00	0.30	0.07	0.66	0.00
Chile	T_1	2.20	0.24	0.00	0.00	1.24	0.60	0.00	0.00
	T_2	2.20	0.21	0.00	0.00	1.76	0.40	0.00	0.00
	T_3	2.00	0.20	0.00	0.00	1.81	0.38	0.00	0.00
Rest of Latin America	T_1	1.80	0.28	0.00	0.00	0.00	0.39	0.30	0.45
	T_2	2.00	0.25	0.00	0.00	0.00	0.39	0.30	0.45
	T_3	2.00	0.20	0.00	0.00	0.00	0.44	0.26	0.30
Finland	T_1	2.14	0.19	0.00	0.00	1.10	0.20	0.16	0.00
	T_2	2.18	0.14	0.00	0.00	1.10	0.19	0.16	0.00
	T_3	2.20	0.10	0.00	0.00	1.20	0.22	0.10	0.00

and, furthermore, the former depends on the domestic demand function and on import supply. Note, however, that only the domestic demand functions are explicit; the rest are implicit in the model.

Assume now that the prices $\pi_k = \pi_k^e$, for $k \neq j$, are equilibrium prices for four examples of equilibria, $e = 1,\ldots,4$, and that $D^1,\ldots,D^4$ are the corresponding demand functions. The four equilibrium prices, π_j^e, are then defined by intersections of supply and demand curves. For $e = 1$, demand is poor and even the efficient capacity is partially underutilized. For $e = 2$, the demand is high enough to employ all the existing capacity, but the white pulp input (ton), and recycled paper input (ton) per ton produced of paper T_3 = new capacity.

		Newsprint				*Other printing paper*			
Region	*Technology*	*Pulpwood*	*C pulp*	*N pulp*	*Recycled paper*	*Pulpwood*	*C pulp*	*N pulp*	*Recycled paper*
Sweden	T_1	1.69	0.22	0.00	0.16	0.80	0.31	0.25	0.00
	T_2	1.94	0.15	0.00	0.09	0.00	0.38	0.46	0.00
	T_3	2.00	0.12	0.00	0.10	0.70	0.21	0.14	0.00
Western Europe	T_1	1.56	0.21	0.00	0.20	0.58	0.34	0.32	0.04
	T_2	1.63	0.16	0.00	0.18	0.51	0.34	0.32	0.05
	T_3	1.60	0.21	0.00	0.25	0.50	0.22	0.28	0.10
USSR	T_1	1.86	0.10	0.00	0.14	0.47	0.41	0.10	0.20
Eastern Europe	T_1	1.86	0.19	0.00	0.20	0.34	0.30	0.32	0.21
Africa	T_1	2.10	0.19	0.00	0.00	0.30	0.19	0.45	0.17
	T_2	2.10	0.17	0.00	0.00	0.30	0.19	0.45	0.15
	T_3	2.10	0.16	0.00	0.00	0.30	0.19	0.45	0.15
Japan	T_1	1.50	0.20	0.00	0.23	0.00	0.12	0.68	0.15
	T_2	1.55	0.18	0.00	0.23	0.35	0.10	0.60	0.10
	T_3	1.62	0.12	0.00	0.25	0.20	0.15	0.45	0.15
Southeast Asia	T_1	2.30	0.17	0.00	0.00	0.00	0.26	0.26	0.42
	T_2	2.30	0.17	0.00	0.00	0.00	0.26	0.26	0.40
	T_3	2.20	0.17	0.00	0.00	0.00	0.26	0.26	0.40
Australia–New Zealand	T_1	2.20	0.18	0.00	0.00	0.00	0.36	0.36	0.11
	T_2	2.20	0.17	0.00	0.00	0.00	0.38	0.38	0.08
	T_3	2.20	0.15	0.00	0.00	0.00	0.37	0.37	0.10
Rest of the World	T_1	2.30	0.11	0.00	0.10	0.00	0.18	0.45	0.42
	T_2	2.30	0.11	0.00	0.10	0.00	0.18	0.45	0.40
	T_3	2.30	0.11	0.00	0.10	0.00	0.18	0.45	0.40

price would not cover all the costs of the new capacity, so that new investments are not profitable. For $e = 3$, an investment for increasing capacity by $x_3 = x_3^3$ is needed to match the demand, and for $e = 4$, demand is so strong that even all the existing capacity and allowed new capacity is insufficient. Capacity expansion in this case is $x_3^4 = U_3$. Finally, note that the constraint (22.3) on the investment budget does not appear in this example; for this illustration it is assumed to be nonbinding.

Next, we discuss how this approach can deal with the investment criterion mentioned above. First, taking into account that normal profit, i.e.,

Table 22.5 Pulpwood (m^3), coniferous (C) and nonconiferous (N) pulp (ton), and recycled paper (ton) inputs per ton produced of paper for household and sanitary paper and for packaging paper and board. Technologies: T_1 = old, T_2 = modern, T_3 = new capacity.

		Household and sanitary paper				*Packaging paper and board*				
Region	*Technology*	*Pulpwood(C)*	*C pulp*	*N pulp*	*Recycled paper*	*Pulpwood(C)*	*Pulpwood(N)*	*C pulp*	*N pulp*	*Recycled paper*
Western Canada	T_1	0.00	0.95	0.11	0.00	1.45	0.26	0.23	0.01	0.53
	T_2	0.00	0.95	0.11	0.00	1.70	0.30	0.29	0.02	0.42
	T_3	0.00	0.94	0.10	0.00	1.87	0.33	0.29	0.02	0.29
Eastern Canada	T_1	0.00	0.95	0.11	0.00	1.45	0.26	0.23	0.01	0.58
	T_2	0.00	0.95	0.11	0.00	1.70	0.30	0.29	0.02	0.47
	T_3	0.00	0.94	0.10	0.00	1.87	0.33	0.29	0.02	0.29
Western US	T_1	0.10	0.59	0.11	0.32	3.50	0.04	0.09	0.01	0.28
	T_2	0.25	0.53	0.09	0.32	3.40	0.04	0.09	0.01	0.20
	T_3	0.30	0.51	0.09	0.35	2.20	0.50	0.09	0.01	0.20
Eastern US	T_1	0.15	0.56	0.11	0.30	1.67	0.35	0.10	0.01	0.31
	T_2	0.30	0.53	0.09	0.30	1.57	0.34	0.11	0.01	0.29
	T_3	0.30	0.51	0.09	0.35	1.74	0.31	0.17	0.01	0.29
Brazil	T_1	0.00	0.11	0.60	0.33	1.95	0.49	0.02	0.17	0.47
	T_2	0.00	0.11	0.60	0.30	1.95	0.49	0.02	0.17	0.47
	T_3	0.00	0.21	0.49	0.30	1.57	0.28	0.04	0.08	0.45
Chile	T_1	1.08	0.50	0.00	0.16	0.46	0.00	0.52	0.00	0.33
	T_2	1.11	0.48	0.00	0.16	0.43	0.00	0.46	0.00	0.40
	T_3	1.05	0.45	0.00	0.20	0.51	0.00	0.33	0.00	0.50
Rest of Latin America	T_1	0.00	0.60	0.00	0.55	1.50	0.70	0.00	0.00	0.80
	T_2	0.00	0.60	0.00	0.50	1.50	0.70	0.00	0.00	0.67
	T_3	0.00	0.56	0.00	0.50	1.50	0.70	0.00	0.00	0.60

Finland	T_1	0.35	0.73	0.18	0.00	2.81	0.50	0.11	0.07	0.08
	T_2	0.35	0.73	0.18	0.00	2.63	0.47	0.13	0.08	0.10
	T_3	0.00	0.64	0.16	0.25	2.50	0.47	0.09	0.04	0.10
Sweden	T_1	0.30	0.60	0.00	0.30	2.38	0.30	0.20	0.04	0.20
	T_2	0.30	0.60	0.00	0.30	2.63	0.35	0.14	0.02	0.14
	T_3	0.00	0.86	0.00	0.20	2.38	0.42	0.12	0.03	0.20
Western Europe	T_1	0.00	0.69	0.09	0.37	0.51	0.09	0.09	0.03	0.73
	T_2	0.00	0.69	0.09	0.34	0.50	0.09	0.09	0.03	0.71
	T_3	0.00	0.55	0.10	0.34	0.48	0.09	0.06	0.01	0.83
USSR	T_1	0.13	0.31	0.31	0.23	1.51	0.21	0.09	0.02	0.30
Eastern Europe	T_1	0.13	0.60	0.13	0.33	1.59	0.21	0.31	0.04	0.24
Africa	T_1	0.00	0.68	0.17	0.22	1.70	0.30	0.07	0.00	0.47
	T_2	0.00	0.68	0.17	0.20	1.70	0.30	0.07	0.00	0.45
	T_3	0.00	0.68	0.17	0.20	1.70	0.30	0.07	0.00	0.45
China	T_1	0.13	0.60	0.13	0.33	1.51	0.21	0.09	0.02	0.50
Japan	T_1	0.00	0.36	0.24	0.42	0.94	0.17	0.05	0.10	0.62
	T_2	0.00	0.36	0.24	0.40	1.36	0.24	0.06	0.10	0.46
	T_3	0.00	0.36	0.24	0.40	1.36	0.24	0.07	0.10	0.54
Southeast Asia	T_1	0.00	0.72	0.00	0.33	1.02	0.18	0.10	0.00	0.72
	T_2	0.00	0.72	0.00	0.30	1.02	0.18	0.10	0.00	0.70
	T_3	0.00	0.72	0.00	0.30	1.02	0.18	0.10	0.00	0.70
Australia–New Zealand	T_1	0.00	0.77	0.09	0.23	1.41	0.39	0.05	0.00	0.52
	T_2	0.00	0.77	0.09	0.20	1.41	0.39	0.05	0.00	0.52
	T_3	0.00	0.77	0.09	0.20	1.41	0.39	0.05	0.00	0.52
Rest of the World	T_1	0.00	0.42	0.14	0.52	0.51	0.21	0.13	0.00	0.72
	T_2	0.00	0.42	0.14	0.50	0.60	0.22	0.12	0.00	0.70
	T_3	0.00	0.42	0.14	0.50	0.60	0.20	0.12	0.00	0.70

Table 22.6 Paper recycling (10^6 ton) and recovery rate (%) in 1980.

Region	*Recycled paper consumption*	*Recovery rate*
Canada	1.2	27
US	16.2	27
Brazil	1.1	33
Chile	0.2	48
Rest of Latin America	1.9	32
Finland	0.2	22
Sweden	0.7	45
Western Europe	12.6	32
USSR	2.2	24
Eastern Europe	1.3	27
Africa	1.1	37
China	1.0	22
Japan	7.9	45
Southeast Asia	0.5	23
Australia–New Zealand	0.8	32
Rest of the World	1.7	28

Table 22.7 Investment expenditure (10^6 \$) per capacity expansion of 10^6 m^3/year for sawnwood, veneer and plywood, and particle board production in 1980.

Region	*Sawnwood*	*Veneer and plywood*	*Particle board*
Western Canada	245	533	490
Eastern Canada	245	565	480
Western US	260	533	488
Eastern US	260	565	482
Brazil	200	546	490
Chile	200	546	490
Rest of Latin America	200	585	600
Finland	185	650	600
Sweden	230	650	600
Western Europe	250	728	650
Africa	200	750	600
Japan	230	715	630
Southeast Asia	200	520	600
Australia–New Zealand	200	650	600
Rest of the World	200	585	600

Table 22.8 Investment expenditure (10^6 \$) for capacity expansion (10^6 ton/year) for pulp and paper production in 1980.

	White pulp					
Region	*Coniferous*	*Nonconiferous*	*Newsprint*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
Western Canada	1100	1100	1100	1300	1300	1150
Eastern Canada	1100	1100	1100	1300	1300	1150
Western US	1000	1000	1000	1200	1200	1060
Eastern US	1000	1000	1000	1200	1200	1060
Brazil	1300	1300	1200	1400	1400	1250
Chile	1300	1300	1200	1400	1400	1250
Rest of Latin America	1300	1300	1200	1400	1400	1250
Finland	1000	1000	1000	1200	1200	1060
Sweden	1000	1000	1000	1200	1200	1060
Western Europe	1000	1000	1000	1200	1200	1060
Africa	1300	1300	1200	1400	1400	1250
Japan	1200	1200	1050	1200	1200	1100
Southeast Asia	1400	1400	1200	1300	1400	1300
Australia–New Zealand	1100	1100	1100	1300	1300	1200
Rest of the World	1400	1400	1200	1500	1400	1300

Table 22.9 Marginal costs (\$/m^3), other than timber, for sawmilling and panels production in 1980 for old and modern technologies.

	Sawnwood			
Region	*Coniferous*	*Nonconiferous*	*Veneer and plywood*	*Particle board*
Western Canada	65	70	264	100
Eastern Canada	65	70	264	100
Western US	53	70	220	81
Eastern US	50	47	220	81
Brazil	65	70	206	100
Chile	65	70	250	125
Rest of Latin America	65	70	203	100
Finland	60	75	250	100
Sweden	65	70	250	100
Western Europe	65	70	230	100
Africa	65	70	156	100
Japan	65	70	242	100
Southeast Asia	65	70	194	100
Australia–New Zealand	65	70	212	100
Rest of the World	65	70	239	100

Table 22.10 Marginal costs ($/ton), other than pulpwood and wood pulp, for coniferous (C) and nonconiferous (N) pulp and paper in 1980. Technologies: T_1 = old, T_2 = modern.

Region	*Tech-nology*	*White pulp* *C*	*White pulp* *N*	*News-print*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
Western Canada	T_1	200	200	157	280	350	210
	T_2	150	150	148	240	320	140
Eastern Canada	T_1	230	230	170	280	350	240
	T_2	185	185	155	230	325	150
Western US	T_1	240	240	222	320	400	220
	T_2	180	180	173	270	360	170
Eastern US	T_1	210	210	210	330	400	210
	T_2	170	170	180	260	360	155
Brazil	T_1	180	180	290	340	490	250
	T_2	160	160	250	320	460	220
Chile	T_1	190	190	300	320	490	260
	T_2	150	150	270	290	460	220
Rest of Latin America	T_1	210	210	300	320	490	260
	T_2	180	180	270	290	460	220
Finland	T_1	240	240	265	310	490	240
	T_2	160	160	229	282	390	180
Sweden	T_1	250	250	313	375	525	270
	T_2	175	175	260	340	455	200
Western Europe	T_1	280	280	295	415	410	285
	T_2	180	180	238	350	390	255
Africa	T_1	200	200	260	300	500	250
	T_2	150	150	230	280	450	220
Japan	T_1	240	240	250	320	450	230
	T_2	170	170	220	300	400	215
Southeast Asia	T_1	280	280	350	320	500	240
	T_2	200	200	260	290	460	210
Australia–New Zealand	T_1	250	250	220	300	400	220
	T_2	180	180	180	270	350	200
Rest of the World	T_1	280	280	300	320	500	280
	T_2	240	240	230	290	460	250

Table 22.11 Production capacity (10^6 m^3/year) for sawmilling and panel production in 1980.

Region	*Sawnwood*	*Veneer and plywood*	*Particle board*
Western Canada	28.7	1.8	1.3
Eastern Canada	15.6	1.0	0.7
Western US	33.1	7.9	3.0
Eastern US	36.7	8.6	8.4
Brazil	14.9	1.2	1.5
Chile	3.1	0.1	0.2
Rest of Latin America	8.7	0.8	0.9
Finland	10.3	0.7	1.1
Sweden	11.3	0.1	1.8
Western Europe	42.4	2.8	19.0
USSR	98.2	2.5	8.1
Eastern Europe	26.4	1.6	7.7
Africa	7.7	0.8	0.5
China	21.2	1.6	0.6
Japan	37.0	8.3	2.0
Southeast Asia	12.0	3.1	0.1
Australia–New Zealand	5.5	0.2	1.0
Rest of the World	22.6	2.6	0.9

an average return on investment for the entire economy, is included in the capital costs, profitability is required for a five-year interval corresponding to the time step of investment. In fact, an excess of profit may be created in situations such as equilibrium $e = 4$, in *Figure 22.1*, or in situations where the shadow price of capital constraint (22.3) exceeds the normal rate of interest. In principle, it is also possible that our rule creates overcapacity for future five-year periods. Consequently, future profitability may not be guaranteed. However, given a relatively smooth and increasing development in five-year averages of prices and demand for forest products and given that some of the old capacity is closed down (see below), overcapacity is unlikely to result from our investment rule. We must caution, however, that profitability may also be lost by changes in relative production costs among producers worldwide.

An additional way of justifying our approach is to assume a high discounting factor that accounts for time preference. As a result, profits carried more than five years into the future would have a relatively low weight among investment criteria.

Table 22.12 Production capacity (10^6 ton/year) for pulp and paper in 1980. Technologies: T_1 = old, T_2 = modern.

Region	*Technology*	*White pulp*	*Newsprint*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
Western Canada	T_1	1.6	0.1	0.1	0.0	0.4
	T_2	3.7	1.1	0.1	0.0	0.2
Eastern Canada	T_1	3.1	3.9	1.0	0.2	1.7
	T_2	2.1	3.6	0.3	0.1	0.6
Western US	T_1	1.4	0.3	0.9	0.5	3.7
	T_2	0.5	1.0	0.2	0.2	1.2
Eastern US	T_1	11.0	0.5	8.5	2.4	22.5
	T_2	4.1	2.4	4.6	0.8	7.5
Brazil	T_1	0.4	0.1	0.4	0.1	1.6
	T_2	1.3	0.1	0.4	0.1	0.5
Chile	T_1	0.2	0.1	0.0	0.0	0.2
	T_2	0.6	0.1	0.0	0.0	0.1
Rest of Latin America	T_1	0.2	0.1	0.6	0.3	1.9
	T_2	0.1	0.1	0.4	0.2	0.5
Finland	T_1	0.6	0.4	0.5	0.0	1.4
	T_2	2.7	1.2	1.5	0.1	0.8
Sweden	T_1	0.8	0.2	0.7	0.1	2.1
	T_2	3.3	1.4	0.3	0.1	1.4
Western Europe	T_1	2.6	1.3	6.7	1.1	12.6
	T_2	1.2	1.6	4.5	0.7	3.2
USSR	T_1	2.6	1.5	3.8	0.2	3.5
Eastern Europe	T_1	1.7	0.4	1.0	0.3	3.8
Africa	T_1	0.2	0.1	0.1	0.0	0.6
	T_2	0.2	0.2	0.2	0.0	0.3
China	T_1	1.5	1.0	2.6	0.1	0.0
Japan	T_1	1.4	1.1	2.5	0.4	7.3
	T_2	3.1	1.6	1.7	0.4	3.1
Southeast Asia	T_1	0.0	0.0	0.2	0.0	0.3
	T_2	0.0	0.1	0.1	0.0	0.2
Australia–New Zealand	T_1	0.1	0.2	0.2	0.1	0.8
	T_2	0.2	0.3	0.1	0.0	0.4
Rest of the World	T_1	0.2	0.3	1.0	0.1	1.3
	T_2	0.2	0.1	0.7	0.0	0.6

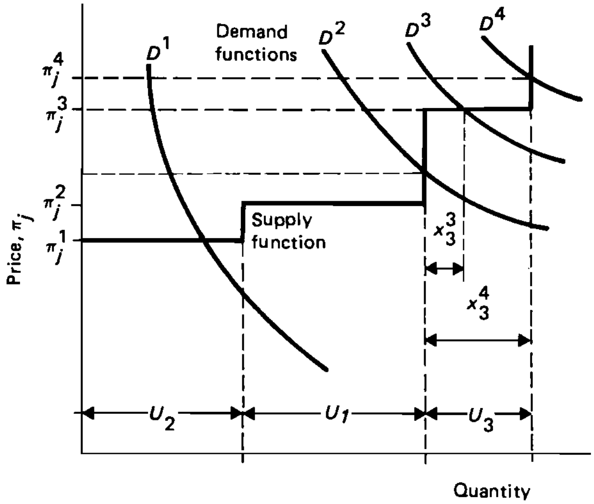

Figure 22.1 An example of a supply function.

For hedging uncertainty, a common approach is that of the optimal portfolio, according to which one allocates capital for risky investment alternatives in such a way that the expected return is high and the variance of return is low. There is a certain analogy to this in our approach of having limits on relative growth in capacity for each production line separately. This prevents too large a share of the capital budget B in constraint (22.3) from being allocated to a single product, even if this product shows the highest return in the model. A maximum of approximately 12% capacity increase annually was allowed for each product in the scenario runs of Part VI.

The liquidity requirement is partly satisfied by the profitability requirement: a healthy industry generates capital for investment. However, because of the growth of the industry, profits alone may not generate adequate financing for investments and, therefore, external capital is needed. Assuming a perfect capital market, one might expect that forest industries, having a relatively small share of the entire economy, could acquire external financing as long as the normal rate of return could be covered. However, owing to imperfections in the capital markets and to the fact that risk aversion in the industry tends to keep the debt–equity ratio low, we restrict external financing in the model by investment constraint (22.3).

To a certain extent, the profitability criterion is in harmony with other economic criteria. However, with slight modifications one may deal directly or indirectly with other criteria as well. For example, if the direct contribution to GNP were the criterion, one would leave out costs, such as labor, that are concerned with the intraregional distribution of income only. As another example, if employment is a concern in regional economic policy, one might deduct a subsidy from the cost coefficients, c_i, in order to make investment in the region possible. (The same, of course, applies to existing capacity that would remain underutilized without a subsidy.) Similarly, one might apply a tax in order to account for the trade-off between environmental criteria and economic benefits. Sustainability of the forest ecosystem is accommodated by the forestry model of Chapter 21.

The investment budget is determined as a share of the value of forest industrial production. More specifically, budget B in constraint (22.3) is calculated as a percentage, given in *Table 22.13*, of the total value of production in the preceding time step. A single budget constraint is applied to countries that are represented by more than one region in the GTM (i.e., Canada and the US). For the planned economies, no capital budget constraints are made explicit in the GTM, but they are presumably implicit in the production plans.

Table 22.13 Percentages that determine the capital available for investments over a five-year period as a share of the value of annual production during the previous period. Relatively high values for developing regions were applied in order to allow rapid development, given that the economic potential exists.

Region	(%)	*Region*	(%)
Canada	15	Western Europe	10
US	15	Africa	25
Brazil	25	Japan	15
Chile	25	Southeast Asia	25
Rest of Latin America	25	Australia–New Zealand	15
Finland	10	Rest of the World	25
Sweden	10		

Finally, a comment on delays that may occur in the investment process is needed. It is assumed that capacity expansion in a given time step is available for production purposes from the beginning of this five-year period. Therefore, the decision for such an expansion is assumed to have taken place during the preceding time steps. The delay between the investment decision and the start of production can be several years.

22.3.2. Aging of productive capacity

A simple Markov chain, illustrated in *Figure 22.2*, characterizes the life-cycle of production capacity. In the current time step, all investments comprise the "new" capacity category and all this capacity is moved into the "modern" category at the beginning of the subsequent step. A share α of the "modern" technology is moved into the "old" category in the next step. The remaining share $(1 - \alpha)$ stays "modern". Similarly, a share β of the "old" capacity is closed down before the next time step. The remaining share $(1 - \beta)$ stays in the "old" category.

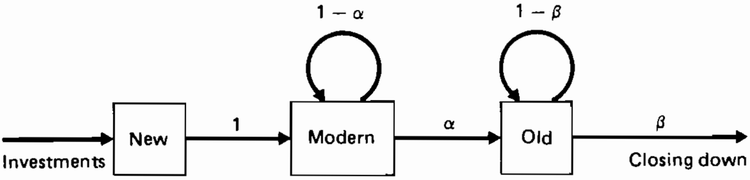

Figure 22.2 Transfer of capacity in the three technology categories between subsequent time steps.

According to this rule, the expected lifetime of capacity is $(1 + 1/\alpha + 1/\beta)$ time steps. In the scenarios of Part VI, we used $\alpha = 1/2$ and $\beta = 1/3$ for all capacity. Given that a step length is five years, the expected capacity lifetime is 30 years. Recall from Section 22.2 that maintenance investments were assumed to be included in production costs. This partly justifies this rather long lifetime.

Note that the rate β for closing down old capacity is independent of the capacity utilization ratio. It would, of course, be a simple modification to establish such an interdependence.

Given that investment decisions have been made, but not yet implemented for the base year, we may set lower bounds on investment activities to ensure that the model will automatically implement the committed expansion. For example, the FAO pulp and paper capacity survey was used to estimate the 1985 capacity for a number of regions. The investments required, given our depreciation rule above, are indicated in *Table 22.14*.

Table 22.14 Requirements for new capacity in the time step 1985 (10^6 ton/year), given base year 1980 capacity, the FAO capacity estimate for 1985, and the depreciation rule adopted in the GTM.

Region	*White pulp*	*News-print*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
US	7.8	1.1	6.5	1.8	14.1
Canada	1.7	2.1	1.1	0.2	1.1
Brazil	0.7	0.2	0.5	0.1	1.4
Finland	0.4	0.4	1.5	0.0	0.5
Sweden	0.5	0.3	0.7	0.1	0.9
Western Europe	1.6	1.3	5.1	1.1	8.8
Japan	0.7	0.7	2.6	0.4	5.6

22.3.3. Technological development

We start the discussion on technological adjustments by considering principles for updating parameters for modern and old capacity. Given that the capacity in these two categories at a specified time step is a mixture of technologies in the previous step, we update the marginal costs, excluding capital costs, and the conversion factors accordingly: the new coefficients are then the weighted averages of the previous ones and the weights are the shares of capacity that enter from each of the previous technology categories. For example, if in period t 20% of modern capacity originated from investments in period $(t-1)$ and 80% from capacity already classified as modern in period $(t-1)$, then the weights are 0.2 for new capacity and 0.8 for modern capacity coefficients in the preceding step.

A general principle adopted in the GTM for the development of new technologies (i.e., technology entering through investment) is the notion that, in the long term, technologies in all the regions will tend to become equally efficient. To be more precise, it is assumed that in 2030, for each product, the net input per unit of product of logs, pulpwood, fuelwood, white pulp, and recycled paper, for each input separately, will be the same in all regions. Furthermore, the loss factor is assumed to vanish by 2030 for all products. Conversion coefficients for 2030 used in the scenario runs of Part VI are given in *Table 22.15*. Between 1980 and 2030 the coefficients change from those in *Tables 22.1-22.5* to those in *Table 22.15* by linear interpolation. The pulp and paper coefficients were obtained from an informal survey at Jaakko Põyry Oy. For solid wood products, the figures are based on the distribution of these coefficients in the base-year data. Given

Table 22.15 Assumed long-term effects of technologies for scenario runs of Part VI.

	Inputs (m^3/m^3, m^3/ton, ton/ton)[a]			
Products	*Logs*	*Pulpwood*	*White pulp*	*Recycled paper*
Coniferous sawnwood	1.5			
Nonconiferous sawnwood	1.7			
Veneers and plywood	1.8			
Particle board		1.4		
Coniferous pulp		4.0		
Newsprint		1.2	0.1	0.5
Printing and writing paper		0.4	0.5	0.2
Household and sanitary paper		0.6	0.3	0.6
Packaging paper and board		1.5	0.1	0.6

[a] Timber input and solid wood product output are in cubic meters. The rest are in metric tons.

the large variation over regions in 1980, the resultant coefficients for 2030, such as the log input of 1.5 m^3 per m^3 of coniferous sawnwood, may be seen as small for some regions.

Furthermore, it was assumed that the shares of coniferous and nonconiferous logs in veneer and plywood inputs remain constant over time. This reflects the fact that there are regional differences in the shares of coniferous and nonconiferous log supplies.

Basically, the same idea is also employed for pulpwood and white pulp inputs. We first calculate the pulpwood and pulp input coefficients based on the principle of constant shares for coniferous and nonconiferous inputs. However, in addition to this, the resultant parameters are modified by a factor that shifts a given share of coniferous input into nonconiferous input. This factor is independent of region and product, but dependent on the time step. For the scenarios of Part VI, we let this factor increase linearly from 0% to 30% over the period 1980–2030. The rationale of using this shift parameter is to adapt to the foreseen shortage of coniferous pulpwood relative to nonconiferous pulpwood.

Finally, we note that there is room for further development of the model to accommodate technological change in a more sophisticated way. An obvious next step would be to make the conversion coefficients price-responsive, while taking into account the engineering constraints on production technologies. This, in turn, can be achieved, for example, by means of additional, alternative production activities in the model. Changes in labor productivity, improving efficiency in energy use, and increasing nonwood furnishing for paper are also missing in the current model version.

22.3.4. Changes in recycled paper

For the base year 1980, the recovery rate for paper recycling is given in *Table 22.6*. For further development of this share, in the current version of the GTM, we assume that by 2030 the recovery rate for all regions converges to 50%, and, second, between 1980 and 2030 the rate is obtained by linear interpolation.

22.3.5. The impact of exchange rates and inflation

The impact on production costs of timber and wood fiber inputs is endogenous to the model, whereas other cost factors have to be updated exogenously. Currently, we account for relative changes in real exchange rates between local currencies and the US dollar and for the changing composition of technologies in modern and old technology categories (as described above). Note that other economic factors, such as changes in labor costs (due to increasing real-wage rates) and changes in energy price, are not explicitly considered in the current model version. Given estimates of changes in real wage rates and energy prices, the implementation of these factors would, of course, be simple.

We discuss now the exchange rate issue in more detail. In a given region, let ϵ be the relative increase of the US dollar value in nominal terms (i.e., not eliminating inflation), from the base year 1980 until a given point in time. For example, in 1980 one US dollar was worth 4.20 Skr (Swedish krona) and in 1985, one US dollar would buy 8.65 Skr, then $\epsilon = 8.65/4.20 = 2.06$. From the difference in exchange rates alone, Swedish production costs therefore declined during this period by a factor of 2.06 compared with US production costs. During the same period, however, the inflation rate was higher in Sweden than in the US, which offset some of the apparent reduction in Swedish production costs.

In order to eliminate the effect of differences in inflation, let λ be the price index in a given region divided by the US price index at a given point in time. Furthermore, define the price indices so that $\lambda = 1$ for the base year 1980. Then, we define the *index of real exchange rate* ρ as follows:

$$\rho = \lambda/\epsilon \tag{22.7}$$

If $\rho < 1$, then the region has gained in cost competitiveness relative to the US since the base year and, if $\rho > 1$, it has lost. In 1985 in Sweden, for

Table 22.16 The index ρ of real exchange rate in 1985 relative to 1980.

Region	ρ	*Region*	ρ
US	1.00	Western Europe	0.65
Canada	0.95	Africa	0.70
Brazil	0.70	Japan	0.71
Chile	0.70	Southeast Asia	0.70
Rest of Latin America	0.70	Australia-New Zealand	0.80
Finland	0.65	Rest of the World	0.70
Sweden	0.63		

example, according to the OECD producers' price index, $\lambda = 1.3$. Thus, $\rho = 1.3/2.06 = 0.63$, i.e., accounting for changes in both exchange rate and inflation, Swedish costs measured in US dollars declined by 37% between 1980 and 1985, the US costs remaining the same. All production costs, excluding capital costs, are scaled by the index of real exchange rate. The 1985 figures for ρ used in the base scenario are given in *Table 22.16.* Values of ρ used in various scenarios described in Part VI are specified in Chapter 27.

CHAPTER 23

Demand Functions for Forest Products

M. Kallio and S. Wibe

The purpose of this chapter is to discuss how the demand functions are dealt with in the GTM. A demand function is specified by time step, region, and final product, i.e., for sawnwood (coniferous and nonconiferous), for panels (veneer and plywood, and particle board), and for different grades of paper.

In the present version of the GTM, a demand function for a given time step, region, and final product may be specified as follows:

$$c/\bar{c} = (\pi/\bar{\pi})^{\beta} \tag{23.1}$$

where c and π are the annual consumption and the price, respectively, parameters $\bar{c}$ and $\bar{\pi}$ are the *reference consumption* and the *reference price* levels, respectively, and $\beta \leq 0$ is the *price elasticity* parameter. For notational convenience, indices referring to region, product, and time step are suppressed.

An example of such a demand function is given in *Figure 23.1*. We call the point where $c = \bar{c}$ and $\pi = \bar{\pi}$ the *reference point*. Note that at this point the slope of the curve $c/\bar{c}$ as a function of $\pi/\bar{\pi}$ is equal to price elasticity, β, and the linear approximation of the demand function at the reference point is:

$$c/\bar{c} = (1 - \beta) + \beta(\pi/\bar{\pi}) \tag{23.2}$$

This approximation may also be employed in the GTM. Notice that equation (23.1) has a constant price elasticity of demand, equal to β for all

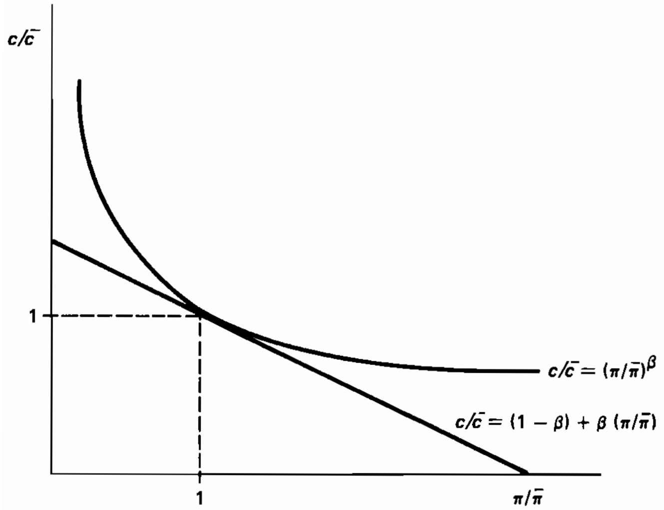

Figure 23.1 An example of a final-product demand function, as used in the GTM.

price levels. The linear approximation, on the other hand, has the property that price elasticity increases along with price and is equal to β at the reference point. The linear form thus possesses the attractive property that substitution tends to increase as the price level increases.

In a more general demand function (see Chapter 20), consumption of product j depends on price π_j *and* on prices π_k of some other forest products k. Such a demand function would be particularly suitable for taking into account substitution among different mechanical wood products (e.g., between plywood and composition-board panels). However, this form is not implemented in the current version of the GTM. For a discussion of the implementation of productwise, interdependent demand functions see Chapter 20.

The evolution of demand functions over time is a complicated matter. Given that forest products are primarily consumed by other producing sectors of the economy, such as the construction and information sectors, one might start analyzing the demand of forest products by studying what happens in such nonforest sectors. Factors to be considered in such an analysis are the volume of output in these sectors and the share of various forest products among all inputs, given technological change and changes in relative prices between forest products and their substitutes.

Such an approach was considered for the GTM (see, e.g., Chapter 10). However, due primarily to lack of data and time, we were restricted to a very simple approach for updating demand functions over time. This approach is based on the assumption that demand curves for forest products shift over time as a result of economic growth, population growth, and technological developments. The current methodology used in the GTM is not, however, rigidly built into the model and can be easily replaced by another methodology if desired. The primary requirement is that the demand functions for each region, product, and time step must depend only on the price of that product in that region at that time step.

23.1. Demand Functions for the Base Year

For the base year 1980, consumption figures according to FAO statistics were used as reference consumption levels $\bar{c}$ (see *Table 23.1*). Our best available estimates for export free on board (FOB) or import cost, insurance, and freight (CIF) prices for 1980 are used as reference prices (*Table 23.2*). Note that these figures have to be interpreted very carefully, because for each product, on the one hand, there are vast quality differences in imports and exports between various regions, and on the other, the GTM only recognizes a single "representative" quality per product for all regions.

Price elasticities, β, are assumed to depend on the product and on the income per capita in the region. The values for β, given in *Table 23.3* are used in the scenarios described in Part VI (for all regions except the USSR and Eastern Europe) and are based on the analysis of Wibe (1984) and on additional analyses summarized in Chapters 12 and 13.

For fuelwood there is a slight modification to the general forms (23.1) and (23.2) of the demand functions. If the price of fuelwood falls to a given level, determined by the prices of alternative energy sources, then there is an unlimited demand at this price. Such lower bounds on fuelwood prices were set at 10–15 $\$/\mathrm{m}^3$, depending on the region.

The linearized versions, equation (23.2), of the demand functions, based on data in *Tables 23.1–23.3*, were used for all regions in 1980, except for the USSR and Eastern Europe. A different type of demand model was used for these two centrally planned regions, which is discussed in Chapter 26.

Table 23.1 *Reference consumption* levels, $\bar{c}$, of fuelwood (10^6 m^3), solid wood products (10^6 m^3), and paper (10^6 ton) in 1980.

Region	*Fuel-wood*	*Coniferous sawnwood*	*Non-coniferous sawnwood*	*Veneer and plywood*	*Particle board*	*Newsprint*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
Western Canada	3.5	7.2	0.1	0.4	0.3	0.1	0.1	0.1	0.4
Eastern Canada	1.6	13.5	1.0	1.7	1.4	0.6	0.9	0.3	2.0
Western US	17.6	9.9	2.9	2.6	1.9	1.8	2.3	0.6	5.1
Eastern US	19.2	54.1	15.4	14.1	9.8	8.8	12.3	3.3	26.5
Brazil	152.0	2.3	9.3	0.6	1.2	0.3	0.8	0.2	2.0
Chile	1.5	0.5	0.1	0.0	0.0	0.1	0.1	0.0	0.2
Rest of Latin America	77.9	3.4	5.8	0.9	1.0	0.9	1.3	0.5	3.4
Finland	2.7	1.4	0.1	0.1	0.6	0.2	0.2	0.0	0.6
Sweden	4.4	5.4	0.0	0.2	1.1	0.2	0.4	0.1	0.7
Western Europe	26.7	51.6	16.4	5.0	29.6	5.3	11.9	1.9	19.8
USSR	77.9	79.9	12.3	2.4	7.6	1.4	4.1	0.2	3.7
Eastern Europe	14.9	18.0	6.8	1.3	6.6	0.3	0.9	0.2	3.4
Africa	383.8	4.8	6.3	1.0	0.8	0.3	0.8	0.1	1.6
China	156.6	13.3	7.9	1.6	0.6	1.1	2.6	0.1	0.7
Japan	0.6	35.1	7.6	8.5	2.1	2.7	3.9	0.9	10.3
Southeast Asia	176.0	0.0	7.3	1.9	0.1	0.5	0.5	0.1	1.0
Australia–New Zealand	1.5	3.2	2.5	0.2	0.9	0.7	0.5	0.2	1.2
Rest of the World	356.8	10.2	15.9	2.2	1.0	1.0	2.2	0.2	2.7

23.2. Updating the Demand Functions over Time

In our approach, demand functions shift over time in response to changes in three factors:

(1) Income per capita.
(2) Population.
(3) Technological trend.

Table 23.2 Reference prices, $\bar{\pi}$, for solid wood products (\$/m^3) and for paper (\$/ton) in 1980.

Region	*Coniferous sawnwood*	*Non-coniferous sawnwood*	*Veneer and plywood*	*Particle board*	*Newsprint*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
Western Canada	165	150	435	180	400	710	780	430
Eastern Canada	165	150	410	180	400	710	780	430
Western US	160	145	430	188	430	730	780	430
Eastern US	160	145	410	182	430	730	780	430
Brazil	200	200	420	190	425	700	780	450
Chile	110	250	425	180	425	700	780	450
Rest of Latin America	200	200	420	190	425	710	780	450
Finland	195	200	470	200	450	760	830	550
Sweden	210	200	490	200	480	800	830	560
Western Europe	220	220	500	230	500	845	850	580
USSR	180	180	500	200	480	760	850	500
Eastern Europe	180	180	450	200	480	760	850	500
Africa	190	210	410	190	425	700	780	450
China	190	200	450	200	425	700	780	450
Japan	210	190	510	230	510	800	830	520
Southeast Asia	210	200	410	200	440	740	790	470
Australia–New Zealand	200	220	470	200	425	720	780	450
Rest of the World	200	200	450	200	425	700	780	450

The first two factors together contribute to a measure of the volume of economic activity in nonforest sectors, such as construction. Technological trend accounts for all the rest; for example, for changes in the share of forest-product inputs to other sectors. It also accounts for the effect on forest-product demand of changes in the prices of substitutes relative to the prices of forest products.

We assume an exponential trend for each of the factors. Let α be the annual growth rate of income per capita in a given region. If λ is the income elasticity of consumption for a given product, then the contribution of income growth to the growth rate of demand is $\lambda\alpha$. Furthermore, if

Table 23.3 Price elasticities, β, by income category and by product.

	Income per capita ($/year)			
Product	> *3000*	*1500–3000*	*750–1500*	< *750*
Fuelwood	–0.7	–0.7	–0.7	–0.7
Coniferous sawnwood	–0.5	–0.7	–1.5	–1.5
Nonconiferous sawnwood	–1.2	–0.9	–0.5	–0.5
Veneer and plywood	–0.4	–0.4	–0.4	–0.4
Particle board	–0.4	–0.4	–0.4	–0.4
Newsprint	–0.3	–0.4	–0.5	–0.8
Other printing paper	–0.2	–0.2	–0.3	–1.2
Household and sanitary paper	–0.1	–0.1	–0.3	–0.7
Packaging paper and board	–0.1	–0.1	–0.3	–0.7

the population simultaneously grows at an annual rate of δ and the contribution of technological trend to the growth rate of demand is γ, then the annual growth rate, μ, of demand for this product in the given region is:

$$\mu = \lambda\alpha + \delta + \gamma \tag{23.3}$$

Let τ be the number of years from the base year 1980 (time step $t = 0$) until time step t (i.e., for five-year steps, $\tau = 5t$). Then the demand function resulting from the rate of growth μ, applied to each price level separately, is equal to $c_0 \exp(\mu\tau)$, where c_0 is the base year demand function specified above by equations (23.1) and (23.2). Note that the price elasticity of demand remains constant over time. This expression applies to all products and all regions except the USSR, for which we assume that demand and production grow at an equal rate (see Chapter 26).

There is one final consideration before the demand function to be employed in the GTM for time step t can be stated. This is the impact of changes in real currency exchange rates. First, suppose that no impact is to be taken into account. Then, under the assumption, for example, that the US dollar strengthens with respect to all other currencies, the costs in US dollars outside the US decrease and consequently the product price tends to decrease. This, in turn, tends to increase consumption and, thereby, also prices. Consequently, at equilibrium, consumption outside the US would tend to increase and, simultaneously, the real prices (after eliminating inflation) in local currency would increase. This seems implausible.

In order to avoid this kind of phenomenon we scale the reference price (which so far has been kept unchanged over time) by the index ρ of real exchange rate (see Chapter 22). Thus, the resultant demand function, shifted over time and scaled to account for the real currency exchange rate, is specified as:

$$c/(\bar{c}e^{\mu\tau}) = [\pi/(\rho\bar{\pi})]^{\beta} \tag{23.4}$$

In other words, the functional form is that of equation (23.1). The reference consumption grows at the rate μ and the reference price follows the real exchange rate.

As a measure of income, the gross domestic product (GDP) was chosen. From statistics for the relative growth rate of GDP per capita and for the level of GDP per capita itself, we observe that for some low-income countries the growth rate is high relative to that in high-income countries; on the other hand, there is a group of very poor countries for which the growth rates are also very low. Therefore, it is not possible to conclude on the basis of statistical evidence that an interdependence between GDP per capita and its growth rate exists. However, in the GTM we have made the conservative assumption that the relative growth rate of GDP per capita declines as GDP itself increases. More precisely, if r is the GDP per capita and $\dot{r}$ is its time derivative, then we assume that:

$$\ln(\dot{r}/r) = a - br \tag{23.5}$$

In other words, the logarithm of relative growth rate declines linearly with increasing r. Furthermore, we assume that b is independent of the region and we calculate the parameter a (for each region–product combination), so that the curve fits the 1980 situation. As an example, for the scenarios given in Part VI, we used $b = 0.06$. The resultant growth figures between 1980 and 2030 for the GTM regions are illustrated by line segments in *Figure 23.2*. (For the numerical values, see *Table 27.1.*)

Estimated values for the income elasticity coefficients λ are shown in *Table 23.4*. They vary by product and by level of income per capita, and are based on Chapters 12 and 13, as well as on Wibe (1984).

In the scenario runs described in Part VI, the rates of population growth are assumed to decline over time for all regions. The figures used in the scenarios runs are given in *Table 27.2*. Technological trend factors, γ, were estimated by Wibe (1984). However, only in the case of coniferous sawnwood was the trend found to be statistically different from zero: its estimated value was $\gamma = -0.03$, which indicates a general trend of substituting other products in place of coniferous sawnwood. This trend for coniferous sawnwood and a trend of $\gamma = 0$ for all the other products were

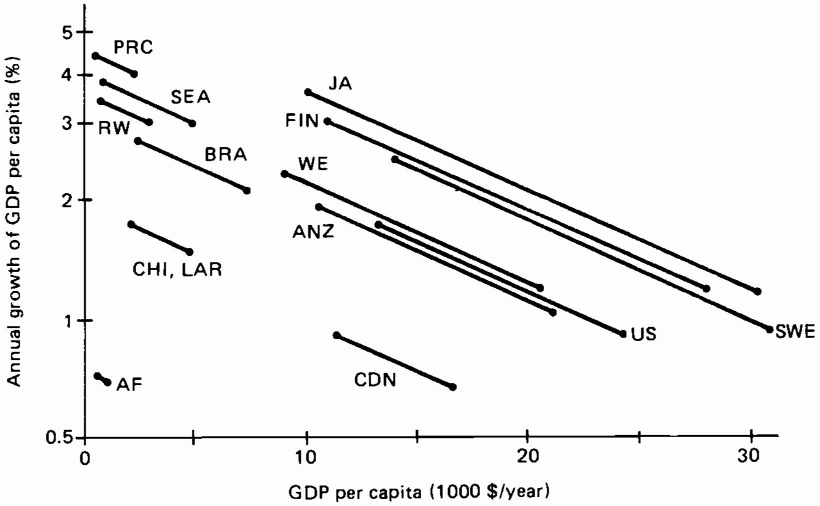

Figure 23.2 Annual growth rates of GDP per capita in 1980–2030 used for the base scenario described in Part VI for the GTM regions. The higher ends of the line segments refer to 1980 and the lower to 2030. (CDN, Canada; BRA, Brazil; CHI, Chile; LAR, Rest of Latin America; FIN, Finland; SWE, Sweden; WE, Western Europe; AF, Africa; PRC, China; JA, Japan; SEA, Southeast Asia; ANZ, Australia-New Zealand; RW, Rest of the World.) The USSR and Eastern Europe are excluded because no explicit assumption is made about their growth rates of GDP per capita.

Table 23.4 Income elasticity, λ, by income category and by product.

	Income per capita ($/year)			
Product	> *3000*	*1500–3000*	*750–1500*	< *750*
Fuelwood	–0.2	–0.2	–0.2	–0.2
Coniferous sawnwood	1.5	1.9	1.2	1.2
Nonconiferous sawnwood	0.7	0.7	1.0	1.0
Veneer and plywood	1.3	1.3	1.3	1.3
Particle board	1.3	1.3	1.3	1.3
Newsprint	0.6	0.8	1.0	1.3
Other printing paper	1.2	1.3	1.3	1.3
Household and sanitary paper	0.6	1.2	1.3	1.3
Packaging paper and board	0.6	1.2	1.2	1.3

Table 23.5 Annual growth rates (%) of demand in forest products by region at the 1980 level of income, according to the base scenario.

Region	*Coniferous sawnwood*	*Nonconiferous sawnwood*	*Veneer and plywood*	*Particle board*	*Newsprint*	*Other printing paper*	*Household and sanitary paper*	*Packaging paper and board*
Western Canada	–0.5	1.8	2.4	2.4	1.7	2.3	1.7	1.7
Eastern Canada	–0.5	1.8	2.4	2.4	1.7	2.3	1.7	1.7
Western US	0.5	2.2	3.2	3.2	2.0	3.0	2.0	2.0
Eastern US	0.5	2.2	3.2	3.2	2.0	3.0	2.0	2.0
Brazil	7.5	4.1	5.8	5.8	4.4	5.8	5.5	5.5
Chile	5.7	3.7	4.7	4.7	3.8	4.7	4.5	4.5
Rest of Latin America	5.6	3.6	4.6	4.6	3.7	4.6	4.4	4.4
Finland	1.7	2.3	4.1	4.1	2.0	3.8	2.0	2.0
Sweden	0.9	1.9	3.4	3.4	1.7	3.2	1.7	1.7
Western Europe	0.7	1.9	3.3	3.3	1.7	3.0	1.7	1.7
USSR	2.4	3.0	4.8	4.8	2.7	4.5	2.7	2.7
Eastern Europe	–2.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Africa	3.8	3.6	3.9	3.9	3.9	3.9	3.9	3.9
China	3.8	3.4	4.0	4.0	4.0	4.0	4.0	4.0
Japan	3.4	3.4	5.7	5.7	3.0	5.3	3.0	3.0
Southeast Asia	7.1	6.3	7.5	7.5	6.3	7.5	7.5	7.1
Australia–New Zealand	1.4	2.9	4.0	4.0	2.7	3.9	2.7	2.7
Rest of the World	4.3	4.0	4.6	4.6	4.5	4.5	4.5	4.5

used for all regions. The resultant annual growth rates, μ, by product and by region for the 1980 income level and corresponding to the base-scenario data (Chapter 27) are given in *Table 23.5.*

Reference

Wibe, S. (1984), *Demand Functions for Forest Products*, Working Paper WP–84–103 (International Institute for Applied Systems Analysis, Laxenburg, Austria).

CHAPTER 24

Trade Barriers and Inertia in International Trade

G. Kornai

The following issues of international trade appear in the GTM in the form of data and/or assumptions:

(1) Bilateral trade flows by forest products.
(2) Trade inertia.
(3) Trade barriers.
(4) Transportation costs.
(5) Import expenditures and export revenues for the centrally planned economies.

In this chapter we deal with the first three issues, while the latter two are discussed in Chapters 25 and 26.

24.1. Bilateral Trade Flows

International trade is represented in the GTM by bilateral trade flows of forest products, which link the regional component models to each other. More precisely, instead of the term "international trade" it would be better to use here "interregional trade", as we do not deal with trade between countries within any one of our model regions, such as Western Europe or Latin America. However, we represent explicitly such domestic commodity flows as moving products from the East coast to the West coast in the US and Canada.

For an 18-region model, each commodity trade matrix in the model is of dimensions 18 × 18. Given 16 products, the total number of theoretically possible trade flows — or trade activities — in the model is 18 × 17 × 16 = 4896. However, as we discuss below, the actual commodity trade matrices incorporated in the GTM are rather sparse.

Trade-flow implementation in the model develops over time. The principle of developing from one time step to the next is similar to that in other parts of the GTM: results obtained from the previous period are used, e.g., for calculating inertia bounds of activities for the next time step. For the base year, we require starting values such as actual trade matrices.

Base-year trade matrices were determined as follows. First, we reconciled the Direction of Trade statistics of the UN Statistical Office (UNSO) with those of FAO (see Chapter 18). To improve the reliability of our data, reconciliation was done on a country-by-country basis. Thereafter, we aggregated the trade matrices according to the 18 model regions, omitting observations for intraregional commodity flows to ensure consistency of the material balances in the model. That is, production plus imports is equal to consumption plus exports for all the regions and products. The number of actual trade flows thus obtained is shown in *Table 24.1*.

Table 24.1. Actual trade flows by commodity in 1980.

Product	*Number of flows*	*Density of the matrix* (%)
Coniferous logs	60	20
Nonconiferous logs	78	25
Coniferous pulpwood	46	15
Nonconiferous pulpwood	2	1
Fuelwood	0	0
Coniferous sawnwood	105	34
Nonconiferous sawnwood	118	39
Veneer and plywood	120	39
Particle board	96	31
Coniferous pulp	94	31
Nonconiferous pulp	91	30
Newsprint	99	32
Other printing paper	115	38
Household and sanitary paper	72	24
Packaging paper and boards	127	42
Recycled (waste) paper	60	20
All products	1283	28

As fuelwood is a commodity that is rarely traded internationally, we have deleted it from the GTM. (Technically, all of the theoretically possible trade activities for the 15 actually traded products are present in the model. However, most of them are fixed at zero.)

The number of actual interregional trade flows reportedly different from zero for 1980 is 1283 or about 28% of all possible trading routes (see *Table 24.1*). Several of these flows are, however, rather minor. Keeping such small trade activities in the model would increase computation time. On the other hand, excluding them from the model might not change the results significantly. Therefore, we decided to retain only the larger flows, within a tolerance of 0.1×10^6 units (m^3 or metric ton), in the model, suppressing the minor flows. Thus, we excluded over half of the actual trade flows from the model, retaining only 621 trading activities.

On the other hand, because of the long projection horizon, we should enable the incorporation of new trade activities. Obviously, the most profitable routes first open up for trade, while many other conceivable trade flows remain nonexistent due to high transportation costs and/or to insufficient price differentials between the regions concerned. Trade barriers may also play a role here (see Section 24.3). The profitability of all the possible flows was studied for 1980 conditions by using all possible trade activities in the model. If the 1980 price in the potential exporting region plus the transportation costs were smaller by a given percentage than the price of the commodity in the importing region, the flow was considered to be profitable. All possible flows promising a minimum 5% trading profit were included in the model. Thereby, 535 of these activities, which were not included among the 621 flows based on the actual 1980 trade, turned out to be profitable. These were reintroduced into the GTM.

Another consideration was to include at least one flow for export and import per region for each product, to ensure that none of the regions were isolated, which might result in unreasonable commodity prices in the region concerned. The number of such additional trade flows in the model is 61.

Altogether, these 621 actual 1980 trade activities plus the 535 profitable trade flows plus the 61 technical trade activities (1217 trading activities in total) were included in the GTM. From the technical aspect, it is simple to reclassify — exclude or include — each of the 4896 possible trade flows.

24.2. Inertia in the GTM

Both the statistical and the econometric illustrations given in Chapter 18 led to the conclusion that there is a good deal of inertia in the development of the present international-trade flow system. This inertia should be incorporated into the GTM in a way that allows for the profit-maximizing assumption concerning the behavior of traders. Within the optimization framework of trade in the GTM, an inertia assumption may be imposed on the "freedom" of the trade by simply setting upper and lower bounds of possible trade activities. Such a solution ensures not only that the trade flows already existing in a given solution period (flows that either are historically observable or arise from the solution for a previous period) will develop according to the changes in relative prices and costs, but also that the structure of the trade will be preserved for some time. To constrain the trade flows in the GTM we set lower and upper bounds for each trade activity:

$$Le_{t-T} \leq e_t \leq Ue_{t-T} \tag{24.1}$$

where e_{t-T} is the bilateral trade flow of a given product, T is a time lag equal to five years in time period t, L is the *lower bound multiplier*, and U is the *upper bound multiplier*. Subscripts for regions and products have been suppressed.

It seems natural that inertia should be included in the model in such a way that we can avoid imposing unrealistically tight constraints. In *Table 24.2* the smallest and largest inertia multipliers are shown for time lag $T = 5$. In order to determine which dimension of a trade flow the multipliers L and U should depend on, the inertia multipliers discussed in Chapter 18 were studied belonging to the time lag $T = 5$ years. As the difference between the highest and lowest multiplier is the largest when the data is grouped by exporting countries, we decided to set the boundary multipliers L and U according to the exporting regions i.

Table 24.2 Range of inertia multipliers by groups of estimation.

Grouping by	*Products*	*Exporters*	*Importers*	*Size*	*Regions*
Minimum	0.89	0.53	0.63	0.57	0.89
Maximum	1.18	1.23	1.13	1.08	1.12
(Max - Min)	0.29	0.70	0.50	0.51	0.23

To obtain the actual value of L_i and U_i we simply produced histograms of the frequency distribution of relative trade flow variations by exporting countries. First, all trade flow series were replaced by their five-year moving averages to reduce the importance of sudden, nonrecurrent changes in flows. Then, we calculated the relative variation, r_t:

$$r_t = e'_{t-5} / e'_t \tag{24.2}$$

for all exporting regions i and for all available importers, products, and years. Here, e' stands for the five-year moving average of the flow. To each r_t we assigned the corresponding trade quantity e'_{t-5} as the weight. Relative frequencies (percentages) of such ratios r_t are shown in *Figure 24.1*.

From these histograms we obtained the lower and upper bound multipliers for some GTM regions, as shown in *Table 24.3*. For regions not represented in our analysis, we used uniform multipliers in the range of the likely average. They were $L_i = 0.5$ and $U_i = 2.0$.

Table 24.3 Trade inertia bound multipliers in the GTM.

Region	L_i[a]	U_i[a]
Western Canada	0.6	1.8
Eastern Canada	0.6	1.8
Western US	0.6	2.0
Eastern US	0.6	2.0
Brazil	0.7	2.7
Chile	0.7	2.2
Rest of Latin America	0.7	2.2
Finland	0.4	2.0
Sweden	0.4	1.6
Western Europe	0.5 (A)	2.0 (A)
USSR	0.5	1.5
Eastern Europe	0.5 (A)	2.0 (A)
Africa	0.5 (A)	2.0 (A)
China	0.5 (A)	2.0 (A)
Japan	0.5 (A)	2.0 (A)
Southeast Asia	0.3	1.8
Australia–New Zealand	0.5 (A)	2.0 (A)
Rest of the World	0.5 (A)	2.0 (A)

[a] (A) = an assumption.

The bounds we derived from L and U apply only to the trade activities for which we have obtained a nonzero trade flow in the previous time step, either in the base year or in the model solution. It is likely that during the long projection horizon of the GTM many new trade routes will open up. For such a new flow we assume that neither a large share of domestic production can be exported into new markets nor that a large share of markets in the importing regions can be acquired. In the case of new flows, we define the upper bound as either the maximum attainable increase in the share of domestic production entering the new markets or as

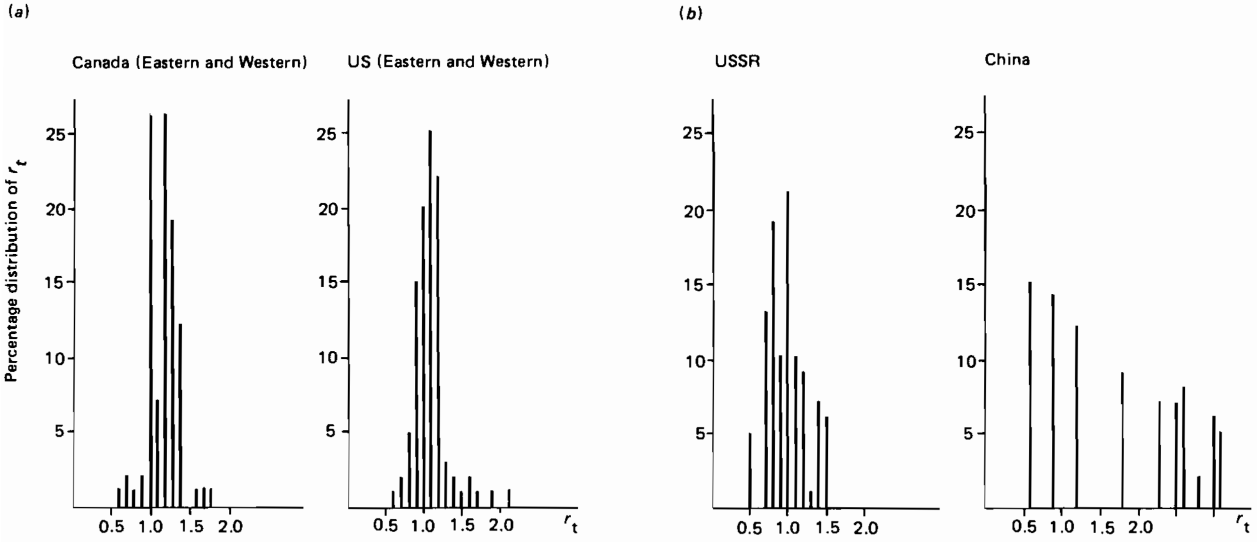

Figure 24.1 Percentage distribution of $r_t = e_t'/e_{t-T}'$ for exporting countries: *(a)* Canada and US; *(b)* USSR and China. Here, e_t' is the moving average of exports in year t and $T = 5$ is the time lag (*cont.*).

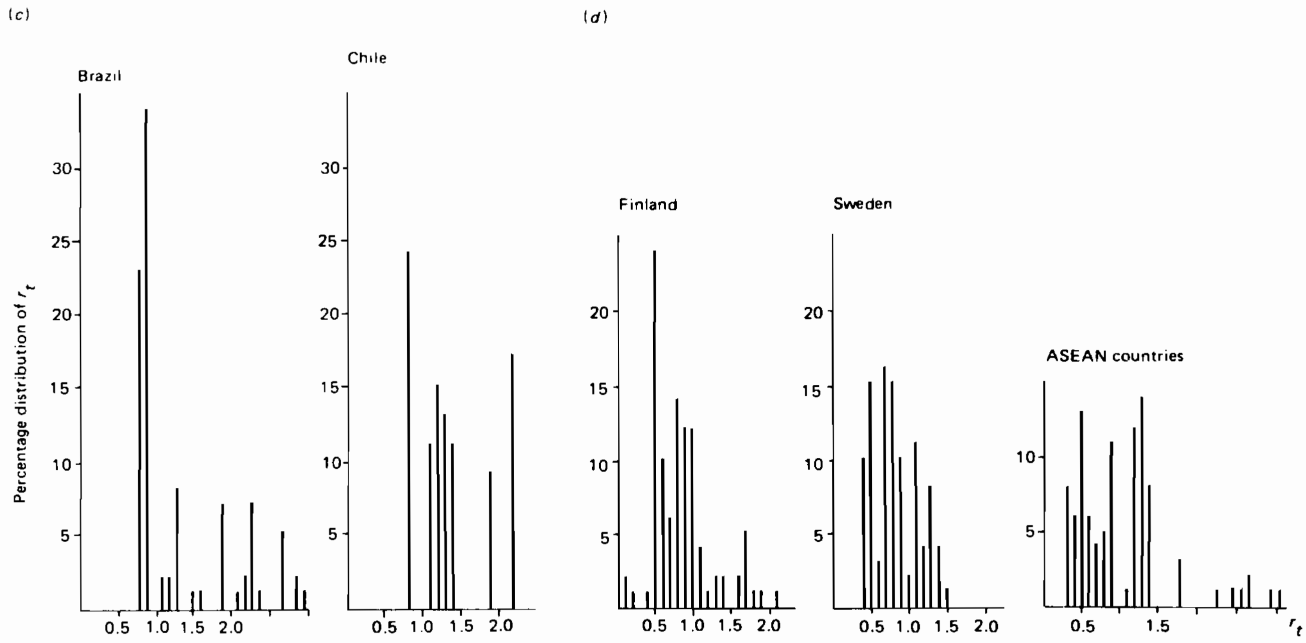

Figure 24.1 Percentage distribution of $r_t = e_t'/e_{t-T}'$ for exporting countries: *(c)* Brazil and Chile; *(d)* Finland, Sweden, and ASEAN countries. Here, e_t' is the moving average of exports in year t and $T = 5$ is the time lag.

Table 24.4 Tariffs imposed on imports, pre-Tokyo Round rates (%).

	Commodity									
Importer	*Logs*	*Pulp-wood*	*Sawn-wood*	*Veneer and plywood*	*Fiber-boards*	*Pulp*	*News-print*	*Printing paper*	*Household and sanitary paper*	*Packaging paper and boards*
Canada			A	15	10		10	10	10	10
US				B	4.5					
Brazil	43	43	56	C	56	56				
Chile	40	40	50	50	50					
Latin America	20	20	30	30	30					
Finland				D	D		D	D	D	D
Sweden				D	D		D	D	E	E
Western Europe		F		11			G	H	I	
Africa	15	15	20	20	20					
Japan			J	K	8	5	I	I	I	I
Southeast Asia	10	10	40	40	40					
Australia–New Zealand				30	30		10	10	10	10
Rest of the World	30	30	50	50	50					

Notes on special and preferential tariffs:

A 1.9% on nonconiferous sawnwood.
B 20% from developed, 8% from developing regions, 11% from Western Europe.
C 56%, except from Latin America.
D 2% from developed regions.
E 4% from developed regions.
F 3.5% from developed regions .
G 9% from developed regions, 5% from Northern Europe.
H 10% from developed regions, 5% from Northern Europe.
I 8% from developed regions.
J 9% on coniferous sawnwood from developed regions.
K 20% from developed, 10% from developing regions.

Table 24.5 Tariffs imposed on imports, post-Tokyo Round rates (%).

	Commodity									
Importer	*Logs*	*Pulp-wood*	*Sawn-wood*	*Veneer and plywood*	*Fiber-boards*	*Pulp*	*News-print*	*Printing paper*	*Household and sanitary paper*	*Packaging paper and boards*
Canada				8	9		7	7	9	5
US				8	3.5					
Finland				A	A		A	A	A	A
Sweden				A	A		A	A	B	B
Western Europe		C		11			D	D		
Japan				F	8	2.2	E	E	B	E
Australia–New Zealand				30	30		10	10	10	10

Notes on special and preferential tariffs:

A 2% from developed regions.
B 4% from developed regions.
C 3.2% from developed regions.
D 9% from developed regions, except for Northern Europe.
E 5% from developed regions.
F 15% from developed, 7.5% from developing regions.

the maximum possible market share in the importing country. The smaller of these two entities defines an upper bound:

$$B_t = \min\{\delta Q_{t-T}\,;\,\sigma C_{t-T}\} \tag{24.3}$$

where Q_{t-T} is production in the exporting region and C_{t-T} is consumption in the importing region in the preceding time step. Values $\delta = 0.1$ and $\sigma = 0.05$ were applied in the model runs described in Part VI. Upper bound B_t is used whenever it is larger than the bound obtained from equation (24.1).

24.3. Trade Barriers

Both tariff and some nontariff barriers to trade are implemented in the GTM. Tariffs are treated as being proportional to the total import price. Obviously, since original tariffs, if available, are given by countries and specific commodities, we had to aggregate the data to correspond to our model regions and products. We may distinguish three basic types of tariffs in the GTM:

(1) Overall tariffs, including duty-free imports, imposed on all imports without any discrimination.
(2) Preferential tariffs, providing lower or no duties for a given group of countries (e.g., developing countries).
(3) Special tariffs, providing individual discrimination or advantage and imposed only on a given exporter.

A summary of tariff data used in the GTM is given in *Tables 24.4* and *24.5*. Overall tariffs are given in the tables directly, while preferential and special tariffs are incorporated in the notes to the tables. (For a more detailed discussion on barriers to trade, see Chapter 15.)

These tariffs are added to the transportation cost coefficients of trade variables and updated for each time period. Tariffs are calculated as a percentage of the sum of export price plus transportation cost, both obtained from the solution to the previous period.

Nontariff barriers (e.g., prohibitions, quotas, import authorizations, voluntary export restraints, etc.), together with the long-term trade agreements, may be imposed directly on the trade flows by fixing the level of trade activities exogenously. Several such fixed flows appear in the GTM, for example, for trade between the centrally planned economies and for timber-export prohibitions.

CHAPTER 25

The Transportation Cost Model

H. W. Wisdom

Transportation cost matrices were developed in four steps (*Figure 25.1*). First, transportation cost equations were estimated for each of the products; second, matrices that showed the distance between all trading regions were prepared; third, matrices that showed the quantity of each product traded on each route for the previous period were derived from the trade flow matrices of the sector model; and fourth, transportation cost matrices were computed for each product. These four steps were repeated for each period, using a recursive approach.

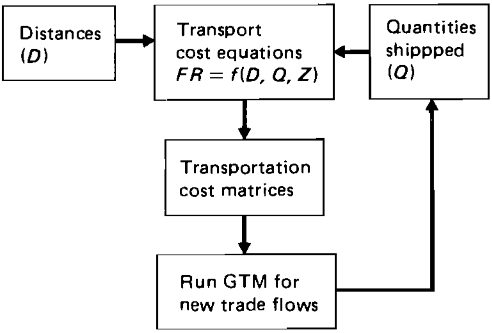

Figure 25.1 The transportation cost model.

25.1. The Transportation Cost Equations

The transportation cost equations were estimated using the transportation cost model presented in Chapter 17. The general form of the model is:

$$FR_{ij} = e^{a} D_j^{b} Q_{ij}^{c} Z_{ij}^{d} \tag{25.1}$$

The estimated form is:

$$\ln FR_{ij} = a + b \ln D_j + c \ln Q_{ij} + d \ln Z_{ij} \tag{25.2}$$

where FR_{ij} is the cost of transporting product i on route j in US \$ per long ton, D_j is the distance of route j in 100 nautical miles, Q_{ij} is the quantity of product i shipped on route j in 1982 in 10^3 long tons, Z_{ij} is a dummy variable, set equal to 1 if there is a discount rate for product i on route j and equal to 0 otherwise, and a, b, c, and d are parameters, discussed later (see *Table 25.1*).

25.1.1. The transportation cost data

The rates posted by liners with the Federal Maritime Commission (FMC) were used as the source for transportation costs. These rates include the cost of transporting, loading, and unloading the cargo onto and off the ship. They do not include inland transportation costs or the costs of unloading (loading) the cargo off (onto) inland carriers at either end of the route.

Examination of the tariff schedules posted by liners with the FMC revealed that far more independent-liner tariff schedules for forest products were on file than conference schedules. In addition, conference schedules were entirely missing for some forest-products trade routes and were limited for others. Discussions with tariff-watching companies and the FMC indicated that the independent-liner schedules probably more closely reflected actual rate charges in 1983 than did conference schedules. The 1983 ocean shipping market was depressed and plagued by overcapacity. In response to the depressed market and to competition from independent liners and tramps, conferences offered discounts, rebates, and other price reductions that were not reflected in their posted rates, to the extent that actual conference rates probably approached nonconference liner rates.

Although the exact differential on any route depends upon the competition that conference liners faced from independent liners and tramps,

Table 25.1 Estimated transportation cost using equation (25.2). Given are estimates for equation parameters a, b, c, and d, as well as the coefficient of determination (RSQ) and sample size (N) (t-values in parentheses).[a]

Product	a	b	c	d	RSQ	N
Coniferous logs	3.69	0.398	-0.049	-0.712	0.32	370
		(8.09)	(-3.71)	(-7.30)		
Nonconiferous logs	4.47	0.192	-0.025	-0.520	0.41	454
		(4.30)	(-2.71)	(-6.58)		
Wood chips	2.15	0.845	-0.076	-	0.94	14
		(11.4)	(-2.14)			
Coniferous sawnwood	3.84	0.319	-	-0.454	0.27	1542
		(15.4)		(-12.6)		
Nonconiferous sawnwood	3.73	0.311	-0.046	-0.374	0.25	1489
		(12.2)	(-8.05)	(-9.00)		
Veneer and plywood	4.41	0.185	-0.061	-0.335	0.42	620
	(5.63)	(-9.99)	(-5.97)			
Particle board	3.83	0.325	-	-0.458	0.24	458
		(9.50)		(-5.98)		
White pulp	3.96	0.269	-0.049	-0.393	0.23	1849
		(14.1)	(-11.8)	(-11.7)		
Newsprint	4.34	0.176	-	-0.397	0.32	295
		(6.85)		(-7.11)		
Other printing paper	4.24	0.280	-0.049	-0.395	0.38	1863
		(16.5)	(-9.92)	(-8.60)		
Household and sanitary paper	4.52	0.302	-	-0.278	0.38	574
		(11.1)		(-4.16)		
Packaging paper and board	3.94	0.322	-0.047	-0.715	0.30	5605
		(25.0)	(-17.3)	(-34.7)		
Recycled paper	4.35	0.238	-0.034	-0.617	0.36	713
		(7.37)	(-3.66)	(-9.76)		

[a] The parameters a, b, c, and d are the coefficients for the intercept term, distance, quantity, and dummy variables, respectively, in the estimated equations.

independent-liner rates were probably about 10% below conference rates in 1983. For these reasons, independent-liner tariff schedules were used to estimate the transportation cost functions.

25.1.2. The estimated equations

The estimated equations are presented in *Table 25.1*. The statistical aspects of the estimated equations are discussed in Jones (1984), so we give only a summary here. The coefficients of determination ranged from 23% for white pulp to 94% for wood chips. These are quite acceptable levels for cross-sectional data and relationships as complex as those of ocean transportation, although they may appear to be low to analysts accustomed to working with time series data. The F-test is highly significant for all equations, indicating that the equations as a whole are significant. The distance variable has the expected sign and is significant in all equations. The quantity variable has the correct sign in all cases and is significant in all cases, except for coniferous sawnwood, particle board, newsprint, and household and sanitary paper. The quantity discount variable has the expected sign and is significant in all equations, except for wood chips, where no quantity discounts were offered. Wood chips require special loading facilities and normally are exported in shipload lots, with only limited shipments moving as break-bulk cargo; that is, cargo shipped as individual, noncontainerized units.

The FMC data cover only US trade routes and thus the estimated equations strictly apply only to routes to and from the US. At the same time, however, the liners' posting rates are not restricted to US trade and there are few barriers to entry into the US trade by foreign liners. Thus, although differences in rate levels surely occur for non-US routes, the major causes of differences in the rate level among routes were distance and volume of trade, both of which are accounted for in the estimated models. The threat of competition from rival shipping companies and the pressure on the individual liner to seek the most profitable routes should inhibit large differences in rates not explained by the factors included in the rate equations. In any case, the lack of comparable rate information for non-US trade routes left little alternative to using the FMC-derived equations for all routes. This approach has the important advantage of consistency among all routes, especially important for forecasting and simulation purposes.

25.2. Distance Matrices

The distances used to estimate transportation costs are shown in *Table 25.2.* Route distances were measured as the distance between the major port city of each region, using the Defense Mapping Publication, *Distances Between Ports, 1976* (Defense Mapping Agency, 1976). For regions containing two or more countries, distance measurements were made using the assumptions shown in *Table 25.3.*

The regions of the forest sector model represent large geographic areas; for example, Africa, USSR, and the Rest of Latin America range over entire continents. Clearly, representation of the distances between regions as large as these as the distances between two points is a gross simplification of actual trading conditions. To further complicate matters,

Table 25.2 Distances between regions (100 nautical miles).[a]

	Destination																	
Source	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0	28	4	32	92	60	49	100	97	91	103	97	98	52	43	72	63	96
2	28	0	26	10	53	58	45	41	37	32	44	38	49	119	109	107	103	103
3	4	26	0	40	84	54	46	96	92	90	97	96	87	58	43	80	65	108
4	32	10	40	0	37	37	25	44	48	43	47	49	56	106	97	126	91	128
5	92	53	84	37	0	33	6	62	62	53	63	58	45	110	99	94	72	58
6	60	58	54	37	32	0	4	84	79	77	87	83	79	102	98	102	65	86
7	49	45	46	25	6	4	0	62	58	56	64	56	54	94	85	117	72	90
8	100	41	96	44	62	84	62	0	2	6	2	15	50	115	122	98	126	72
9	97	37	92	48	62	79	58	2	0	6	4	11	46	110	138	93	126	70
10	91	32	90	43	53	77	56	6	6	0	9	6	41	109	128	88	127	68
11	103	44	97	47	63	87	64	2	4	9	0	17	71	19	5	33	53	83
12	97	38	96	49	58	83	56	15	11	6	17	0	31	89	84	69	102	55
13	98	49	87	56	45	78	54	50	46	41	35	31	0	88	89	64	117	66
14	52	119	58	106	110	102	94	115	110	109	83	89	88	0	12	25	49	63
15	43	109	43	97	99	98	85	122	138	128	79	84	89	12	0	32	50	65
16	72	107	80	126	94	102	117	98	93	88	63	69	64	25	32	0	52	69
17	63	103	65	91	72	65	72	126	126	127	96	102	117	49	50	52	0	62
18a	96	103	108	128	58	86	90	72	70	68	81	55	66	63	65	69	62	0
18b	79	110	80	138	97	97	118	101	96	88	70	75	74	22	30	13	56	0

[a] 1, Western Canada; 2, Eastern Canada; 3, Western US; 4, Eastern US; 5, Brazil; 6, Chile; 7, Rest of Latin America; 8, Finland; 9, Sweden; 10, Western Europe; 11, USSR; 12, Eastern Europe; 13, Africa; 14, China; 15, Japan; 16, Southeast Asia; 17, Australia–New Zealand; 18a, Rest of the World, except nonconiferous logs; 18b, Rest of the World; nonconiferous logs.

liners generally apply a single rate to a broad range at both ends of the route. For instance, a single rate will be quoted for shipping out of any port between Maine and Virginia to any Northern European port.

The exponential form of the distance variable indicates that the influence of distance on transportation costs is greatest for short routes and becomes less for long routes (*Figure 25.2*). The explanation is that costs not related to distance are distributed over more miles as the route distance increases and so their impact declines accordingly. Thus, a 500-mile differential between two short routes may lead to significant rate differences; the same 500-mile differential on long routes would have little, if any, impact on rates. For these reasons, the use of distances weighted by volume of trade was considered and rejected.

The four Canadian and US regions presented a special problem, because a shipper has a choice not only between ocean and land carriers, but also between ship and barge for ocean shipping and truck and rail for overland shipping, or a combination of these modes. Mixed-mode shipping is becoming increasingly important with, for example, lumber shipped by

Table 25.3 Determination of shipping distances for multicountry regions.

Region	*Basis for calculation of the route distance*
Rest of Latin America	Average of Argentina and Venezuela
Western Europe	FRG
USSR	European USSR for all imports and exports except exports to Asian–Pacific regions. Asiatic USSR for exports to Japan, China, Southeast Asia, Australia–New Zealand, and Rest of the World
Eastern Europe	Hungary
Africa	Average of North, East, and West Africa (South Africa is part of Rest of the World)
Southeast Asia	Indonesia
Australia–New Zealand	Average of the two countries
Rest of the World	Average of South Africa and India for all imports and exports, except exports of nonconiferous logs where Burma was used as the export point

rail from British Columbia to reloading points in the Midwest, where it is reloaded onto trucks for final shipment to Midwestern markets. The restrictions placed upon US intercoastal shipments by the Jones Act, which restricts US intercoastal shipping to US vessels, further complicate the estimate of transportation costs.

The approach adopted was to use the ocean transportation cost functions, shown in *Table 25.1*, but to adjust the mileage between points to approximate actual differences between overland and ocean transportation costs. The distance between the US West and East coasts was set substantially greater than the actual distance to reflect the impact of the Jones Act upon US intercoastal shipping costs. In effect, the Jones Act provides a protective barrier behind which US railroads can increase their rates without fear of losing cargo to ocean carriers. This protection is not complete, because shippers have the alternatives of shipping on Canadian carriers or, in the case of large producers, of using their own ships.

Ideally, separate transportation cost functions should be estimated for each mode and route and the combination of least cost selected. This approach would have required a major effort of data collection and analysis and would have substantially increased the complexity of the transportation cost model. The crude adjustment adopted here has the advantage of

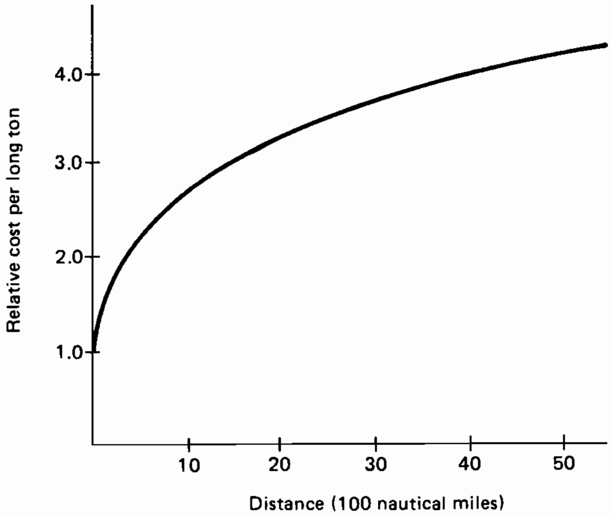

Figure 25.2 The relationship between transportation cost and distance. The unit of cost is arbitrarily chosen so that only relative changes in transportation costs with varying distances are indicated.

retaining the quantity-sensitive feature of the equations, while, at the same time, reflecting actual differences in freight rates among the regions.

25.3. The Quantity Matrix

In the model, the quantity of a shipped product influences the transportation cost of a route in two distinct ways. First, the quantity shipped influences the general level of the freight rate. As the quantity shipped increases, carriers tend to reduce the freight rate for the product for three reasons:

(1) Shippers gain bargaining power with the liners.
(2) Competitive carriers are attracted to the trade, forcing down rates.
(3) Specialized, cost-reducing handling equipment becomes feasible.

The exponential form of the quantity variable causes the rate to decline rapidly at first and level off thereafter, suggesting that benefits from economies of scale and competition accrue rather quickly and then decline as the rates approach the liner's long-run marginal cost curve. The relationship is unrealistic, however, at quantities below 10^5 long tons. Once the quantity shipped of a particular product becomes small, it is assigned a general rate and does not decline further. This discontinuity in the cost–quantity function is recognized by setting the rate for all shipments less than 10^5 tons at the 10^5 ton rate. That is, liners are assumed to begin to reduce rates only after a threshold quantity of 10^5 tons is reached. The model also assumes that this minimum rate applies for the case where no actual shipments were made, thereby avoiding the problem of zero quantity in the log-linear model.

Second, quantity also influences transportation costs via quantity discounts offered by carriers for large lot shipments. The rate charged for a particular product on a route depends upon whether the product is shipped in small lots, lots large enough to qualify for quantity discounts, or as a full shipload. The average rate depends upon the size distribution of shipments during the period. In the absence of this information, it was assumed that if the annual quantity shipped was 10^5 long tons or less, the cargo was shipped at the full liner rate. If the quantity shipped was greater than 10^5 tons and less than 5×10^5 tons, the cargo was shipped at the discount rate, and if the quantity was 5×10^5 tons or greater, it was shipped by charter. White pulp, newsprint, packaging paper and board, and recycled paper were assumed to be always shipped at the charter rate. Specialized carriers exist for these products and very little cargo moves on small, noncontainerized units. This rate structure recognizes the advantages enjoyed by large-scale shippers and the barriers that high transportation costs present to small-volume exporting countries who attempt to increase their exports.

The combined effect of these two influences of quantity upon transportation cost is shown in *Figure 25.3*. The peculiar shape of this curve reflects reasonably well the rate-setting practices of liners and gives a visual emphasis to the importance of the volume of trade in ocean shipping. Low-volume export countries tend to face very high shipping rates, making it difficult for them to compete with large-volume exporters. Their dilemma is how, in the face of high transport costs, to increase their export volume to a level that qualifies them for the lower discount rates.

Clearly, transportation cost estimates of the model are sensitive to the points at which the discount and charter rates are assumed to begin. It would be convenient to have a smooth, continuously declining function, but this simply is not the way that the ocean shipping market behaves. Judgment in setting the breaking points is unavoidable, but these points can be easily adjusted if desired.

The factors used to convert the trade flow into long tons are shown in *Table 25.4*. The pulpwood and white pulp trade flows in the global forest

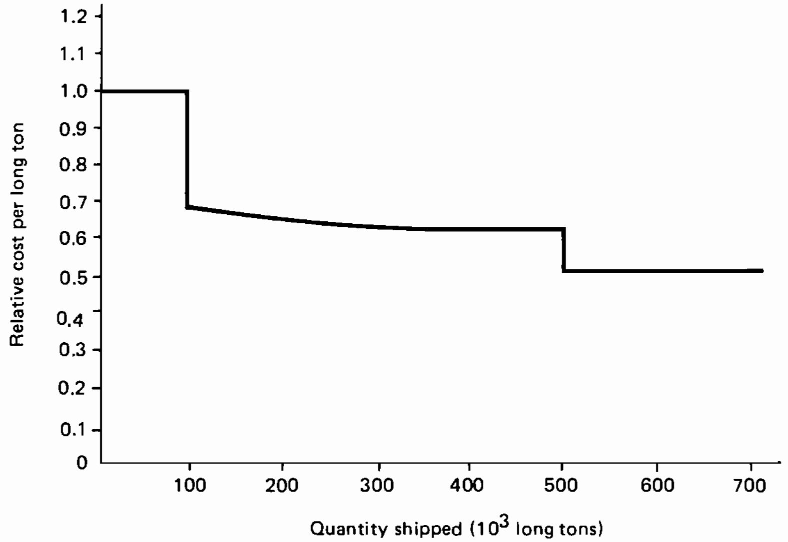

Figure 25.3. The relationship between transportation cost and the quantity shipped.

Table 25.4 Factors used to convert cubic meters and metric tons into long tons (FAO, 1984).

Product	*Conversion factor*		
Coniferous sawlogs	1 m^3	=	0.6897 long tons
Nonconiferous sawlogs	1 m^3	=	0.7519 long tons
Coniferous pulpwood	1 m^3	=	0.6410 long tons
Nonconiferous pulpwood	1 m^3	=	0.7407 long tons
Coniferous sawnwood	1 m^3	=	0.5405 long tons
Nonconiferous sawnwood	1 m^3	=	0.6897 long tons
Veneer and plywood	1 m^3	=	0.6849 long tons
Particle board	1 m^3	=	0.6944 long tons
Pulp and paper products	1 metric ton	=	0.9843 long tons

sector model (also known as the global trade model, GTM) are separated into coniferous and nonconiferous trade; however, liners do not distinguish between coniferous and nonconiferous pulpwood or pulp. Since only one transportation cost equation is used for each product, it is necessary to aggregate these trade flows.

The quantity matrices are derived from trade flows (10^6 m^3 for solid wood products and 10^6 tons for pulp and paper products) of the GTM. Before they can be used in the transportation cost equations, they must be converted into 10^3 long tons.

25.4. Calculation of Transportation Costs and Updating Procedures

Once the distance and quantity matrices were in the appropriate form, it was a simple task to compute the transportation cost matrices required to run the GTM. The initial set of transportation costs were generated using actual 1980 trade flows. For subsequent periods, the trade flows generated in the previous time step were used, proceeding in a recursive manner. It was assumed that transportation costs were not influenced by inflation or exchange rate fluctuations. It would be necessary to determine the nationality of liners carrying forest products on each route and where they purchased their inputs to make these adjustments.

The transportation cost equations shown in *Table 25.1* were modified slightly in making the actual transportation cost estimates. The first modification was to add a factor to each equation to convert the rate from dollars per long ton into dollars per m^3 for solid wood products and into dollars per metric ton for pulp and paper products (*Table 25.4*). Since these are full liner-rate equations, the dummy variable is equal to zero and not shown.

Table 25.5 Factors used to adjust the full liner rates to the discount rates (compiled from *Table 25.1*).

Coniferous logs	0.491
Nonconiferous logs	0.594
Pulpwood	0.491
Coniferous sawnwood	0.635
Nonconiferous sawnwood	0.688
Veneer and plywood	0.716
Particle board	0.633
White pulp	0.675
Newsprint	0.673
Other printing paper	0.674
Household and sanitary paper	0.758
Packaging paper and board	0.489
Recycled paper	0.539

Table 25.6 Transportation cost equations for full liner rates, by product. Transportation costs are in $\$/m^3$ for solid wood products and \$/ton for pulp and paper products. Distance is measured in 100 nautical miles, and quantity in 10^3 long tons.

	Transportation cost
Coniferous logs	$0.690 * \exp(3.69 + 0.398 \ln D - 0.049 \ln Q)$
Nonconiferous logs	$0.752 * \exp(4.47 + 0.192 \ln D - 0.025 \ln Q)$
Pulpwood	$0.667 * \exp(2.15 + 0.844 \ln D - 0.076 \ln Q)$
Coniferous sawnwood	$0.541 * \exp(3.84 + 0.319 \ln D)$
Nonconiferous sawnwood	$0.690 * \exp(3.73 + 0.311 \ln D - 0.046 \ln Q)$
Veneer and plywood	$0.685 * \exp(4.40 + 0.185 \ln D - 0.061 \ln Q)$
Particle board	$0.694 * \exp(3.83 + 0.325 \ln D)$
Wood pulp	$0.984 * \exp(3.96 + 0.269 \ln D - 0.049 \ln Q)$
Newsprint	$0.984 * \exp(4.34 + 0.176 \ln D)$
Other printing paper	$0.984 * \exp(4.24 + 0.280 \ln D - 0.049 \ln Q)$
Household and sanitary paper	$0.984 * \exp(4.52 + 0.302 \ln D)$
Packaging paper and board	$0.984 * \exp(3.94 + 0.322 \ln D - 0.047 \ln Q)$
Recycled paper	$0.984 * \exp(4.35 + 0.238 \ln D - 0.034 \ln Q)$

Table 25.7 Transportation costs for coniferous logs, coniferous sawnwood, and veneer and plywood, selected routes ($US\$/m^3$).

	Destination			
Source	*Eastern Canada*	*Eastern US*	*Western Europe*	*Japan*
Coniferous logs				
Western Canada	42	46	65	48
Eastern US	27	0	48	67
Brazil	52	45	52	67
Sweden	45	50	22	77
USSR	49	50	26	20
Southeast Asia	69	74	64	43
Coniferous sawnwood				
Western Canada	47	51	67	53
Eastern US	33	0	53	68
Brazil	57	50	56	69
Sweden	51	55	28	77
USSR	54	55	32	26
Southeast Asia	71	75	67	48
Veneer and plywood				
Western Canada	57	59	70	61
Eastern US	46	0	61	70
Brazil	63	59	63	71
Sweden	59	62	42	75
USSR	61	62	45	40
Southeast Asia	72	74	69	57

Table 25.8 Transportation costs for white pulp, packaging paper and board, and other printing paper, selected routes (US$/ton).

	Destination			
Source	*Eastern Canada*	*Eastern US*	*Western Europe*	*Japan*
White pulp				
Western Canada	56	59	75	61
Eastern US	41	0	61	76
Brazil	65	59	65	77
Sweden	59	63	36	84
USSR	62	63	40	34
Southeast Asia	78	82	75	57
Packaging paper and board				
Western Canada	47	51	68	53
Eastern US	33	0	53	69
Brazil	57	51	57	70
Sweden	51	55	29	78
USSR	54	55	32	26
Southeast Asia	71	75	67	48
Other printing paper				
Western Canada	96	102	130	105
Eastern US	70	0	105	132
Brazil	112	101	111	133
Sweden	101	109	61	146
USSR	106	108	68	57
Southeast Asia	136	142	129	97

Discount liner rates for each product and route combination were estimated by multiplying the full liner rate by a discount factor (*Table 25.5*). The discount variable is represented in the original transportation cost equations as a downward shift in the intercept. The discount coefficients can either be used as an additional variable in the transportation cost equations in *Table 25.1* or be transformed into a discount factor by raising e to the power of the dummy variable coefficient. The latter approach is adopted here (*Table 25.6*).

Tables 25.7 and *25.8* show abbreviated examples of transportation cost estimates for selected forest products. Differences in the costs shown in these tables reflect differences in:

(1) Commodity stowage (handling characteristics).
(2) Commodity unit value.
(3) Distance shipped.
(4) Quantity shipped on a route.

Thus, long routes may have relatively low rates because the large quantity shipped permits the optimum utilization of shipping technology and competition reduces the monopoly power of the liners. Or, the market may not be sufficiently large to justify large-scale shipments.

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CHAPTER 26

Planned Economies in the Global Forest Sector Model

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The purpose of this chapter is to discuss specific features of the components for the planned economy regions in the GTM, concentrating on the USSR. However, basic assumptions in the model formulation for Eastern Europe and China are also presented.

26.1. A Survey of the USSR Forestry Sector

26.1.1. Forest resources and removals

A brief survey of the USSR forest sector statistics shows the scale and dynamics of the resources and production by different branches of the industry. These aggregate statistics are useful for the analysis of significant structural changes in the wood-processing industries that have taken place in the last two decades. The sources of data at the aggregated level are widely available and have been reviewed in a number of studies. However, there have been only a few attempts to analyze changes at the industrial level on the basis of rather detailed technological information.

The general forestry situation for the benchmark year 1983 is presented in *Table 26.1* (Volkov, 1985). Since 1975 logging in the USSR has declined in terms of both roundwood as a whole and industrial roundwood.

On average, the annual increase in forest resources is about 1% for the growing stock, of which about 70% is potentially available. However, total timber removal is almost constant (see *Table 26.2*). From *Table 26.1* it also follows that the potential logging volume is rather limited in

Table 26.1 USSR forest resources in 1983.

	Unit	*Total*	*Coniferous*
Area of forests	10^6 ha	810	590
Total growing stock	10^9 m^3	86	69
Mature or overaged	10^9 m^3	54	46
Net annual increment	10^6 m^3	850	600
Economically exploitable annual increment	10^6 m^3	640	400
European part	10^6 m^3	250	140
Asian part	10^6 m^3	390	260

European USSR, where coniferous logs constitute less than 50% of the resources, whereas the potential is about twice as large in Asian USSR. This gives some insights into the forecasting of the future of forest resources.

Table 26.2 USSR timber production (10^6 m^3).

	1960	*1965*	*1970*	*1975*	*1980*	*1983*
Total removals	369	379	385	395	357	356
Industrial removals	265	283	299	312	278	275
Industrial fuelwood	2	9	18	29	21	–
Other industrial roundwood	261	274	281	283	257	–
Total chips used for industrial purposes	–	8.6	13.5	21.0	26.5	–
Chips from logging	–	0.0	0.1	1.6	4.2	–

Table 26.2 reveals changes in the quality structure of roundwood in the last two decades. The share of raw materials used for industrial purposes (mainly for pulp and panels) has systematically increased. The total production of roundwood has stabilized during the last few years (annual production during 1980–1983 fluctuated between 356 × 10^6 and 358 × 10^6 m^3). From the data given in *Tables 26.1* and *26.2*, it is clear that the logging of high-quality roundwood has decreased substantially in the 1970s, probably due to the geographic location of forestry resources. Thus, the utilization of residues and low-quality grades became an efficient and necessary technological development, which was pursued for a long time by timber producers. Some estimates show that in the near future the utilization of residues may reach 65–70 × 10^6 m^3, of which logging may account for more than 15 × 10^6 m^3, and that the production of particle board will be based only on the use of low-quality resources.

An analysis of the qualitative structure of timber resources shows that it is almost constant over time. The observed decrease in the fuelwood volume (defined as the difference between total and industrial removals; see *Table 26.2*) was not a result of the supply structure, i.e., the decrease of the share of low-quality timber classified as fuelwood, but rather it was the response of industry to a relatively modest growth of timber harvesting. During its decline in the late 1970s, more and more fuelwood was used for other industrial purposes, whereas about 28% of timber was classified by quality in the 1960s as fuelwood. In the 1970s if we also take into account low-quality pulpwood, then the share of low-quality timber was almost 30%, so its share has slightly increased over the last decade.

By analyzing the data in *Tables 26.1* and *26.2*, it is clear that in the near future the situation could change significantly due to the construction of new roads and railways. For instance, the Baikal–Amur railway could, in principle, make available for logging an area of about 54 $\times$ 10^9 ha, with a merchantable stock of about 2.0 $\times$ 10^9 m^3. Some rather moderate estimates show that in the next decade roundwood production could approach 440 $\times$ 10^6 m^3.

26.1.2. The Siberian region

The Siberian land under forest, excluding Yakutia, is 313 $\times$ 10^6 ha, the total volume of the growing stock being 39 $\times$ 10^9 m^3. These figures account for 40% and 48.5%, respectively, of the USSR forest as a whole. The forest area accounts for 76.3% of the land area in the Siberian region, while the area under forest accounts for 90.2% of the forest area. The dominant species in Siberia are coniferous, 78.3% by area and 84.6% by volume of stocks. The forests, including "reserve" forests, nominated for cutting are mainly located in the taiga. Exploitation of the reserve forests is limited by economic factors, primarily by the lack of roads. At present only a single railway line, the Trans-Siberia Railway, runs through the southern zone.

The main transporting Siberian rivers, Ob, Yenisey, and Lena, flow into the Arctic Ocean and of them only the Yenisey estuary is convenient for timber floating and transshipment into ocean vessels. The opening of the new Baikal–Amur railway line, 3 400 km in length, considerably increases access to the reserve forests in the taiga zone, making them available for forest exploitation. It will be the main channel for the export flow of wood and wood products to the Pacific countries.

The raw material potential of the Siberian forest is estimated from the volume of the mature and overaged forest stocks, which amount to 27.2

$\times 10^9$ m^3, 25.7% in Western Siberia and 74.3% in Eastern Siberia. If we take into account the inaccessible forest areas of the tundra and mountainous zones and the limitations on cutting forests in the steppe forest zone, then the raw material potential considerably decreases, and is estimated to be only 19.3 $\times 10^9$ m^3. This potential also includes reserve forests presently inaccessible to transport. A specific characteristic of the forests of Eastern Siberia is the high proportion of coniferous species, especially larch. This factor predetermines the development and location of the woodworking industries in the region.

The allowable cut for the Siberian forests amounts to 270 $\times 10^6$ m^3, excluding the reserve forests. The total volume of cutting is much less, 95 $\times 10^6$ m^3, i.e., only 35% of the allowable cut. Some 50% of the allowable cut for coniferous species (170 $\times 10^6$ m^3) is actually cut, the equivalent figure for deciduous species being only 10%.

The figures presented above clearly indicate that Siberia has enormous potential for increasing wood removal, given the appropriate economic decisions. The volume of the cuttings in the Siberian forests necessarily depends on many factors.

Economic analyses indicate that roundwood transport to European USSR from Siberia is not effective. This is because alternative supplies of wood are available from the utilization of forests located in Europe.

The volume of cutting in the Siberian forests must

(1) Meet the demands for timber and other forest products of the local market.
(2) Supply raw materials to local forest industries.
(3) Deliver roundwood to the Central Asian Republics and Kazakhstan.
(4) Develop an export trade in wood products via local ports, on the River Yenisey, for instance.

Economic calculations indicate that the application of machinery to the existing logging systems is profitable where the volume of growing stock is greater than 140 m^3/ha. Such stands are found only in the southern taiga zone.

Some Siberian regions have favorable conditions for the development of sawmilling, but the production of sawn timber remains considerably below that sustainable by the supply of local sawlogs. Factors that stimulate the sawmill industry are:

(1) High-quality sawlogs.
(2) A concentrated supply of sawlogs to facilitate large-scale sawmills and economies of scale.

(3) A growing export demand for sawn timber goods, e.g., via Igarka port.
(4) The economic advisability of exporting coniferous sawn goods to European parts of the country by train.

The pulp and paper industry is considered to be a fundamental part of the forest industrial complex in Siberia. There are many factors favorable to the development of the pulp and paper industry in this region:

(1) Enormous resources of coniferous roundwood.
(2) Superior water resources; 70% of the country's water resources are located in the region.
(3) Considerable sources of energy; gas and oil fields in Western Siberia, coal in Eastern Siberia, and hydroelectricity from the rivers of the Angara–Yenisey basin.
(4) The establishment of new towns on the basis of pulp and paper mills.

The forest resources of Siberia are sufficient to triple or quadruple the capacity of the pulp and paper industry by the year 2000 if the capital investments are charged to the state. A forecast of the development of the forest industrial complexes in Siberia is given in *Table 26.3.* It shows the great opportunities that exist for increasing the share of the Siberian forest industrial complexes in the country's total output of wood and forest products. Whatever increases occur, very much depends on the state's role in financing the necessary capital investments. In order to make the correct decisions concerning the economics of the distribution of capital investments, the competitive alternatives must be considered. These must be carefully analyzed, taking into account transportation costs, labor supply, regional wood consumption, and the time factor.

We must stress that some problems concerning the utilization and regeneration of the Siberian forests do exist. The main one is to supply forestry and the forest industries with a sufficient labor force. This is achieved by:

(1) The introduction of mechanized logging and woodworking to increase labor productivity.
(2) The improvement of the existing social conditions, such as the supply of consumer goods, etc.
(3) The stimulation of the economy in order to attract people to Siberia from European USSR.
(4) The development of new logging arrangements, such as the season's stocks of piled wood remaining in the forest during the summer ready for haulage in the winter.

Table 26.3 High and low forecasts of the development of the forest industrial complexes in Siberia in 2000. Percentage figures for the share of the Siberian production of the total USSR production are given.

		2000	
Products	*1980*	*Low*	*High*
Roundwood	27	30	32
Sawnwood	26	35	40
Plywood	10	26	34
Particle board	10	20	29
Fiberboard	16	19	28
Furniture	7	8	9
Market pulp	29	44	58
Paper	7	31	50
Paper board	24	40	52

Economic, ecological, and social problems created by the utilization of the Siberian forests are the subjects of a program of scientific investigations entitled "Siberian Forests and Their Rational Utilization". This program is part of a wider project, "Siberia", which has been planned by the Siberian department of the USSR Academy of Sciences in Novosybyrsk. Many research institutes and universities throughout the country are actively contributing to the study of reasonable economic, ecological, and social means for improving the efficiency of the utilization and regeneration of the Siberian forests.

26.1.3. Trade

Changes over time in the major exports and imports of forest products are shown in *Table 26.4*. The most significant relative increase is observed in the production and export of high value-added products (pulp, paper, and panels). At the same time, the production and export of raw wood products were stabilized and sometimes even decreased.

The main importers of USSR sawnwood are European countries: the GDR (18% of total USSR exports in 1983), the UK (17%), Hungary (9%), the FRG (8%), Italy (5%), France (4%), the Netherlands (4%), and Belgium (3%). The European market is also the basic one for USSR exports of wood-based panels and pulpwood, while Japan leads as an importer of coniferous logs (about 70% of 1983 USSR exports). About two thirds of the

Table 26.4 USSR exports and imports of forest products.

Product	*1970*	*1975*	*1980*	*1981*
Logs (coniferous and nonconiferous)				
Exports (10^6 m^3)	7.4	8.5	6.6	6.3
Imports (10^6 m^3)	0.1	0.3	0.3	0.3
Exports as percentage of production	4.4	5.0	4.3	4.1
Pulpwood and chips (coniferous and nonconiferous)				
Exports (10^6 m^3)	6.6	8.5	7.8	7.9
Imports (10^6 m^3)	0.0	0.0	0.0	0.0
Exports as percentage of production	20.0	19.9	20.6	21.0
Sawnwood (coniferous and nonconiferous)				
Exports (10^6 m^3)	8.0	7.8	7.1	7.2
Imports (10^6 m^3)	0.29	0.32	0.36	0.39
Exports as percentage of production	6.9	6.7	7.2	7.0
Wood-based panels				
Exports (10^6. m^3)	0.20	0.58	0.96	1.01
Imports (10^6 m^3)	0.09	0.08	0.19	0.13
Exports as percentage of production	3.3	6.2	9.1	9.2
Pulp				
Exports (10^6 ton)	0.45	0.52	0.82	0.84
Imports (10^6 ton)	0.29	0.24	0.22	0.27
Exports as percentage of production	6.7	6.0	9.2	9.2
Newsprint				
Exports (10^6 ton)	0.26	0.28	0.32	0.32
Imports (10^6 ton)	0.09	0.05	0.03	0.05
Exports as percentage of production	23.6	20.6	20.9	20.9
Printing and writing paper				
Exports (10^6 ton)	0.48	0.62	0.65	0.66
Imports (10^6 ton)	0.42	0.48	0.69	0.61
Exports as percentage of production	11.3	11.8	12.2	12.2
Packaging paper and board				
Exports (10^6 ton)	0.25	0.30	0.37	0.39
Imports (10^6 ton)	0.06	0.09	0.21	0.21
Exports as percentage of production	9.8	9.1	10.8	10.9

USSR exports of pulp and paper products are delivered mainly to the European socialist countries.

Despite the fact that imports of forestry products seem to be negligible compared with total imports, as shown in *Table 26.5*, they are now quite large, in particular for finished products, such as paper and paper board. In value terms, forest product imports of 0.8 × 10^9 rubles amount to 40% of the exports of forest products (see *Table 26.6*).

Table 26.5 USSR imports (10^6 rubles).

	1960	*1970*	*1980*	*1981*	*1982*	*1983*
All sectors	5 100	10 600	44 500	52 600	56 400	59 600
Forest sector	94	224	889	939	884	797
Pulp	13	49	89	129	102	99
Paper and paper board	22	99	456	431	459	365
Converted paper products	9	37	213	230	202	218

Table 26.6 USSR exports (10^6 rubles).

	1960	*1970*	*1980*	*1981*	*1982*	*1983*
All sectors	5 000	11 500	49 600	57 100	63 200	67 900
Forest sector	275	765	2 058	1 952	1 845	1 969
Roundwood	55	254	615	531	451	499
Logs	21	142	389	307	249	278
Pulpwood	16	70	153	152	133	138
Sawnwood	165	300	784	712	661	694
Plywood	13	31	77	80	81	83
Fiberboard	–	8	30	37	33	32
Particle board	–	8	19	22	21	21
Pulp	23	54	221	242	258	280
Paper	17	65	172	188	212	217
Paper board	–	30	80	86	76	90

Export growth in semifinished products is an important characteristic when analyzing changes in the supply side. The direct and indirect use of logs for exports is estimated to be in the range of 10% of high-quality timber (see *Table 26.7*). A peak of 12% was reached in 1978.

Table 26.7 USSR production and exports in high-quality roundwood.

	1960	*1965*	*1970*	*1975*	*1980*
Exports of timber in terms of roundwood[a] (10^6 m^3)	12.9	24.7	28.0	30.2	26.0
High-quality roundwood production (10^6 m^3)	261.5	272.0	271.8	274.4	248.6
Share of export in production (%)	4.9	9.1	10.6	11.0	10.5

[a] Assumes 1.7 m^3 of logs per m^3 of sawnwood.

All these facts on the supply side make it clear that significant changes in the end-use side might occur, especially for industries using timber in the rough and as sawnwood. Some changes, such as the use of timber in transportation (sleepers), in communications (poles), and in mining (pitprops), can be seen as impacts of technological progress, which have been reinforced by the conditions on the supply side mentioned earlier.

26.2. The Assumptions and Structure of the USSR Model

The principal part of this section was first reported in Fedorov *et al.* (1984). The modeling of the Soviet forest sector has to satisfy at least three main requirements: to be compatible with the common structure of the GTM, to reflect the basic features of the centrally planned economy of the USSR, and to adjust data requirements to the statistics available from IIASA's data bank or from the collaborating USSR organizations. Compromises between these requirements lead to the following set of assumptions, which is the basis for the construction of the USSR module of the GTM:

(1) Consumption of forest products outside the forest sector (e.g., sawnwood and panels for construction, paper for printing, etc.) is specified by *target levels* and by a *penalty* for deviating from such levels. Such a penalty may be considered, for instance, as the *social cost* of not meeting the target levels (see also Chapter 20).
(2) The annual target levels for final forest products and their dynamics are generated or specified exogenously from long-term state plans or scenarios. In a more fully developed version of the model, the target levels can be defined endogenously through an input–output submodel whose target levels of production for industries that consume forest products are exogenous.
(3) The structure of the forest industry is developed independently from world prices of forest products.
(4) Domestic prices are independent of world prices.
(5) Foreign trade in forest products is required to meet two main constraints: first, for total imports there is an exogenously given budget and, second, for exports there is an exogenously specified minimum total revenue. A permanent reduction in imports or an increase in revenues from exports may be typical scenarios. Imports and exports should also satisfy exogenously specified trade inertia constraints, trade agreements, quotas, and other trade policy requirements. *Efficiency* in trade is assumed to result from maximizing what we call

the *trade surplus* subject to all these constraints. Trade surplus is the net revenue from exports (negative contribution from import) after transportation costs and after the *social cost* of exporting commodities from the economy (a benefit from importing). Note that such an efficiency criterion directs the exports (under the specified limits) to regions so that the free on board (FOB) price (i.e., the export price at the USSR border) is the highest possible. Similarly, imports are chosen from regions that provide the lowest cost, insurance, and freight (CIF) price (i.e., the import price at the border).

(6) The mathematical structure of the model (or, more accurately, its computerized version) has to enable the improvement of individual modules. This will allow the use of submodels that are under preparation in the collaborating research institutes.

An outline of the USSR module is given in *Figure 26.1.* It contains three main submodules: demand, production, and exchange. We are aware that some of the assumptions made in formulating this model [see, for instance, (3) and (4) and *Tables 26.1-26.7*] are a rather rough approximation of reality. However, they simplify the mathematical structure of the model significantly, without unreasonably contradicting the existing data. A detailed discussion of the blocks in *Figure 26.1* is given below.

26.2.1. Forest sector production

At present, the approach being used for forest sector production is based on regression models that are constructed for every final forest-industry product considered in the GTM. Changes in white pulp production are assumed equal to changes in pulp consumption. Production of raw materials can be defined through regression models or given by scenarios. The relative shares of timber assortments (coniferous and nonconiferous, logs as well as pulpwood) in removals are assumed equal to those shares in timber consumption, which are derived from production levels of forest industry products and the related conversion coefficients.

For the construction of regression models, time series from 1966 were used for data analysis in a manner consistent with IIASA's data bank. One can find regression models with longer time series in Fedorov *et al.* (1984). Practically, the corresponding prognoses coincide with historical data when piece-wise linear models are used.

In *Tables 26.8* and *26.9* we summarize the regression models used for production forecasting in the present version of the USSR module of the GTM. These models have the following basic form:

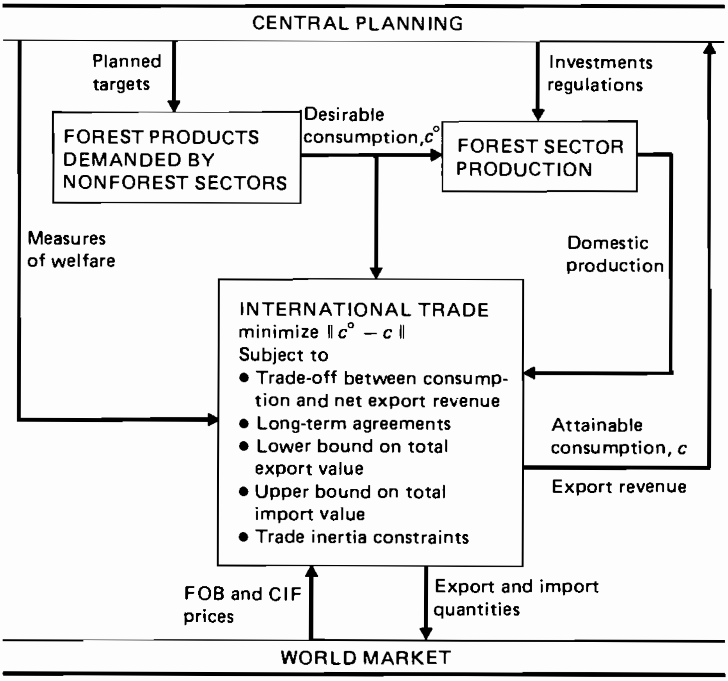

Figure 26.1. Structure of the USSR forest sector model.

$$RESPONSE\ (t) = \eta(t) ROUNDWOOD_t + \epsilon_t$$

where t is the time variable (t = current year – 1966), $ROUNDWOOD_t$ = roundwood removals during period t, and ϵ_t is the error term. The function $\eta(t)$ was approximated by either of the following:

$$\theta_1 + \theta_2 t + \theta_3 t_1 \tag{26.1a}$$

$$\frac{\Theta_3\, e^{\Theta_1 + \Theta_2 t}}{1 + e^{\Theta_1 + \Theta_2 t}} \tag{26.1b}$$

where t_1 is zero when $t \geq 9$, otherwise $t_1 = t - 9$. The latter type of spline function is sometimes used to represent the *saturation* effect

Table 26.8 Spline regression. θ are parameter estimates and τ are the t-ratios.

Products	θ_1	τ_1	θ_2	τ_2	θ_3	τ_3
Coniferous logs	0.346	60.4	0.003	3.2	-0.005	-1.7
Nonconiferous logs	0.056	58.0	0.0005	2.9	-0.0008	-1.5
Coniferous pulpwood	0.061	15.8	0.006	8.9	-0.009	-4.2
Fuelwood	0.256	65.5	0.006	-8.1	0.009	4.1
Coniferous sawnwood	0.255	67.9	0.001	1.6	-0.005	-2.5
Nonconiferous sawnwood	0.050	28.8	-0.0015	-4.8	0.0010	1.0
Veneer and plywood	0.0057	31.5	0.00015	4.6	-0.00015	-1.5
Particle board	0.0046	9.4	0.0012	14.7	0.0004	1.6
Coniferous pulp	0.0032	14.0	0.0002	7.1	-0.0001	-1.0
Nonconiferous pulp	0.00080	18.9	0.00005	7.1	-0.00005	-1.0
Newsprint	0.0024	63.9	0.00013	14.1	-0.00003	-1.4
Other printing paper	0.0070	59.2	0.0003	14.9	0.0001	1.1
Household and sanitary paper	-0.00001	-0.18	0.00002	2.5	0.00004	2.6
Packaging paper and board	0.0044	38.6	0.0005	23.6	-0.0001	-1.7

Table 26.9 Logistic regression. (Θ are parameter estimates and τ are the t-ratios.)

Products	Θ_1	τ_1	Θ_2	τ_2	Θ_3	τ_3
Coniferous logs	2.06	15.8	0.704	4.14	0.369	18.5
Nonconiferous logs	2.05	34.2	0.726	3.04	0.060	147
Coniferous pulpwood	0.009	0.06	0.335	3.90	0.113	22.6
Fuelwood	-5.69	-0.66	-0.016	-0.53	74.2	0.60
Coniferous sawnwood	3.02	5.12	0.860	0.96	0.260	13.0
Nonconiferous sawnwood	0.511	0.15	-0.064	-0.90	0.079	0.66
Veneer and plywood	1.02	1.10	0.607	6.82	0.007	115
Particle board	-1.80	-12.8	0.176	11.00	0.036	6.27
Coniferous pulp	0.120	1.20	0.247	4.66	0.006	22.4
Nonconiferous pulp	0.120	1.12	0.249	4.69	0.0015	23.3
Newsprint	-0.054	-0.40	0.110	6.11	0.005	12.5
Other printing paper	-0.401	-1.15	0.066	6.60	0.018	0.26
Household and sanitary paper	-8.56	-0.44	0.198	4.95	0.153	0.05
Packaging paper and board	-0.578	7.22	0.163	10.20	0.012	17.2

commonly observed in improving technologies. The values of θ_1 in the first case can be interpreted as technological coefficients, with θ_2 and θ_3 representing changes in these coefficients over time. From the formal statistical point of view all of the models appear to fit the observed data very well ($R^2 > 0.95$ in each case).

Typical regression models are presented in *Figures 26.2* and *26.3*, where observed and predicted production figures for the past, as well as predictions with standard deviations for the future, are given for two products, coniferous sawnwood and newsprint. All prognoses presented in these figures were made under the assumption that the annual production of roundwood will be constant and equal to 356×10^6 m^3.

For high value-added products, model (26.1b) gives more pessimistic results than the alternative model (26.1a). Moreover, practically all the production levels approach saturation in the middle of the 1990s when model (26.1b) is applied. Note that if one assumes the production of roundwood is growing then the production of high value-added products will grow proportionally. It is also useful to point out that the models of type (26.1a) for raw materials give unrealistic prognoses for the more distant future (e.g., for 2020) and may sometimes even give negative figures. These can be avoided by assuming an increase in the production of roundwood. Consequently, one has to be careful in long-term prognoses with regression models: the stability of the production structure of the wood product under consideration is one of the main, necessary assumptions.

26.2.2. Consumption targets

Two alternative approaches for deriving the consumption targets of the USSR module may be considered. The first, which is currently used in the GTM, assumes a certain consistency between changes in production and consumption. The second derives consumption levels by applying input–output analyses to the nonforest sector.

In the first approach, we assume that, for each final product, the relative change in consumption target level is the same as the change in production, as implied by the regression models. The base-year consumption target is assumed equal to the apparent consumption in 1980 (see Chapter 23).

The second approach to model forest-product consumption is based on the construction of input–output matrices that describe the use of forestry products. A constant input–output matrix can be used for reasonably short periods only, say 5–10 years, for the forest sector economy. This is especially true for final products, whereas input coefficients for raw

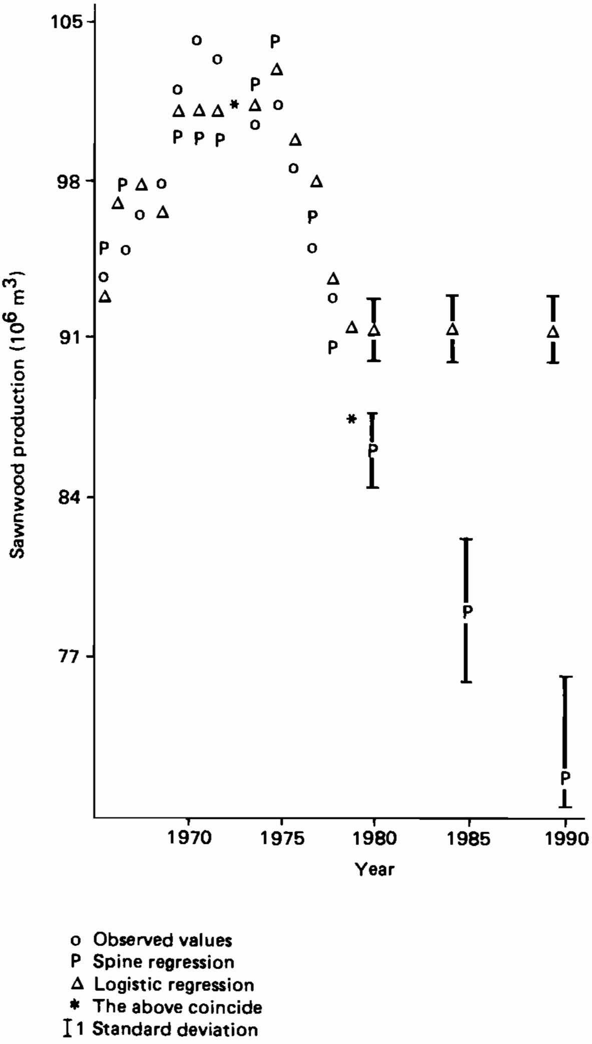

Figure 26.2. USSR coniferous sawnwood production.

materials seem quite stable. For a longer horizon, one should apply some method of extrapolation to these coefficients.

The list of scenario variables in this second approach comprises some macroeconomic characteristics, such as disposable income and investments.

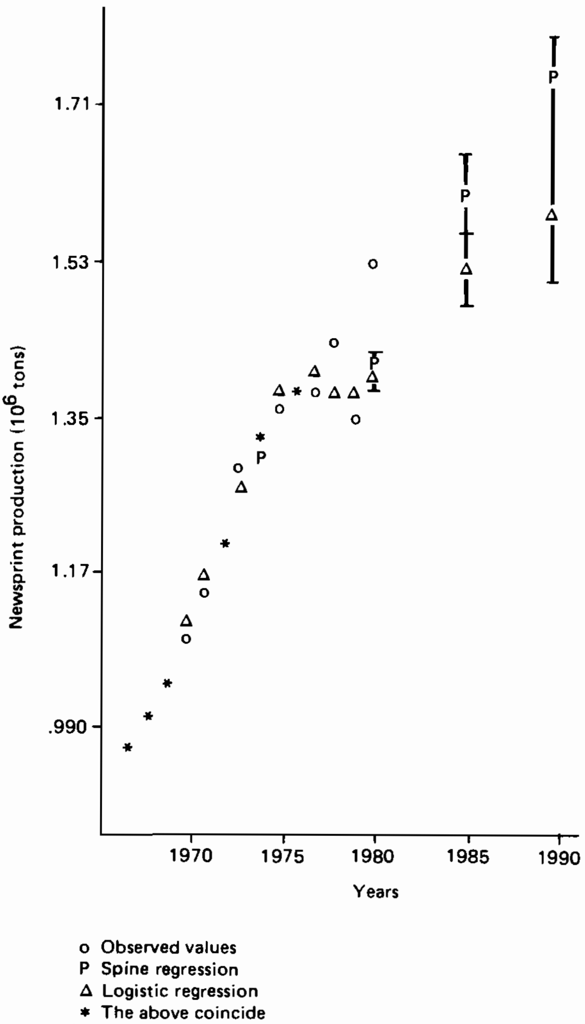

Figure 26.3. USSR newsprint production.

These, combined with an input-output model, may be used to forecast demand by households, by the construction sector, as well as by other wood-intensive industries, such as mining and transportation.

The construction industry is perhaps the most important among the end users of timber products, both processed and unprocessed. For example, one quarter of sleepers is used for construction and both the input–output survey for the year 1972 and industrial studies show that about 9% of unprocessed roundwood was used in construction. However, its share is substantially decreasing (by a factor of two in volume over the last decade). Therefore, one may expect this share to be rather low in the more distant future. This approach proves useful when the relations between different industries and the problems of substitution of forestry products by other products are of interest.

26.2.3. International trade

The entire exchange between the USSR module and the rest of the GTM is represented by the *international trade* module. The information inputs to the USSR module are FOB and CIF prices of forest products and the outputs are export and import volumes of these products. Consumption targets, c^0, and domestic production are additional data inputs to the trade module. Feedbacks between trade and other modules are realized through planned targets and investment regulations information (see *Figure 26.1*).

The guidelines for the trade module are to satisfy consumption targets and to maximize the net revenue of foreign trade. To formalize this idea we may think of trade-off functions, such as illustrated in *Figure 26.4*. As an example, given consumption target c^0, there may be two alternatives A and B, which are "equally good" (from the point of view of plans for the USSR economy). Alternative A results exactly in the planned consumption level c^0. In case B, the decrease in consumption is compensated by an increased export revenue.

Let c_j be a vector of attainable consumption levels, P_{sj} and P_{js} be vectors of export and import volumes, respectively, π_j^+ be a vector of FOB prices, π_j^- be a vector of CIF prices, L_{sj} and U_{sj} (L_{js} and U_{js}) be vectors of lower and upper bounds on export (import) volumes, E_s^0 be the required minimum export revenues, and M_s^0 be the given budget for total import expenditures. Index s refers to the USSR, whereas index j is used for other exporting and importing regions.

One of the simplest formalizations of the objective function for the USSR that explicitly reflects assumptions (1), (5), and the trade-off between net export revenue and consumption is defined as follows. Let:

$$\Delta_{sk} = W_k \frac{c_{sk}^0 - c_{sk}}{c_{sk}^0} \qquad (26.2)$$

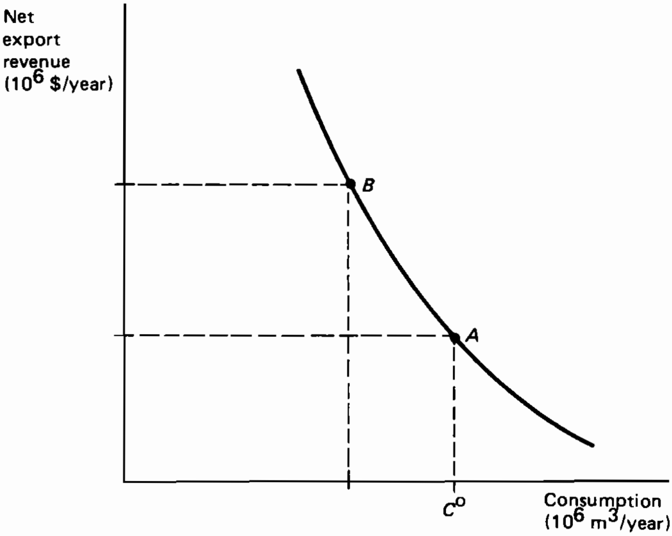

Figure 26.4 Trade-off between net export revenue and consumption in the planned economies.

measure the level of welfare given the planned consumption, c_{sk}^0, for product k and the actual consumption c_{sk}. Weight W_k may, for instance, reflect the "importance" of the product. If the target is met, then $\Delta_{sk} = 0$.

The USSR trade is then obtained by the model:

$$\min \Delta \tag{26.3}$$

subject to:

$$\Delta \geq 0,\ \Delta \geq \Delta_{sk} \tag{26.4}$$

$$c_s + \sum_j (e_{sj} - e_{js}) = y_s^0 \tag{26.5}$$

$$L_{sj} \leq e_{sj} \leq U_{sj} \tag{26.6}$$

$$L_{js} \leq e_{js} \leq U_{js} \tag{26.7}$$

$$E_s = \sum_j \pi_j^- \; e_{sj} \geq E_s^0 \tag{26.8}$$

$$M_s = \sum_j \pi_j^+ \; e_{js} \; \leq M_s^0 \tag{26.9}$$

where y_s^0 is the vector of net production in the USSR. This formulation minimizes the largest weighted relative deficiency, Δ_{sk}, over all the products. If Δ is equal to zero, then all the targets can be met and, as the next step, we may maximize the net trade revenue subject to the additional requirement that all consumption targets, c_{sk}^0, be satisfied.

This model is rather simple from the computational viewpoint. It reflects the assumption that consumption targets should be satisfied first and, thereafter, the trade surplus should be maximized. This model does not permit imports of products (even if they are cheap) if target levels are attained.

A slight modification of the above occurs when the objective function is replaced by min $\sum \Delta_{sk}$, i.e., by a weighted sum of relative deficiencies. Again, the minimization is subject to the requirement that consumption cannot exceed the target levels c_{sk}^0. If all the targets are attainable, then the second step should be taken as described above.

In the model implementation, it was assumed that:

$$\pi_j^- = \pi_j^* - D_{sj} \text{ and } \pi_j^+ = \pi_j^* - D_{js}$$

where D_{sj} and D_{js} is a vector of trade costs, including transportation costs and possible tariffs (see Chapter 24), between the USSR and region j and π_j^* is the price vector for region j.

The third alternative, which was used for the experimental runs of the GTM described in Part VI, can be described as follows. Let $P_{sk}(c_{sk})$ be the marginal penalty (per product unit) at consumption level c_{sk} for deviating from the target level c_{sk}^0, reflecting the trade-off illustrated by *Figure 26.4*. The functional form for $P_{st}(c_{sk})$ was chosen as follows:

$$P_{sk}(c_{sk}) = \pi_{sk}^0 (c_{sk}/c_{sk}^0)^{-\gamma_{sk}}$$

where parameter π_{sk}^0 is the marginal penalty at the target level c_{sk}^0 of consumption. In this notation, the mathematical structure of the penalty conforms to the consumption function used for regions with a market economy (see Fedorov *et al.*, 1984, and Chapter 23).

For the USSR, the net revenue from exports and imports is $E_s - M_s$. For product k, the social cost, when exports (or imports) result in a consumption level c_{sk}, is:

$$\int_{0+}^{c_{sk}} P_{sk}(c)\mathrm{d}c$$

Note that this is a negative and monotonically increasing function of c_{sk}, i.e., the higher the consumption, the lower the social cost. The model for determining trade (and thereby consumption) is:

$$\max \left\{ \int_{0}^{c_{sk}} P_{sk}(c)\mathrm{d}c + E_s - M_s \right\} \tag{26.10}$$

subject to conditions (26.5)–(26.9).

Note that this problem is not dealt with directly in the GTM. The optimal solution is obtained as part of the equilibrium solution, as discussed in Chapter 20.

26.3. Other Planned Economy Regions

Finally, we discuss the specific features of the two other planned economy regions in the GTM, namely Eastern Europe and China.

In the case of Eastern Europe, the basic differences compared with the USSR module are:

(1) Consumption is specified by a lower bound, i.e., a target level has to be met for each product. This target level is shifted over time according to the same principles as the demand functions are shifted (see Chapter 23). The base-year consumption is equal to the apparent consumption in 1980. The income elasticity in the scenario runs described in Part VI was set to zero.

(2) The relative increase in production of final products is equal to the growth in consumption target. Timber production is kept constant over time in the scenario runs. The increase in pulp production is equal to the increase in its consumption.

For China, consumption is specified by a demand function, as described in Chapter 23, and production is handled as for Eastern Europe.

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Part VI

Scenario Analysis

CHAPTER 27

Introduction to the Scenarios

D.P. Dykstra and M. Kallio

In any modeling project, the primary interest of potential users centers on how useful the model will be for analyzing policy issues that are pertinent to decision makers. To test the ability of the IIASA global forest sector model (commonly called the Global Trade Model, GTM) to serve as an acceptable abstraction of the forest sector and also to demonstrate the model's capabilities for analyzing policy alternatives, we have made a series of computer runs under a variety of scenario assumptions. In this section of the book we outline the assumptions and discuss the important results for each of these scenarios.

Every mathematical model, such as the GTM, includes two broad types of parameters — endogenous variables and exogenous data parameters. The endogenous parameters are calculated as part of the model solution, so it is not necessary to estimate or forecast values for them. Examples in the GTM include product prices and the level of production for each category of forest product in the market economy regions. Values for the exogenous parameters, on the other hand, have to be specified before solving the model. In the GTM, we estimate what we call *known parameters* and make assumptions about the levels of those we call *scenario parameters.*

A GTM solution comprises a set of *conditional projections* because the results are conditional on the values of the exogenous parameters. In this context, a *scenario* may be thought of as a model solution that utilizes forecasts for *known* parameters and assumptions about *scenario* parameters. These two types of exogenous parameters may be distinguished as follows:

(1) *Known parameters* are parameters whose values are not necessarily known precisely, but which fall into one of the following categories:

   (i) Parameters whose future values can be forecast with a high degree of confidence, but for which the model's sensitivity, with respect to changes in parameter values, is low to moderate.
   (ii) Parameters whose future values can be forecast with only a modest degree of confidence, but for which the model's sensitivity, with respect to changes in parameter values, is very low.

   Examples of known exogenous parameters in the GTM include transportation costs, population growth rates, and demand elasticities for final products.

(2) *Scenario parameters* are exogenous parameters that fall into either of the following categories:

   (i) Parameters whose future values can be forecast with a high degree of confidence, but for which the model's sensitivity, with respect to changes in parameter values, is very high.
   (ii) Parameters whose future values can be forecast with only a low degree of confidence, but the model is sensitive to changes in the parameter values.

   Examples of scenario parameters in the GTM include income per capita growth rates, future levels of real currency exchange rates, and the future volume of annual timber removals in the USSR.

Finally, the distinction between known parameters and scenario parameters is somewhat arbitrary; depending on the type of study undertaken, almost any of the exogenous parameters that are treated as known parameters in this analysis could be redefined as a scenario parameter. In our GTM runs, the parameters used in the various scenarios all retain the values assigned to them in the base scenario, with the exception of the specific parameters selected for change in individual scenarios.

In defining the scenarios to be investigated for this book, we drew on the expertise both of scientists and of managers and policymakers who are active in the forest sector. With their help, we attempted to develop a set of scenarios that would not only test the sensitivity of the model to a variety of assumptions, but would also provide interesting and perhaps useful conjectures as to how long-term trends in the forest sector might be influenced by policy decisions, by developments within or outside the forest sector, or even by chance occurrences during the coming decades. To some extent, the details of these scenarios are arbitrary. We have utilized expert opinion and the results of complementary research, when they were available, in order to make the scenarios as relevant as possible. Nevertheless, it is always possible to call into question scenario assumptions, because they are just that — assumptions. The intent of the scenario analyses is to demonstrate how the model works and to illustrate its capabilities for analysis, rather than to provide a fully comprehensive analysis of possible future developments in the forest sector.

Much of our attention in defining the scenarios for analysis was focused on the base scenario, which may be regarded as representing a moderate set of assumptions about developments that are likely to influence the forest sector over the next several decades. In addition to the base scenario we have considered eight alternative scenarios that reflect a wide variety of assumptions about the future of the global forest sector. The base scenario and these alternatives are described briefly in the following sections and the results of the scenario runs are discussed in the chapters that follow.

27.1. Base Scenario

In our base scenario we assume that during the 50-year *projection horizon* of the IIASA global forest sector model, the average level of economic growth globally will be slightly lower than that of the 1960s and 1970s. More precisely, we assume that the average annual growth in income per capita during the period 1980–2030 will be proportional to the "base" growth rates shown in *Table 27.1*. These growth rates are based on an analysis of FAO data by Wibe (1984) and have been modified as a result of discussions with various collaborators. The actual rates of growth of per capita income used in the model decline as real income (Gross Domestic Product, GDP) per capita rises. The empirical relationship used to adjust income growth as a function of income level is discussed in Chapter 23. In *Table 27.1* we show the estimated 1980 GDP per capita for each region and the corresponding 2030 rate of growth in per capita income (the 1980 rate is the *base* rate shown in the first column).

The demand for forest products depends upon population growth and related factors, as well as upon income growth. Furthermore, the sensitivity of the model with respect to income per capita depends on the size of the population. For example, large deviations in income growth in small regions, such as Finland and Sweden, do not affect model behavior significantly, whereas this growth in large countries, such as China, is a highly sensitive parameter.

In the base scenario we assume that population in the GTM regions will grow according to the rates indicated in *Table 27.2*. Note that in regions with high current rates of population growth we expect a gradual decline in these rates.

Table 27.1 Rates of growth of income per capita for the base year 1980 and for 2030. These growth rates decline as GDP per capita rises; the methodology for calculating them is discussed in Chapter 23. Also shown for reference are the estimated levels of GDP per capita in 1980. Base rates are from Wibe (1984) and have been modified as a result of discussions with collaborators; 1980 GDP per capita figures are from the World Bank (1984); other figures are calculated (see Chapter 23).

	Income per capita growth rates (%/year)		*Estimated GDP per capita in 1980*
Region	*Base*	*2030*	(10^3 US $)
Canada	0.90	0.65	11.32
US	1.65	0.84	13.16
Brazil	2.77	2.00	2.24
Chile	1.67	1.42	2.21
Rest of Latin America	1.67	1.45	2.00
Finland	2.99	1.04	1.87
Sweden	2.48	0.88	14.04
Western Europe	2.20	1.10	9.04
Africa	0.73	0.72	0.67
China	4.35	3.83	0.31
Japan	3.73	1.08	1.08
Southeast Asia	3.82	2.95	0.92
Australia–New Zealand	1.88	0.97	1.58
Rest of the World	3.38	2.91	0.63

In addition to these assumptions on income and population growth, the base scenario makes the following assumptions:

(1) The exchange rates of all currencies, as compared with the US dollar, will, by 1990, recover two thirds of the real devaluation that took place during 1980–1985. After 1990 the real exchange rates will remain unchanged at the 1990 levels. Since the 1985 levels represent a very strong US dollar, the base scenario thus assumes that the dollar will weaken significantly, but will not fall to the 1980 level (when, according to many authorities, the dollar was undervalued). The base scenario assumption on exchange rates is illustrated in *Figure 27.1*, which also shows the assumed exchange-rate developments for two alternative scenarios discussed in the following section.

(2) Import tariffs will, by 1987, move to the levels agreed upon in the Tokyo Round negotiations (see Chapters 15 and 24) and then will stay at these levels to the year 2030. In general, this implies a reduction of average tariff rates for forest products from the levels that prevailed before 1987.

Table 27.2 Estimated annual population growth rates for the GTM regions. [World Bank (1984) and discussions with members of the IIASA Population Project].

	Annual increase in population (%)		
Region	*1980–1990*	*1995–2000*	*2005–2030*
Canada	1.2	1.2	1.2
US	1.0	1.0	1.0
Brazil	2.2	2.0	1.9
Chile	2.5	2.1	1.9
Rest of Latin America	2.4	2.2	2.0
Finland	0.2	0.2	0.2
Sweden	0.2	0.2	0.2
Western Europe	0.4	0.4	0.4
USSR	0.8	0.7	0.6
Eastern Europe	0.8	0.7	0.6
Africa	2.9	2.7	2.5
China	1.2	1.1	1.0
Japan	0.8	0.6	0.5
Southeast Asia	2.5	2.0	1.7
Australia–New Zealand	1.6	1.5	1.4
Rest of the World	2.3	2.2	2.0

(3) In the GTM, timber removals in the USSR and Eastern Europe are determined exogenously rather than as the result of market forces, as is the case for other regions. The base scenario assumes that the maximum annual volume of timber removals in the USSR will increase gradually from 360 × 10^6 m^3 in 1980 to 430 × 10^6 m^3 in 1990, approximately a 20% increase, and will stay at this level throughout the remainder of the projection horizon. Timber removals in Eastern Europe are assumed to remain constant at the 1980 level.

(4) The base scenario assumes that there will be no substantial change in forest growth, forest area, or mortality rates due to atmospheric pollution or climatic change during the period 1985–2030.

27.2. Economic Growth Variations

Since the IIASA GTM is an economic model, it is sensitive to assumptions about the future development of the general global economy. For the purposes of this book we decided to test two alternative scenarios that modify the assumptions about economic growth used in the base scenario. These alternative scenarios are defined in terms of different annual rates of growth in income per capita. The two sets of growth rates are shown in

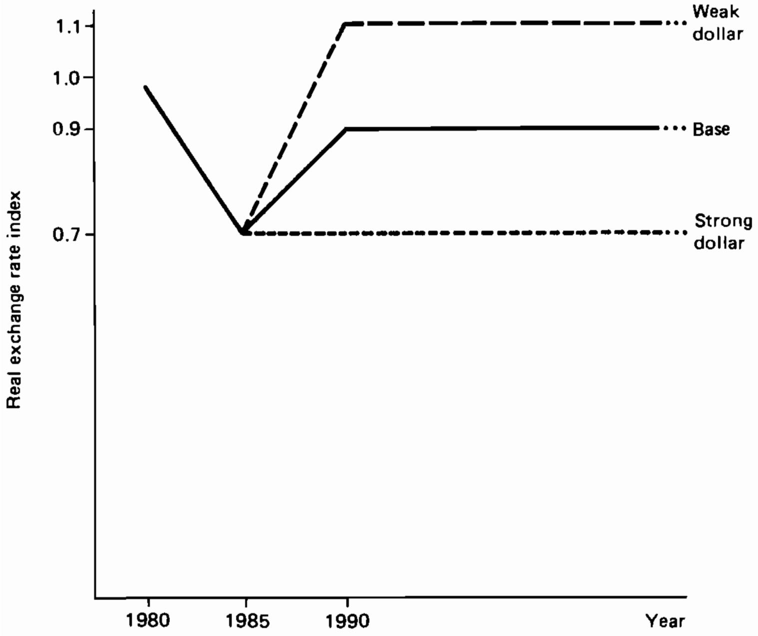

Figure 27.1 The index of real currency exchange rates over time, as assumed in the base scenario and two alternative scenarios. The vertical axis is scaled to illustrate the situation for regions, such as Japan, whose currencies have declined in real value by about 30% against the US dollar during the period 1980–1985.

Table 27.3 together with a set of growth rates for the base scenario taken from *Table 27.1*. The alternative growth rates have been derived as follows:

(1) *Low-growth scenario* in which we assume that per capita incomes in all regions (in the base year) grow at only one half the rate assumed in the base scenario.

(2) *High-growth scenario* in which we assume that per capita incomes in the industrialized regions grow at the rates assumed in the base scenario, but that per capita incomes in the developing regions (in the base year) grow at rates that are 50% higher than those in the base scenario.

In both cases the rate of growth after the base year 1980 is adjusted as a function of income per capita, as described in Chapter 23.

Table 27.3 Base growth rates for income per capita in the two economic growth scenarios. The base growth rates for the base scenario are shown for comparison.

	Base growth rates for per capita income (%/year)		
Region	*Base scenario*	*Low growth*	*High growth*
Canada	0.90	0.45	0.90
US	1.65	0.82	1.65
Brazil	2.77	1.38	4.15
Chile	1.67	0.83	2.50
Rest of Latin America	1.67	0.83	2.50
Finland	2.99	1.49	2.99
Sweden	2.48	1.24	2.48
Western Europe	2.20	1.10	2.20
USSR	3.08	1.54	3.08
Eastern Europe	3.20	1.60	3.20
Africa	0.73	0.36	1.09
China	4.35	2.17	6.52
Japan	3.73	1.86	3.73
Southeast Asia	3.82	1.91	5.73
Australia–New Zealand	1.88	0.94	1.88
Rest of the World	3.38	1.69	5.07

27.3. Exchange Rate Variations

One of the more sensitive parameters in the IIASA GTM and, indeed, in any long-term economic model involving international trade, is the currency exchange rate.

To test the sensitivity of the model to changes in currency exchange rates and also to provide an interesting projection of the possible effects of different exchange-rate developments on the future of the forest sector, we made two scenario runs under exchange rate assumptions that differ from those in the base scenario. These are illustrated in comparison with the base scenario in *Figure 27.1.*

(1) *Weak US dollar scenario* in which we assume that during 1985–1990 the real exchange rates of all currencies as compared with the US dollar will be revalued. For a given region, we assume that four thirds of the devaluation in 1980–1985 is regained by 1990, and that these new levels would continue to the end of the model's projection horizon (see *Figure 27.1*). Given that the US dollar is revalued with respect to all

other currencies, the assumption in this scenario is that the US dollar in 1990 is weaker than in 1980. The situation during the second half of the 1970s corresponds roughly to this weak US dollar assumption.

(2) *Strong US dollar scenario* in which we assume that the real exchange rates of all currencies as compared with the US dollar will continue at the 1985 levels (when the dollar was relatively strong) to the end of the projection horizon.

27.4. Trade Liberalization

The trade-liberalization scenario is designed to measure the effects of global free-trade policies on the long-term development of the forest sector. The base scenario assumes that by 1987 tariffs on forest products will be reduced to the levels agreed upon in the Tokyo Round trade negotiations and will stay at those levels to the end of the projection horizon. By comparison, the trade-liberalization scenario first reduces tariffs in 1987 to those of the Tokyo Round and then phases them out altogether by 2000.

Only tariffs are eliminated in the trade-liberalization scenario; trade-inertia constraints remain in effect. We view the trade-inertia constraints (see Chapter 24) as accounting primarily for organizational and logistical difficulties associated with substantially changing the level of trade, rather than as representing protective barriers.

27.5. USSR Timber Exploitation

As discussed in Chapters 21 and 26, the annual volume of timber removals in the USSR is well below the sustainable harvest level. In 1980, timber removals were about 360×10^6 m^3, compared with an estimated net annual increment of 880×10^6 m^3 in the growing stock. Even though a considerable fraction of the net annual increment is on timber far removed from transportation networks, the net annual increment on timber considered to be economically exploitable is reported in Chapter 26 to be 640×10^3 m^3. This suggests a considerable potential for substantially increasing the annual volume of timber removals in the USSR. The USSR timber-exploitation scenario is designed to test the impact on the global forest sector of a major increase in annual USSR timber removals.

The basic assumption in this scenario is that the volume of annual timber removals in the USSR would increase by approximately two thirds as compared with the present, so that the average annual level of removals would eventually reach a plateau of about 600×10^6 m^3. Note that only a given share of the increase in removals contributes to industrial roundwood production (see Chapter 29). Because much of the currently unexploited timber in the USSR is located either in Siberia or the Far East, an increase in annual removals of this magnitude would depend largely on the development of the necessary logistical infrastructure. Therefore, we assume that the increase would be phased in gradually, reaching a maximum in about the year 2010. In addition, we assume that all of the incremental industrial roundwood would be exported as roundwood; production of final forest products is therefore held constant at the same levels as in the base scenario (see Chapter 26). This is a conservative scenario in the sense that the benefits to the USSR could be even more if higher value-added forest products were exported as a result of the increased removals.

27.6. Acid Rain

We refer to this scenario as the acid rain one only for convenience. We recognize that many types of atmospheric pollution apparently contribute to the *Waldsterben* problem and that acid rain may not even be the major contributor. Nevertheless, this term has come to be generally associated with the damage of forests due to air pollution, so we have decided to refer to the atmospheric pollution scenario as the acid rain scenario.

Because of increasingly strong evidence that atmospheric pollution is damaging and even killing trees in many forested areas, particularly in Central Europe, we have developed one scenario designed to illustrate the potential economic effects of such a disturbance on the forest sector. In this scenario, which has been developed in collaboration with IIASA's Acid Rain Project, we assume that only the forests of Eastern and Western Europe, excluding the USSR and the Nordic countries, are significantly affected by atmospheric pollution. The effects assumed in the scenario are of two types:

(1) Between 1985 and 1995, we assume that the supply of timber in Europe will increase through salvage harvests equal to 20% of the base-scenario removals in Eastern and Western Europe. This increase represents the additional mortality of trees that would not otherwise have been considered economically ready for harvest. To model this in the GTM we shift the short-run roundwood supply curves to the right, thus treating the fraction of removals attributable to salvage harvests as inelastic. (See Section 21.1.4 for a discussion of this procedure, which affects the Western European supply curve, but not that of Eastern Europe.) Note that annual timber removals are unlikely to increase by the full 20%. Increasing the timber supply implies that roundwood prices will fall, as a result of which, some

healthy timber that would otherwise have been harvested will be held for future harvests. Market forces will thus determine the amount by which removals actually increase. In the acid rain scenario we assume that all of the trees killed or damaged by air pollution would have been salvaged by 1995 and thus the scenario includes no further increases in timber supply.

(2) Beginning in 1985, the growth rates of Eastern and Western European forests are reduced by one third as compared with the growth rates used in the base scenario (see *Table 21.5*). As a consequence, timber supply in Western Europe declines over time, the long-term sustainable yield being decreased by one third. Timber removals in Eastern Europe were held unchanged compared with the base scenario, thereby resulting in a decreased growing stock relative to the base scenario.

27.7. Climatic Warming

The final scenario that we have investigated for this book utilizes information from IIASA's Climate Project (Kauppi and Posch, 1987; see also Binkley, 1987) to assess the possible economic effects of climatic warming due to a doubling of atmospheric carbon dioxide by the year 2030. Although such warming would have many diverse effects on terrestrial life, in the forest sector we assume that there would be only two significant effects, both being limited to boreal forests. The reasoning is that only in the boreal forests would climatic warming be sufficiently pronounced to have a measurable effect on forests. The two effects are as follows:

(1) Forest growth rates would increase substantially in five of the 18 GTM regions where boreal forests predominate: Western and Eastern Canada, Finland, Sweden, and the USSR. The magnitude of the increase varies by region and depends upon the average annual temperature increase. We assume that the increase in growth rates would occur gradually between 1985 and 2030 and have implemented these increases as linear trends.

(2) The second major effect assumed in the climatic warming scenario is an increase in the forest area of the five boreal regions. Increased average annual temperatures would cause the zone of suitability for tree growth to be extended northward into areas that currently support trees, but at stocking levels too low to be designated "forest". As with the increase in growth rates, the expected percentage increase in forest area varies by region.

Note that this is an extreme scenario in the sense that the changes in forest-land area and timber growth rates are assumed to take place to completion during a 50-year period. In reality, such a transition may take longer. In *Table 27.4* we summarize the parameters in the forest-growth equations for the climatic warming scenario, showing the expected changes over time for the five boreal regions and the area of land classified as forest.

Table 27.4 Parameters for the climatic warming scenario. For the full growth equations, see *Table 21.5.* Only the b_0 parameters are affected in this scenario; the b_1 and b_2 parameters remain the same as in the base scenario. For a detailed discussion, see Binkley (forthcoming).

	Growth equation intercept (b_0)		*Forest land area* (10^6 ha)	
Region	*1980*	*2030*	*1980*	*2030*
Western Canada			93	127
Coniferous	0.046	0.056		
Nonconiferous	0.022	0.035		
Eastern Canada	0.030	0.057	99	121
Finland	0.070	0.101	20	24
Sweden	0.070	0.086	22	26
USSR	0.030	0.039	535	989

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CHAPTER 28

Base Scenario

D.P. Dykstra and M. Kallio

The IIASA global forest sector model, referred to as the GTM, is designed to deal, in a systematic and analytical way, with the problem of making economically consistent projections of long-term structural changes in the forest sector that might result from policy decisions, from developments within or outside of the forest sector, or from chance occurrences. In making the scenario runs to test such a model, the base scenario inevitably becomes the standard against which all other results are judged. Because of its importance we therefore give the base scenario a more-than-equal share of this part of the book, just as we gave its formulation and evaluation a major share of our time.

Details of the assumptions reflected in the base scenario are given in Chapter 27. In brief, the base scenario represents a moderate set of assumptions about the developments that are likely to influence the forest sector over the next several decades. It should be emphasized that these are *assumptions*, not forecasts, and we make them explicit so that our results can be judged on the basis of these assumptions. In the base scenario, we assume that the average level of economic growth globally will be slightly lower than that of the 1960s and 1970s, with the rates of growth varying by region (*Table 27.1*) and slowing over time within a particular region as per capita income rises. The rates of population growth will stabilize in the industrialized countries and will gradually decline after 1995 in the developing countries (*Table 27.2*). Exchange rates of all currencies as compared with the US dollar will, by 1990, recover two thirds of the value lost against the dollar between 1980 and 1985 and will stay at this level for the remainder of the projection horizon. By 1987 import tariffs on forest products will be reduced to the levels agreed upon in the Tokyo Round negotiations (Chapters 15 and 24) and will stay at these levels to 2030.

The maximum annual volume of timber removals in the USSR will increase by 20% from 360 × 10^6 m^3 in 1980 to 430 × 10^6 m^3 in 1990 and will stay at this level to 2030. Finally, the base scenario assumes that there will be no substantial change in forest growth, forest area, or mortality rates due to atmospheric pollution or climatic change during the period 1985–2030.

Many of the graphs used in the following sections to summarize results from the scenario solutions are *cumulative* graphs. For example, in *Figure 28.1* a particular curve represents the annual timber removals summed over a number of regions and the top line in the graph represents the world total. The quantity for an individual region is represented by the slices between the lines. In all of these graphs, the GTM regions are plotted in a consistent order, with Canada (the total of Regions 1 and 2, Western and Eastern Canada) at the bottom and the Rest of the World (Region 18) at the top (see also the regional disaggregation in Chapter 19).

Note that the graphs of *Figures 28.2–28.8* have been produced by summing over regions in the standard order (see Chapter 19). Slices referring to regions (or in some cases several regions) with a large share in export or import have been indicated explicitly. Slices left unidentified refer to regions that can be established from the list of all 18 regions and the ones referred to on the graph. For example, the slice between Japan and Western Europe for coniferous sawnwood imports in *Figure 28.5* refers to the sum of imports to the USSR, Eastern Europe, Africa, and China; and the line between Western Europe and the US indicates that the sum of imports to Latin America and the Nordic Countries is too small to show in the graph.

For prices, conventional, noncumulative graphs are used (*Figures 28.9–28.11*), but all the other graphs are cumulative over regions or over products. In most of the graphs used to summarize scenario results the curves have been plotted only for a 30-year period, in spite of the fact that the model's projection horizon for these scenario runs was 50 years. There are several reasons for this. First, we recognize that policy decisions generally reflect shorter term considerations; even 30 years is a relatively long projection horizon for policy analysis. Second, a number of the exogenous parameters in the GTM are expressed as rates, so that the quantities they represent grow exponentially. A projection horizon of 50 years permits them to become very large, particularly near the end of the horizon, so that even small errors in the growth rates can be magnified many times. Our chief reason for making the model runs over a 50-year projection horizon is to convince ourselves that the model performs in an acceptable way over this period of time. We are more interested, however, in the projected developments over the next 20 or 30 years and therefore concentrate primarily on this period in the discussion of the scenario results.

28.1. Timber Removals

The development of annual *industrial* timber removals over time as determined by the base scenario is illustrated in *Figure 28.1*. Industrial removals represent the portion of annual timber removals that are used for the production of logs and pulpwood only. Fuelwood removals are thus excluded from the graph, which shows total industrial removals for both coniferous and nonconiferous timber.

In most regions, according to the base scenario, total industrial removals will increase only moderately between 1980 and 2030. The most notable exceptions are Canada and the US, which together accounted for about one third of such removals in 1980. These two countries would account for 60% of the increase in industrial removals between 1980 and 2030, so that by the end of the projection horizon their combined share of global industrial removals would have grown to 45%. Although smaller in terms of the world total, Brazil, Chile, and Australia–New Zealand all show significant growth in the level of industrial timber removals.

28.2. Forest Industry Production

Figures 28.2–28.4 show for all ten forest industry products of the GTM the production volume in the base scenario in 10^6 m^3 or 10^6 tons per year during the 30-year period 1980–2010. Again, the graphs are cumulative over regions so that the top curve indicates total world production, which simultaneously equals the total world consumption. The presence of imports and exports means that production and consumption, of course, are not necessarily equal in any particular region.

Some general observations can be made with respect to industrial processing. The relative growth of sawnwood production at the world level is significantly less than the growth in panel production. In this scenario, the growth of veneer and plywood production may be seen as high compared with particle board. Newsprint production increases somewhat slower than the production of other paper grades. It is important to remember, however, that such results are sensitive, in particular, to assumptions concerning income elasticity parameters for various products.

A general observation concerning structural change in the regional distribution of production is the increasing importance of North America, in particular the US forest industry, in this scenario. This is partially due to the increasing share of wood raw-material supply from North America.

A number of changes occur for various products. For nonconiferous sawnwood, the US share of world production increases dramatically due to

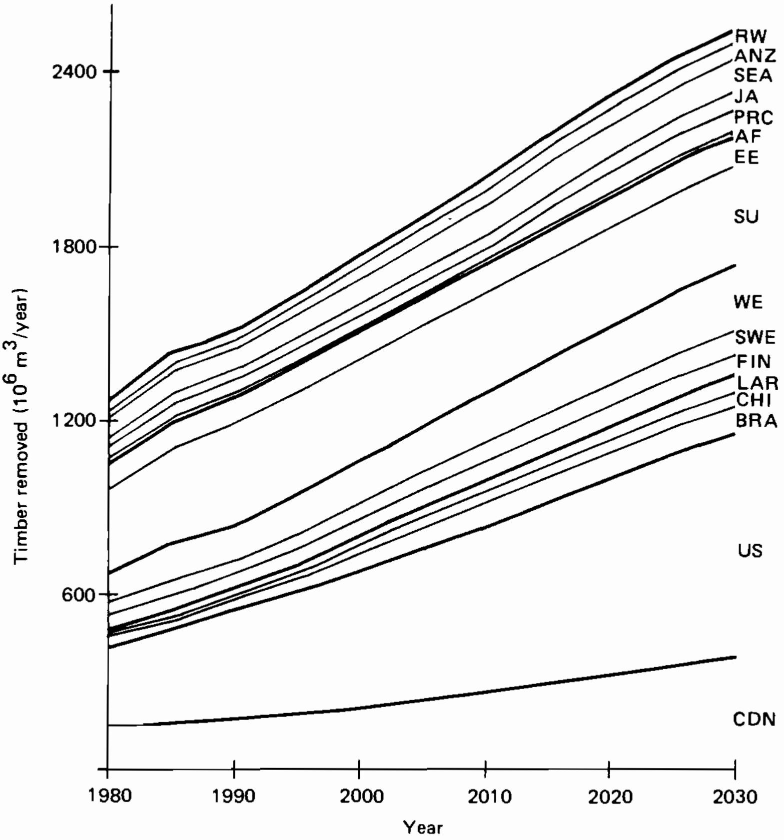

Figure 28.1 Timber removals for the production of logs and pulpwood in the base scenario. Fuelwood removals are excluded. The curves are cumulative over regions, so that the top curve represents the world total. CDN, Canada; BRA, Brazil; CHI, Chile; LAR, Rest of Latin America; FIN, Finland; SWE, Sweden; WE, Western Europe; SU, USSR; EE, Eastern Europe; PRC, China; JA, Japan; SEA, Southeast Asia; ANZ, Australia-New Zealand; RW, Rest of the World.

vast timber resources, particularly of nonconiferous timber. Also, Chinese production of coniferous sawnwood increases rapidly, a result that is strongly dependent on assumptions concerning sawnwood consumption (e.g., income elasticity) and log import possibilities in China (e.g., trade policies). For veneer and plywood, the primary contributors to increasing world production are the US, Latin America, Western Europe, China,

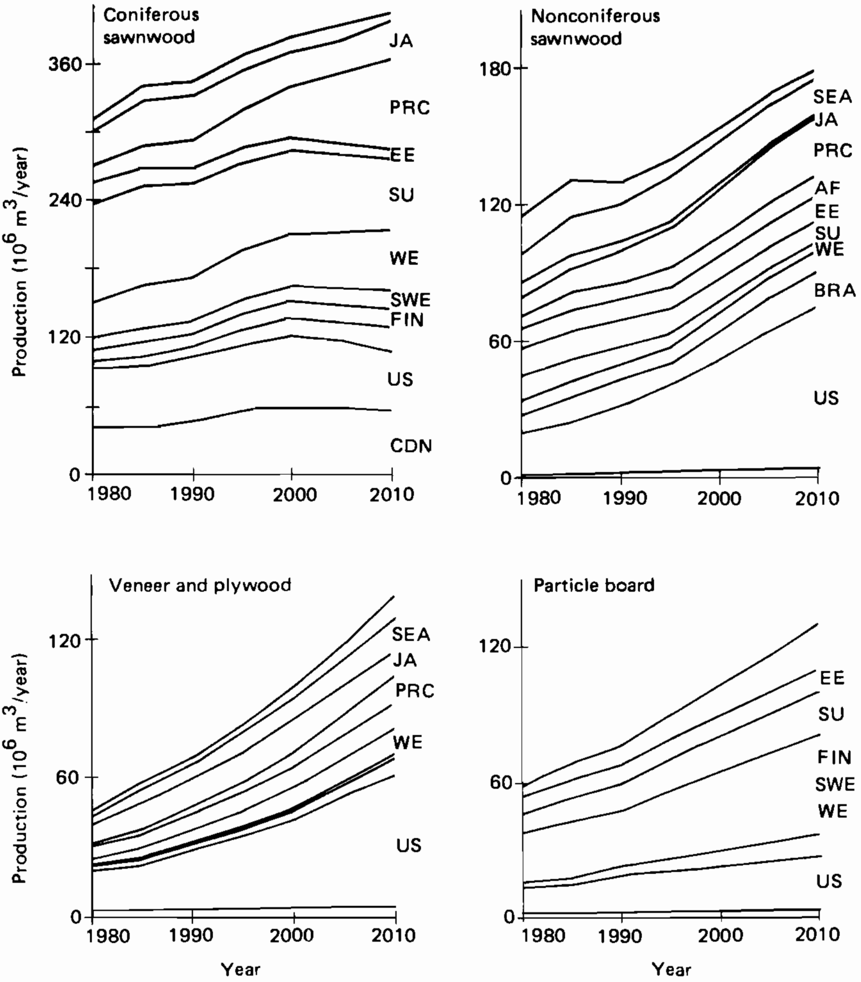

Figure 28.2 Sawnwood and panel production in the base scenario. Each year's production is shown cumulatively over regions so that the top line refers to total world production. Abbreviations are as in *Figure 28.1*.

and Southeast Asia, and for particle board they are the US, Latin America, Western Europe, and the USSR.

According to the base scenario, Canada maintains its position as the main producer of newsprint, with some of the developing regions rapidly

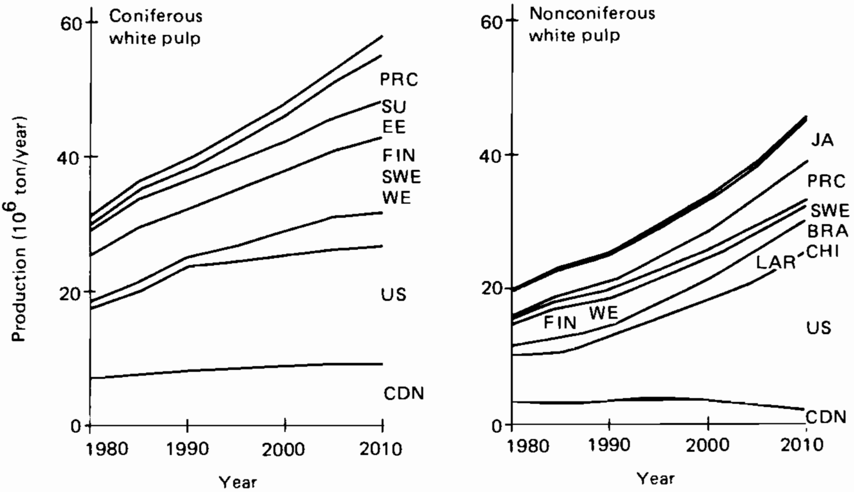

Figure 28.3. White pulp production in the base scenario (each year's figures are cumulative over regions). Abbreviations are as in *Figure 28.1*.

becoming important producers as well. For all other paper grades the US share remains large, although at the same time the shares of Latin America and China become more and more important. The scenario also shows a significant increase in printing paper production in the Nordic countries. Pulp production generally reflects the changes in paper production, with the US and Canada maintaining large shares. Particularly noticeable is a major increase in US nonconiferous white pulp production.

28.3. Consumption and Trade

Given that no changes in product inventory volumes are accounted for (see Chapter 22), consumption in each region is equal to production minus the net exports. To save space we omit graphs that show the regional distribution of world consumption, which can be determined from the production volumes above and from the import and export volumes shown in *Figures 28.5–28.8*.

In the GTM, total world exports are equal to world imports. Intraregional trade among countries within the same GTM region, such as Western Europe, is not counted. Therefore, *Figures 28.5–28.8* show only trade between the 18 GTM regions.

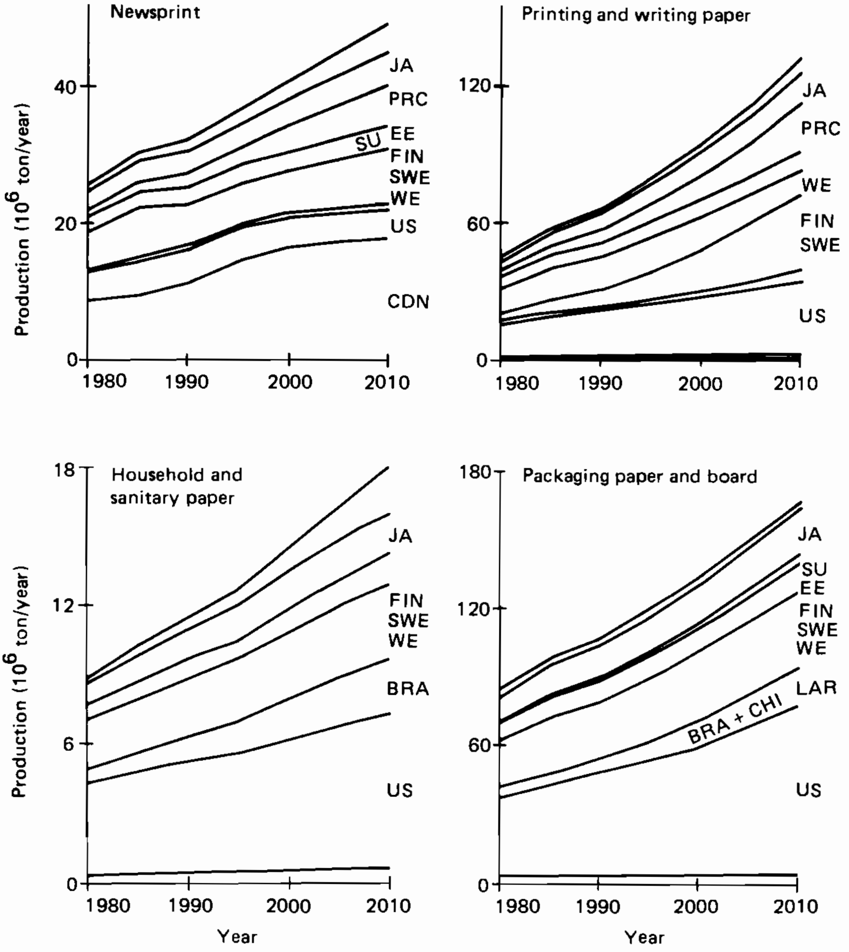

Figure 28.4 Paper production in the base scenario (each year's figures are cumulative over regions). Abbreviations are as in *Figure 28.1.*

Given that we deal with trade on a bilateral basis, a complete description of trade in the base scenario would require presentation of trade flow matrices for each product in each time period. As an example of such matrices, in *Table 28.1* we summarize coniferous sawnwood trade in the year 2000. In *Table 28.1*, however, we have aggregated the 18 GTM regions into 10 regions. Given that the GTM has 18 regions, 15 trade

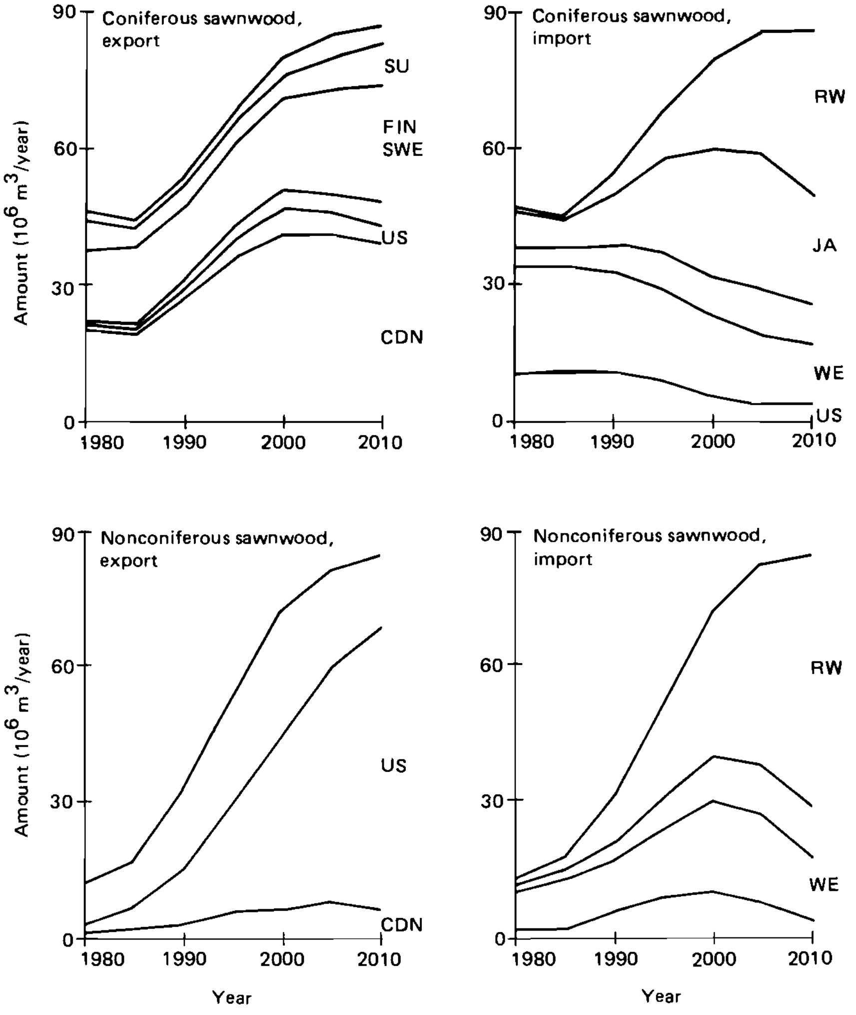

Figure 28.5 Sawnwood exports and imports in the base scenario (each year's figures are cumulative over regions). Abbreviations are as in *Figure 28.1*.

commodities, and 11 time steps, a full presentation would require 165 of the 18 by 18 trade flow matrices for each scenario. Because this is impractical, we report only total exports and imports over time by region (*Figures 28.5–28.8*). All of the complete trade matrices are available for study in the GTM computer printouts, however.

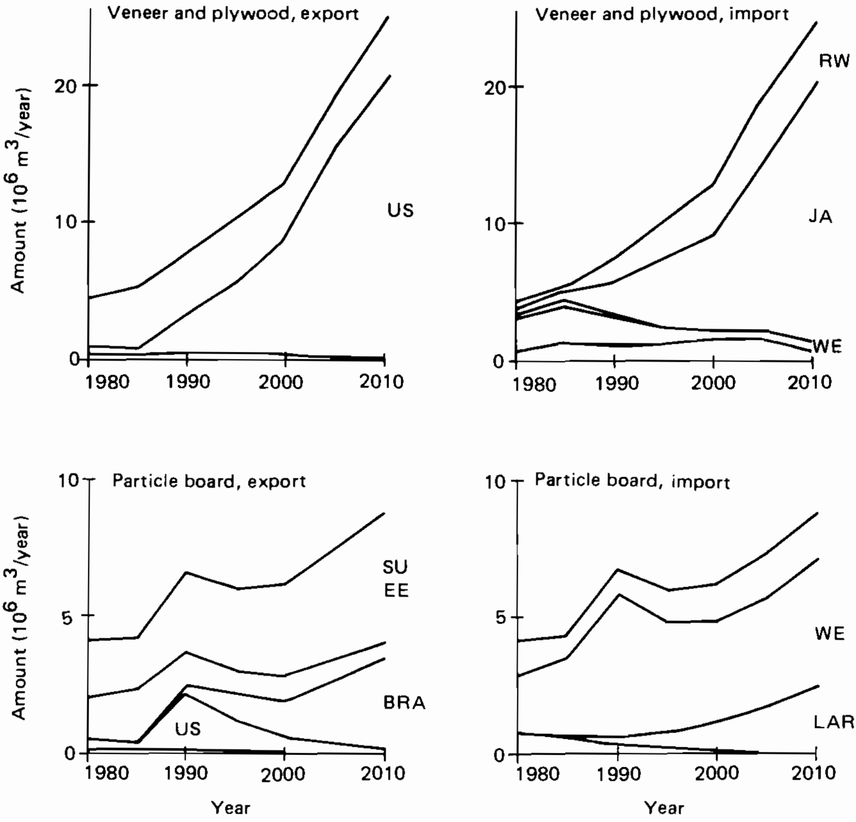

Figure 28.6 Wood based panel exports and imports in the base scenario (each year's figures are cumulative over regions). Abbreviations are as in *Figure 28.1*.

Productwise, several observations can be made concerning changes in trade patterns over time:

(1) *Coniferous sawnwood*: the Canadian share of total exports is increasing, the major growing markets being Japan and the Rest of the World.

(2) *Nonconiferous sawnwood*: most of the increase in US production is due to exports to the Rest of the World. This result, of course, is dependent upon assumptions concerning the development of future demand in the importing regions.

(3) *Veneer and plywood*: the US takes the major share of trade, with Japan importing most of the US exports.

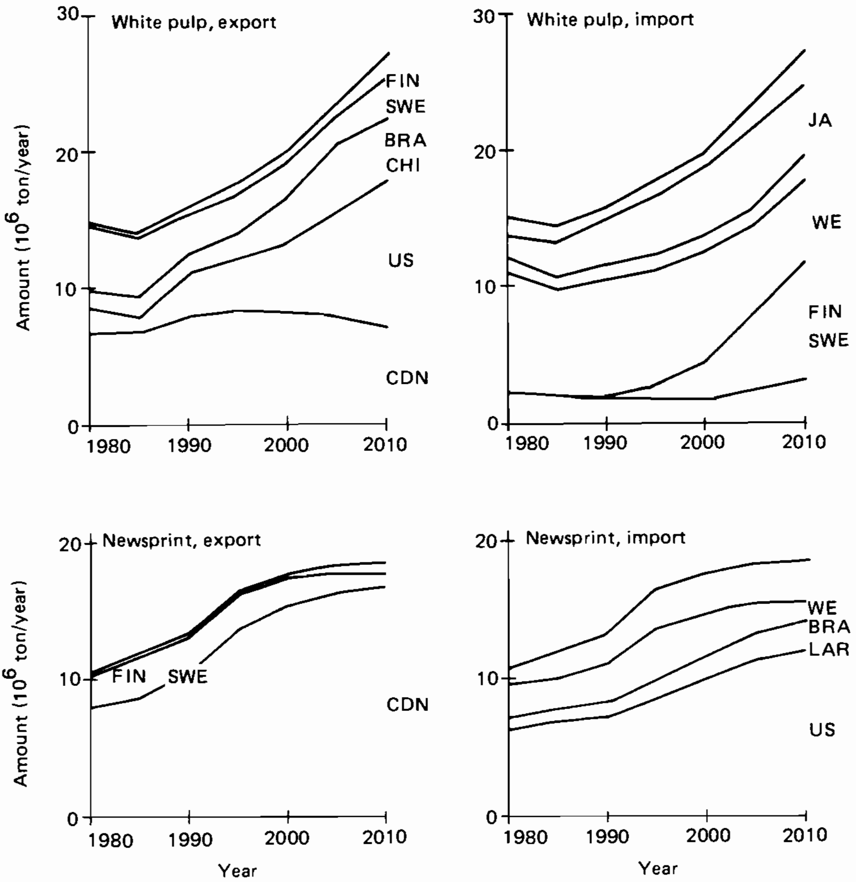

Figure 28.7 White pulp and newsprint exports and imports in the base scenario (each year's figures are cumulative over regions). Abbreviations are as in *Figure 28.1*.

(4) *Particle board*: the total volume of trade remains relatively low, with the USSR, Eastern Europe, and Brazil becoming the main exporters and the importers being Western Europe and the Rest of Latin America.

(5) *Newsprint*: exports are dominated by Canada, the main importers being the US and Western Europe, as is currently the case.

(6) *Printing paper*: exports that originate almost exclusively from the Nordic Countries enter mainly Western European, Southeast Asian, and Latin American markets.

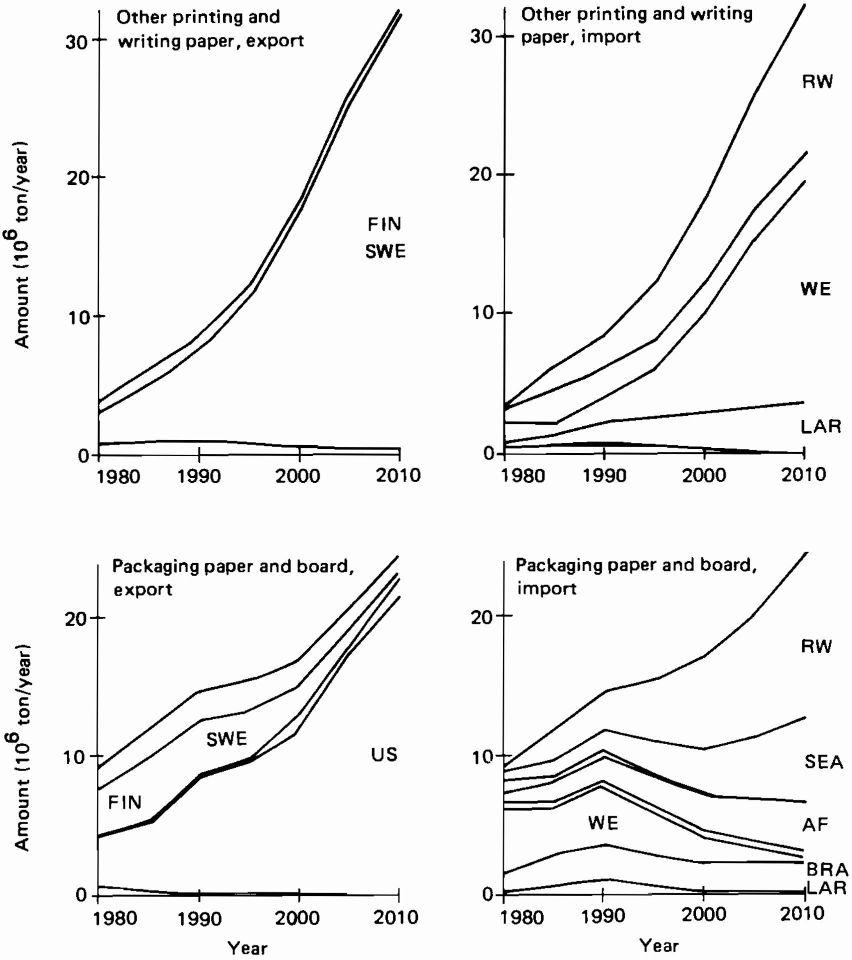

Figure 28.8 Paper exports and imports in the base scenario (each year's figures are cumulative over regions). Abbreviations are as in *Figure 28.1*.

(7) *Packaging papers and boards*: the world market share of the Nordic countries is declining in favor of the US. The Western European import market is declining and the increasing US exports reach a number of developing regions.

Table 28.1 Main trade flows of coniferous sawnwood for the year 2000 in the base scenario (10^6 m^3 per year). Numbering of the regions is the same for both exports and imports.

	Importing region										
Exporting region	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	*Total exports*
(1) Canada		5			1		4	27		4	41
(2) US			2							4	6
(3) Latin America											0
(4) Finland and Sweden					10		2			8	20
(5) Western Europe											0
(6) USSR and Eastern Europe					1		1	2		2	6
(7) Africa and China											0
(8) Japan											0
(9) Southeast Asia and Australia–New Zealand										2	2
(10) Rest of the World											0
Total Imports	0	5	2	0	12	0	7	29	0	20	75

(8) *White pulp*: North America's share in the world market increases, with the US supplying mainly nonconiferous pulp and Canada supplying mainly coniferous pulp. Other important exporters are the Nordic countries, Brazil, and Chile, the first region with declining and the second two with increasing market shares. Major importers are Japan and Western Europe. Owing to increasing printing paper production, over the long term, the Nordic countries become major importers as well, especially in nonconiferous pulp.

(9) *Other products*: for roundwood the major exporters are North America, the USSR, and Southeast Asia; the main importers are Western Europe, Japan, and China. Whether or not such trade could actually develop depends on policies concerning wood raw-material export and decisions related to investments in logistical systems. For household and sanitary paper, trade is insignificant because of high transportation costs. For recycled paper, significant exports develop over time from major paper-consuming regions to regions that are major producers, but minor consumers of paper.

According to some trade experts, changes in the base scenario trade may be somewhat of an overreaction (see, for example, the changes in coniferous sawnwood trade between 1980 and 2000). This is because we intentionally employed relatively relaxed inertia constraints (see Chapter 24), so that these exogenous bounds would not predetermine trade flows.

28.4. Prices

In *Figures 28.9–28.11* we summarize the development of product prices over time for four representative regions, as computed by the base scenario. Product prices are determined by the market equilibrium solution in each model period and are thus endogenous to the GTM (see Chapter 20 for a discussion of this point). The price graphs therefore represent outputs from the model, rather than exogenous price forecasts.

It should be remembered that the prices computed by the GTM are international market-clearing prices, rather than domestic ones. Price

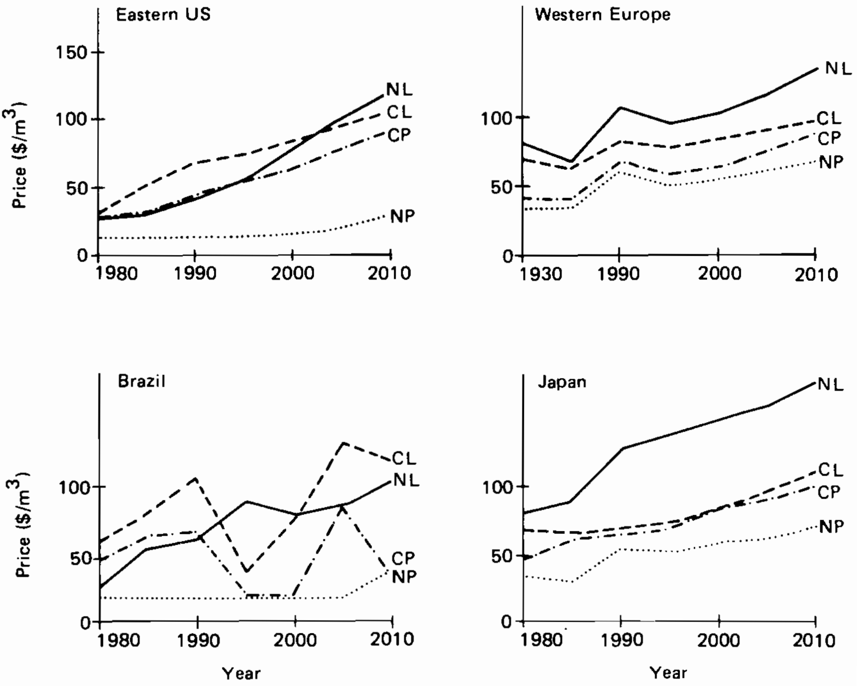

Figure 28.9 Prices of logs and pulpwood in the base scenario. CL, coniferous logs; CP, coniferous pulpwood; NL, nonconiferous logs; NP, nonconiferous pulpwood.

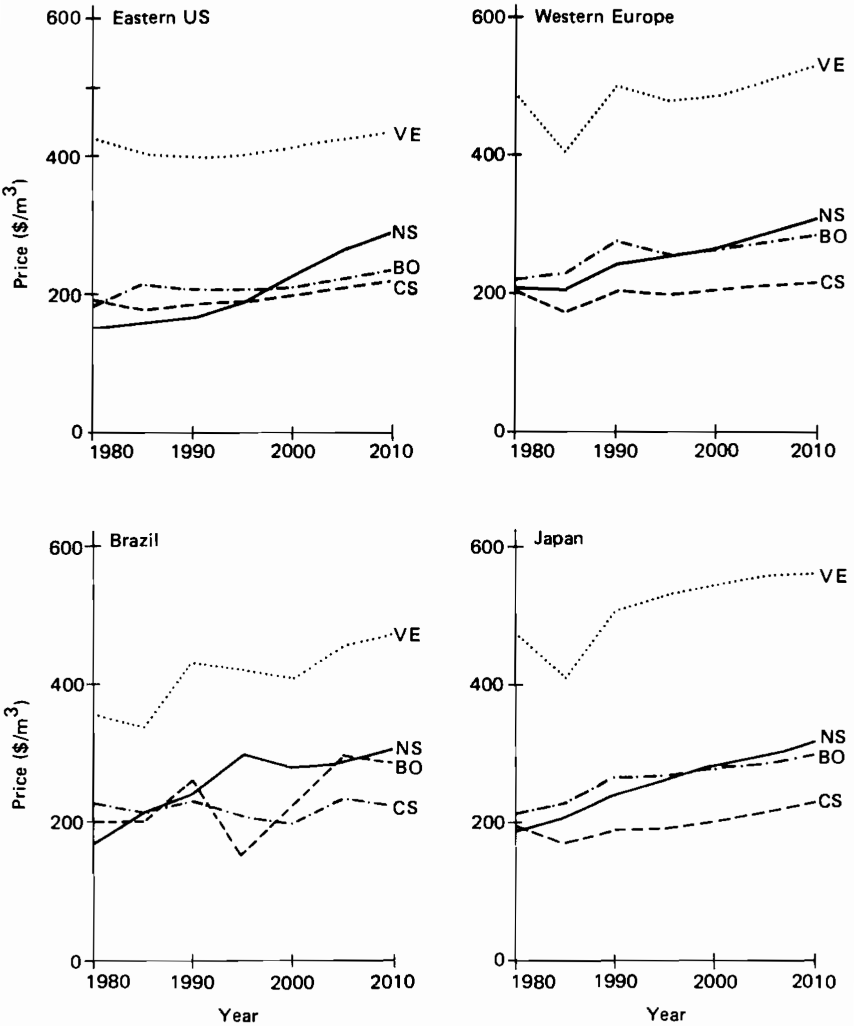

Figure 28.10 Prices of sawnwood and panels in the base scenario. CS, coniferous sawnwood; NS, nonconiferous sawnwood; BO, particle board; VE, veneer and plywood.

levels for some products therefore appear to be high compared with current prices in individual countries. This is because of the assumption in the GTM that all the production of a given product represents a single quality suitable either for domestic use or for export.

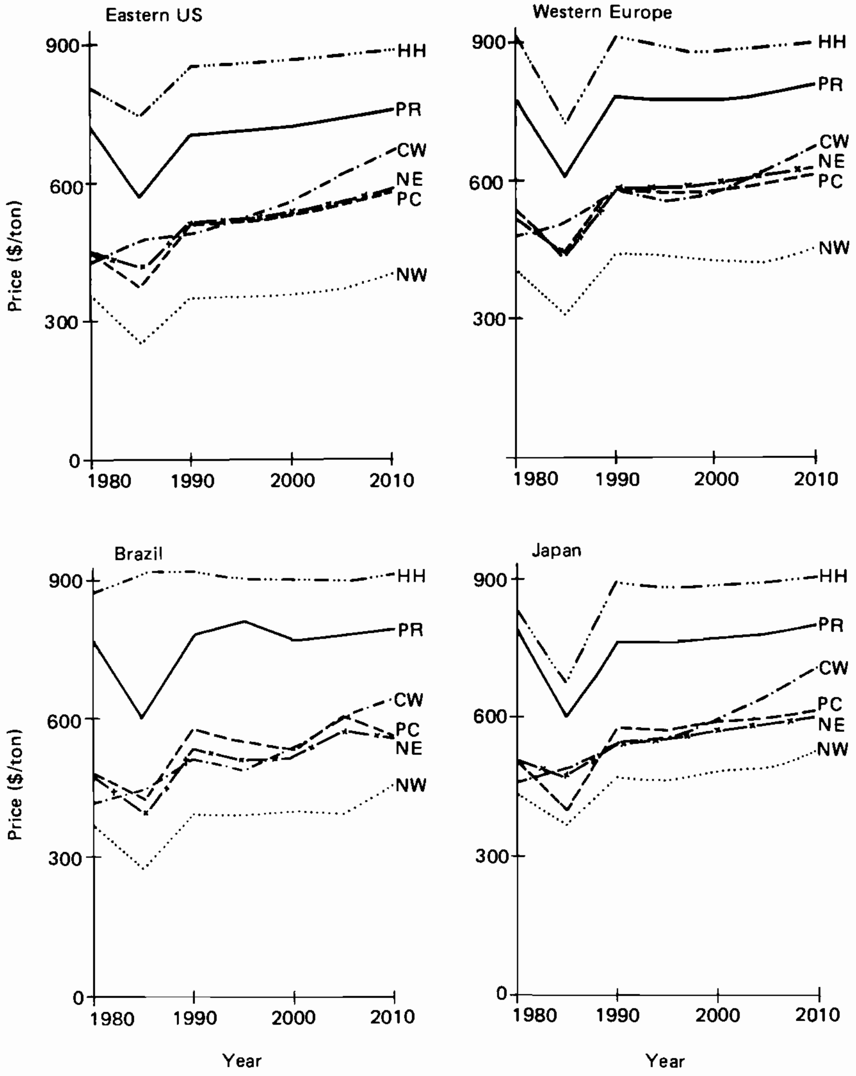

Figure 28.11. Prices of pulp and paper in the base scenario. CW, coniferous white pulp; NW, nonconiferous white pulp; NE, newsprint; PR, printing and writing paper; HH, household and sanitary paper; PC, packaging paper and board.

In many of the price graphs, both for the base scenario and for the alternative scenarios, price trends exhibit a curious dip in 1985 and then recover afterward. Except for pulp and paper, this does not happen in the US, or at least the effect there is dampened. The major cause of this price dip is the worldwide devaluation of currencies as measured against the US dollar that occurred between 1980 and 1985. Since all the GTM prices and costs are measured in US dollars, the devaluation causes all regions to become more competitive in 1985 compared with the US, permitting the US-dollar prices to drop. Under the base scenario assumption, all currencies experience a revaluation compared with the US dollar between 1985 and 1990, which causes prices to increase during that period. An additional cause of the 1985 price dip for pulp and paper products is the fact that we have used data from FAO (1983) to fix pulp and paper capacities for 1985. This results in an excess of capacity in 1985, which causes the prices of pulp and paper to drop everywhere, including in the US. Although these short-term effects are interesting they only deserve limited attention in a long-term model of this type; more attention should generally be paid to the long-term trends than to the short-term fluctuations.

Real prices generally do not increase very much in the base scenario. Most of the price increases result from a steadily increasing scarcity in the timber resource. The larger increases are in logs and pulpwood, with generally smaller percentage price increases in mechanical products, and still smaller increases in paper products; except for the dip in 1985, the latter are almost flat over the period 1980–2010. The price of coniferous white pulp increases much more than that of paper products because of the steady increase in the price of coniferous pulpwood. This is despite the fact that over time an increased substitution of nonconiferous pulpwood for coniferous pulpwood was implemented in the base scenario (see Chapter 22).

The price trends for Brazil are notably more erratic than those for the other regions. This is due to the age structure of Brazil's plantation forests (see Chapter 21). In the scenario, until 1990 there is a scarcity of timber that causes prices to rise significantly (even overcoming the effects of devaluation of the Brazilian cruzeiro). In 1995, however, the maturing of timber relieves this scarcity and prices fall substantially. By 2005, because of the installation of new productive capacity, the timber supply once again becomes relatively scarce and prices rise.

28.5. Structural Change of the Forest Industry by Region

One way to measure the total industrial output of the forest sector is to value the production of pulp and paper as well as that of solid wood products at prices that result from the GTM solutions, i.e., at prices that typically are cost–insurance–freight (CIF) import prices or free-on-board (FOB) export prices. Because of quality differences, not accounted for in the GTM, between the average commodity consumed domestically and the average commodity traded in the world market, the value of production tends to overestimate the real value of industrial output. Nevertheless, the use of product value provides a useful means for summarizing up the various GTM product lines. It is employed here to measure growth and changes in forest industrial structures in various regions.

Figures 28.12 and *28.13* show the total value of production in 10^9 US dollars per year for eight aggregate regions during the period 1980–2010. Each graph is cumulative over products so that the top thick line indicates the sum over all the products, starting with coniferous sawnwood, etc., up to packaging papers and boards. The lower thick line indicates the value of all solid wood products. Thinner lines are used to distinguish between other products or groups of products. The slices between lines indicate the value of production in a given product or product group. These are identified on the graphs where space permits.

In 1980 the US forest products industry had a very high level of output and the base scenario provides a high rate of growth, which is relatively uniform over various production lines, but with a slightly higher relative growth in nonconiferous sawnwood and panels. The growth in Canada is somewhat slower than in the US. The most promising product lines for Canada, according to the base scenario, are newsprint and coniferous sawnwood.

Overall, growth in Western Europe and Japan is significantly slower than in North America. In Western Europe, the main growing product lines are panels and packaging materials, whereas in Japan growth is almost exclusively due to increasing production in pulp and paper as a whole.

The Nordic countries represent a fast-growing, but inconsistent industry. As in Japan, solid wood products have a relatively slow growth. However, printing paper production, in particular, appears highly competitive and consequently grows rapidly. However, other paper products are unable to compete effectively for capital and wood raw-material, so they stagnate. The relative growth rates in Latin America, Southeast Asia, and Australia–New Zealand are high. They eventually become significant participants in the world forest sector, particularly in solid wood products. However, given the relatively low starting levels of output in 1980, the share of these regions in the world forest industries remains moderate until the year 2010.

The figures for the USSR and Eastern Europe are almost predetermined by the exogenous scenario assumptions concerning volume of production. Given rather conservative assumptions, the growth rates are low and the share of solid wood products remains high.

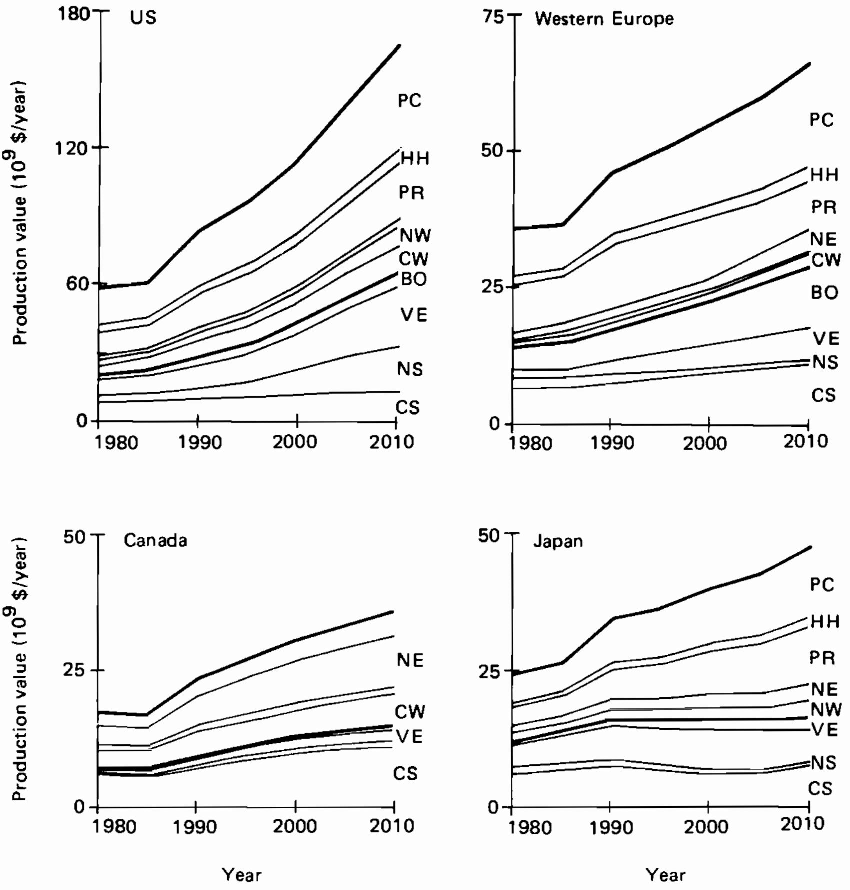

Figure 28.12 Production value of processed goods. Each curve is cumulative over products so that the top thick line indicates the total value of all products. The lower thick line represents the total value for solid wood products. CS, coniferous sawnwood; NS, nonconiferous sawnwood; VE, veneer and plywood; BO, particle board; CW, coniferous white pulp; NW, nonconiferous white pulp; NE, newsprint; PR, printing and writing paper; HH, household and sanitary paper; PC, packaging paper and board.

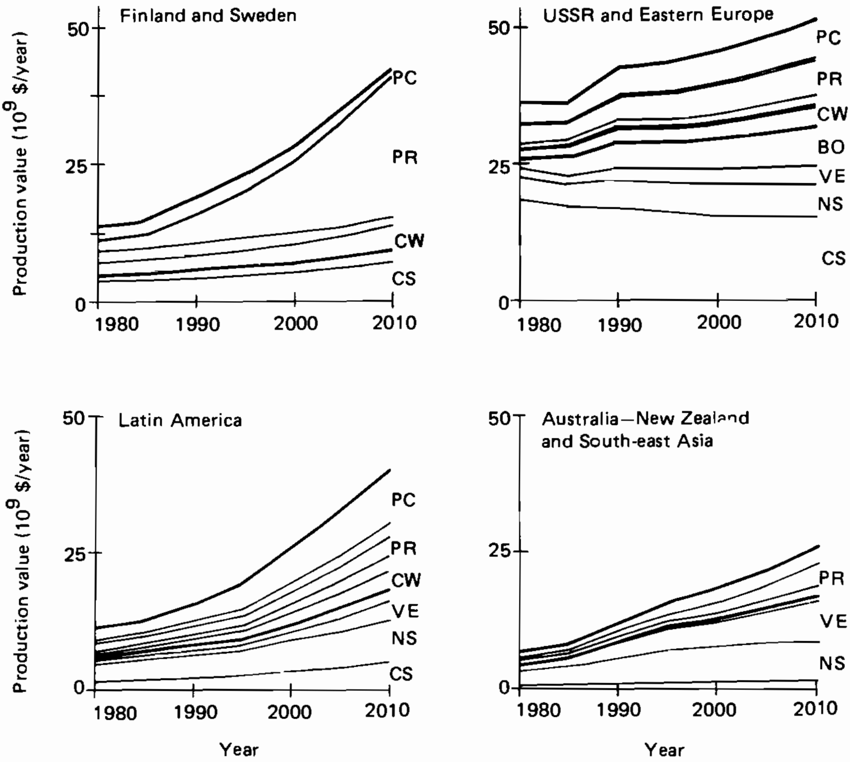

Figure 28.13 Production value of processed goods. Each curve is cumulative over products so that the top thick line indicates the total value of all products. The lower thick line represents the total value for solid wood products. Abbreviations are as in *Figure 28.12.*

28.6. Sensitivity Analysis

As a final topic on the base scenario, we discuss interpretations of the dual solution to the GTM (see Chapter 20). In particular, we consider the marginal value of productive capacity and the marginal values of changing trade flows. Some familiarity with the basics of optimization theory (see, e.g., Dantzig, 1963) are expected from the reader.

28.6.1. Return on investment in processing capacity

According to our formulation of the GTM, the reduced gradient component for any given investment activity (i.e., production activity for technology T_3; see Chapter 22) is the profit per unit of product ($\$/\text{ton}$ or $\$/\text{m}^3$), which results from subtracting from product price the costs of processing, timber, pulp, and recycled paper, as well as capital costs. Let g be such profit added by the capital costs and denote by I the investment expenditure per unit of capacity that produces one unit of product per year. A simple formula for the return on investment is $q = 100g/I$, i.e., given that a profit of g $\$/\text{ton}$ ($\$/\text{m}^3$) per year is maintained over the years to come, then the resultant return on investment is $q\%$. Of course, this formula gives only an approximation. First of all, the profit g applies to marginal changes in capacity and an actual increase in capacity may change this figure. Second, the profit g applies only to a single time step, i.e., to five years, whereas the formula assumes an indefinite stream of annual profits g.

In *Table 28.2* we show the return q by product line and region in 1980, when no capacity expansion was allowed in the model. The larger the figure, the more attractive the investment possibility. A negative

Table 28.2. Return on marginal investment (%) in processing capacity expansion in 1980.

Product	*Canada*	*US*	*Brazil*	*Finland and Sweden*	*Western Europe*	*Japan*	*South-east Asia*	*Australia–New Zealand*
Coniferous sawnwood	20	38	16	17	17	13	19	-1
Nonconiferous sawnwood	28	25	55	21	-6	-1	12	7
Veneer and plywood	15	30	12	14	14	17	21	38
Particle board	7	13	2	6	11	9	12	11
White pulp	17	17	12	11	12	17	17	22
Newsprint	16	17	6	8	6	13	11	24
Printing and writing paper	19	22	12	20	15	17	21	26
Household and sanitary paper	21	12	9	10	15	9	16	17
Packaging paper and board	13	21	6	15	10	11	14	16

return or, given the risks involved, a small positive return indicates a negative incentive for investment. However, one may use these values to calculate how much the production costs should be reduced or production subsidized (per ton or m^3) in order to make an investment attractive. Given no subsidies nor other changes that influence profitability, *Table 28.2* indicates where in the model the strongest pressures for expansion existed in 1980. Note, however, that changes due to the strengthening US dollar are not reflected in this table.

28.6.2. Impact of inertia and barriers to trade

As discussed in Chapter 20, the reduced gradient, denoted by h, for a trade flow indicates the marginal profit ($\$/m^3$ or $/ton) from increasing this flow. Such profits are given in *Table 28.3* for coniferous sawnwood trade flows in the year 2000 between ten aggregated regions of the GTM; the same regions that were used to illustrate the actual trade flows of this product in *Table 28.1*. As a general rule, one may observe that $h = 0$ if there is a flow (figures indicated in a **bold** figure). In such a case, the price differences between exporting and importing regions cover exactly the trade costs (transportation costs and tariffs). In some cases there is a (small) nonzero marginal profit associated with a trade flow, indicated by a bold figure. If the value is negative, such as –6 $\$/m^3$ for the flow from Canada to Western

Table 28.3 Marginal profits (shadow prices) of coniferous sawnwood trade flows for the year 2000 in the base scenario ($\$/m^3$). Flows appearing at positive level are indicated by **bold** figures (see also *Table 28.1*).

	Importing region									
Exporting region	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Canada		**0**	–15	–40	**–6**	–36	**–10**	**0**	–55	**5**
(2) US	–33		**0**	–53	–31	–49	–31	–19	–64	**8**
(3) Latin America	–78	–44		–73	–51	–70	–30	–59	–88	–25
(4) Finland and Sweden	–61	–37	–106		**0**	–20	**0**	–78	–92	**2**
(5) Western Europe	–81	–59	–134	–50		–45	–31	–104	–115	–20
(6) USSR and Eastern Europe	–63	–37	–102	–19	**–2**		**0**	**0**	–73	**0**
(7) Africa and China	–92	–67	–129	–84	–62	–75		–29	–86	–147
(8) Japan	–95	–72	–139	–94	–72	–80	–42		–92	–17
(9) Southeast Asia and Australia–New Zealand	–63	–34	–95	–57	–35	–47	–13	–19		**21**
(10) Rest of the World	–131	–110	–169	–112	–90	–103	–98	–92	–128	

Europe, an inertia lower bound is binding and the loss (to be shared between importer and exporter) is –6 \$/m^3. We may conclude that such a trade flow would tend to decrease more rapidly than the inertia constraint allows. The opposite is the case when h is positive, e.g., export from Canada to the Rest of the World. In this case an extra profit of 5 \$/m^3 could be made to cover the possible costs of expanding marketing efforts or improving logistics, so that trade would tend to increase faster than the assumed inertia would allow.

In the case where there is no trade between two regions in a given year of the scenario, h can be positive, negative, or zero. In *Table 28.3* it is always negative and indicates the reduction required (e.g., in transportation costs and in the domestic price of sawnwood, tariffs, subsidies, etc.) in order to make the trade break even. As an example, to induce exports of coniferous sawnwood from the US to Western Europe, savings of 31 \$/m^3 would be needed. A value of $h = 0$ indicates that there are alternative patterns for an equilibrium trade. A positive value of h indicates that the trade flow activity is not included in the model, for example because of export prohibition. In such cases the value of h indicates the amount by which profits could maximally be increased (per m^3 or per ton) if the export prohibition were lifted.

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CHAPTER 29

Scenario Variations

D.P. Dykstra and M. Kallio

29.1. Alternative Rates of Economic Growth

To test the sensitivity of the GTM to changes in the overall economic conditions we consider two alternative economic growth scenarios: low growth and high growth. Recall from Chapter 27 that in the low-growth scenario we assume a *base* growth rate of income per capita that is 50% lower than in the base scenario. As outlined in Chapter 23, the *base* growth rate applies only to the beginning of the projection horizon and is reduced as income per capita increases. For the high-growth scenario the base growth rate is increased by 50%, but only for developing regions. Rather than discussing the results of these two scenarios in their entirety, we concentrate on a few points of interest only.

Figure 29.1 shows industrial timber removals in the period 1980–2010 for the base scenario and the two alternative economic growth scenarios. These removals include all log and pulpwood removals, both coniferous and nonconiferous, but exclude fuelwood removals. The figure shows that the growth rate in the high-growth scenario is about one quarter higher than in the base scenario and that in the low-growth scenario the growth rate is about one third lower than in the base scenario. Price effects tend to absorb somewhat the impacts of changes in economic growth. For example, in the low-growth scenario, decreasing demand brings down prices, which in turn tends to increase demand. Therefore, the overall decrease in consumption is less than one would expect from the decrease in economic growth and related income elasticity parameters alone.

Figure 29.2 shows the impact of the economic growth scenarios on total world production (and thereby on total consumption) for various forest products. For some products, like veneer, plywood, and printing

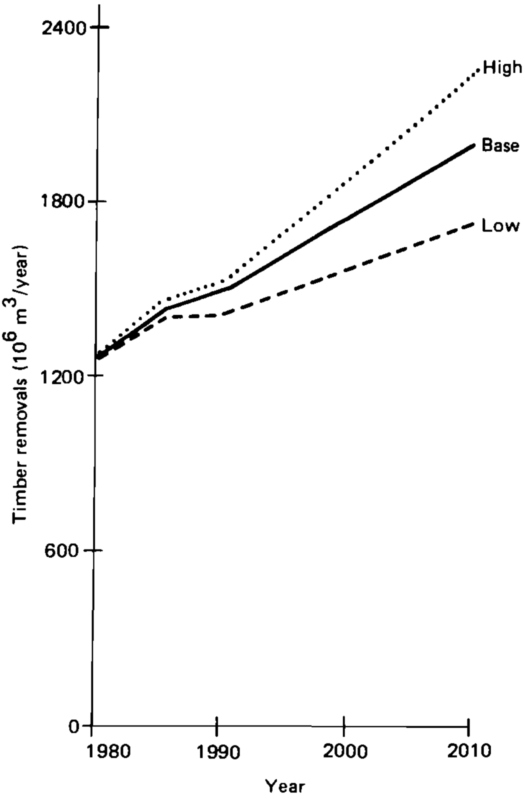

Figure 29.1 Industrial timber removals in the high- and low-growth scenarios and in the base scenario.

paper, the rule for industrial timber removals of "one quarter increase–one third decrease" in growth rates also applies approximately. For other products, however, there are some notable exceptions to this rule. Nonconiferous sawnwood, for instance, is almost completely insensitive to changes in economic growth rates. The reason is that, for this product, the income elasticity is low and the price elasticity is high in regions that are major consumers. For coniferous sawnwood and reconstituted boards, demand seems to be insensitive to increases in the economic growth rates of developing countries. The main reason for the former product is a relatively high price elasticity and for the latter a relatively low share of world consumption in the developing regions.

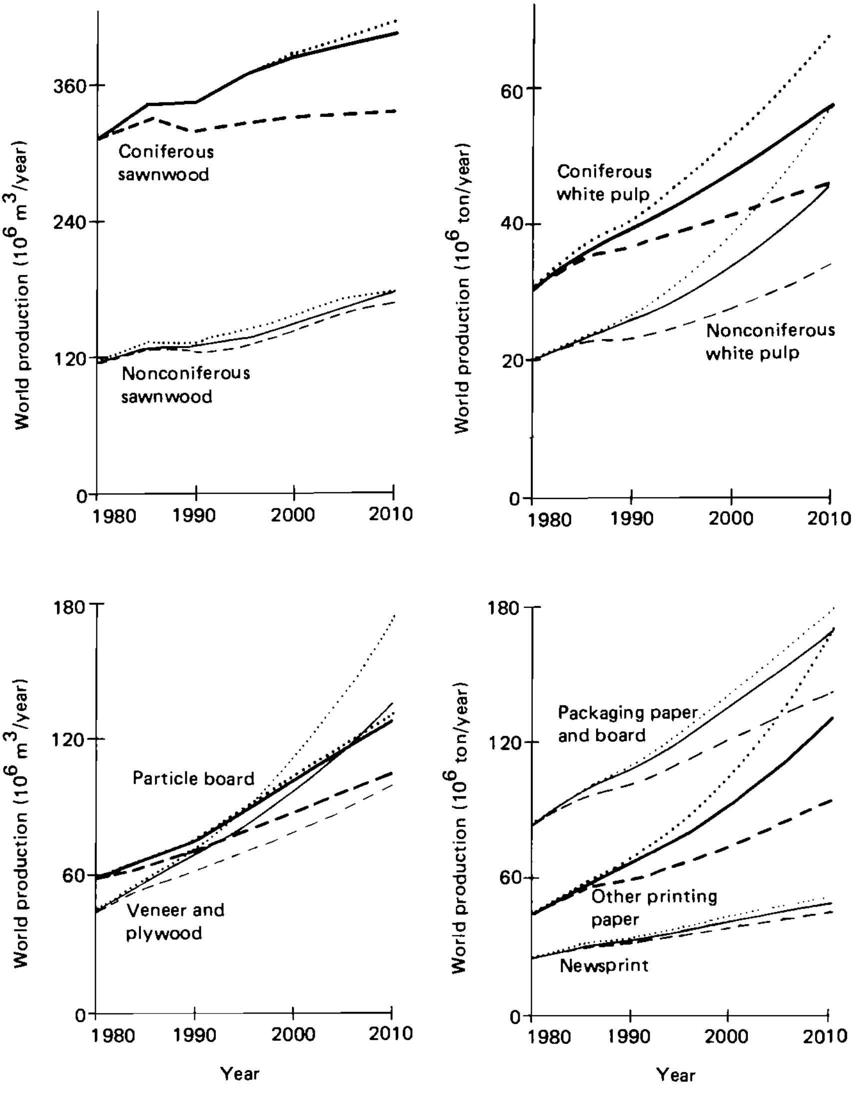

Figure 29.2 World productions (= consumptions) in the high- (dotted lines) and low-growth (dashed lines) scenarios versus those in the base scenario (full lines).

Figure 29.3 shows price developments in the Eastern US for the alternative growth scenarios. In the low-growth scenario, prices are almost

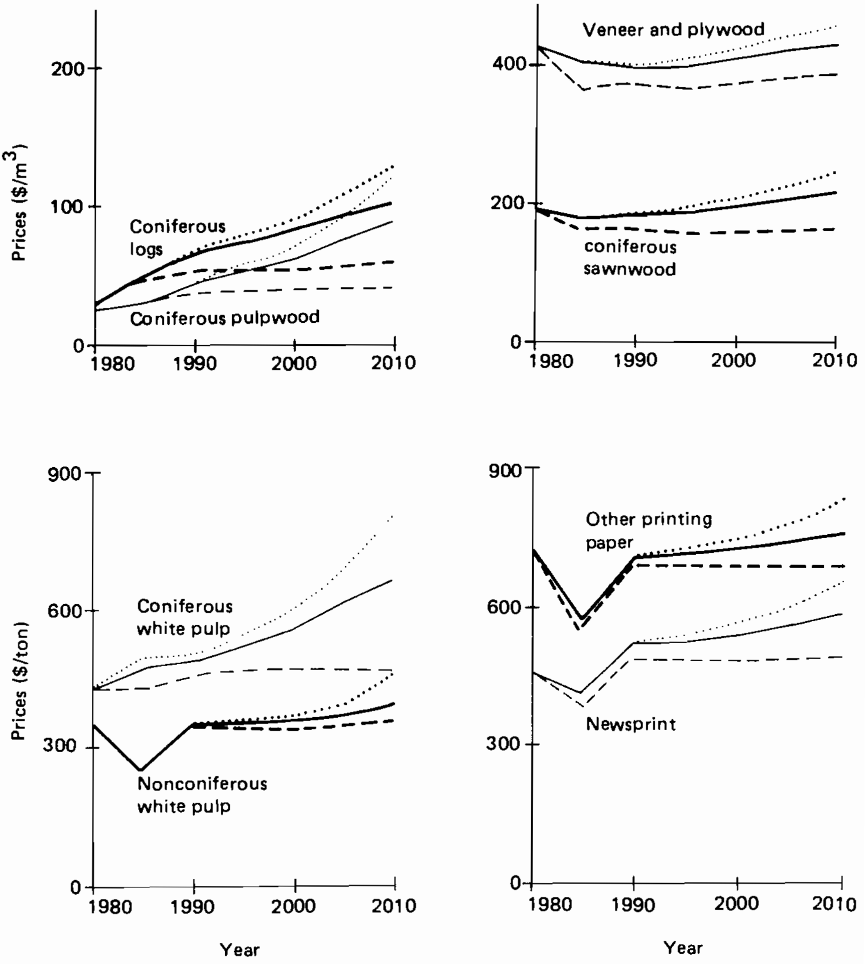

Figure 29.3 Prices in the Eastern US in the high- (dotted lines) and low-growth (dashed lines) scenarios versus those in the base scenario (full lines).

constant over time, i.e., in this case demand for forest products increases in harmony with supply so that timber does not become increasingly scarce over time. Again, the high price elasticity of coniferous sawnwood in developing countries explains the minor price difference between the high-growth and the base scenarios.

Finally, *Figure 29.4* indicates the impact of economic growth assumptions on the growth of the forest industries in terms of the value of industrial products (measured in world market prices) in a number of regions. The distribution of increased growth over regions in the high-growth scenario is relatively uniform. However, relative benefits to the Western European and Japanese forest industries seem to be lower than for other

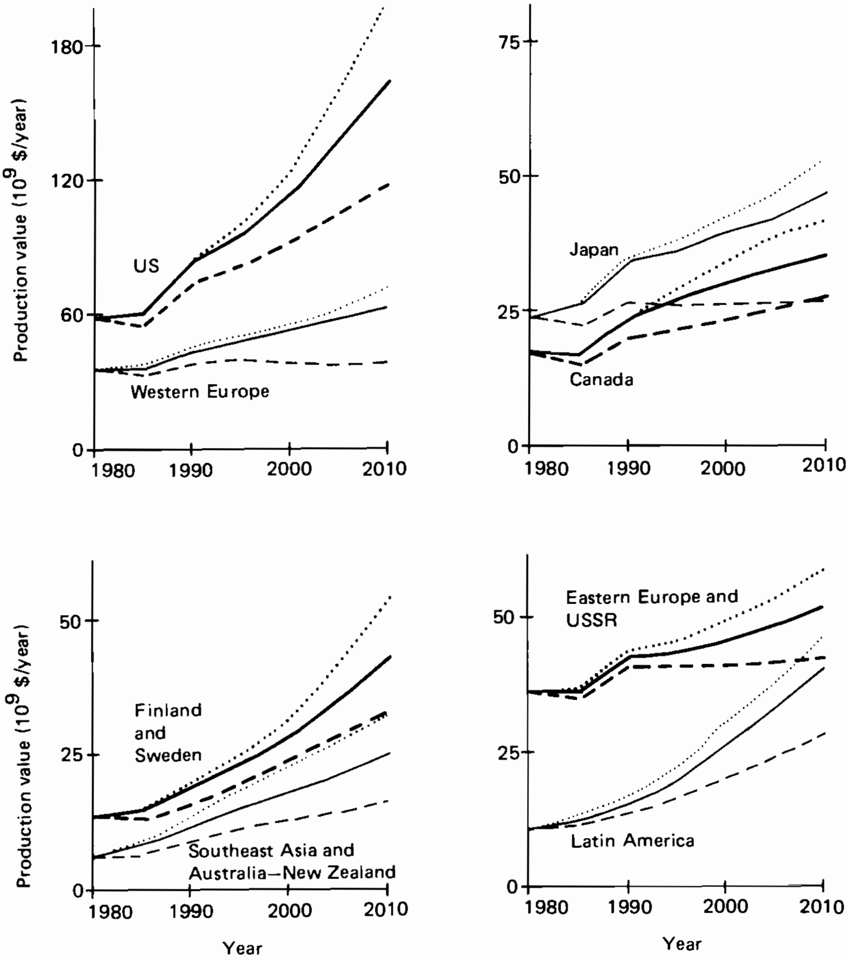

Figure 29.4 Production values in the high- (dotted lines) and low-growth (dashed lines) scenarios versus those in the base scenario (full lines).

regions. In addition, a notable feature of the low-growth scenario is that the growth of forest industries in Western Europe and Japan is almost negligible. This appears to be due to the strong competitive position of imported forest products in these regions, i.e., imports are less sensitive to slowed growth than domestic production in Western Europe and Japan. At the same time, roundwood imports to Japan decrease drastically in this scenario.

29.2. Exchange Rate Variations

As described in Chapter 27, in the strong-dollar scenario exchange rates are held at the 1985 level until the end of the projection horizon. In the weak-dollar scenario, the real values of currencies relative to the US dollar climb by 1990 to levels that are above the 1980 value by one third of the 1980–1985 devaluation. We first discuss the impacts of these assumptions on production, consumption, and trade in a number of regions in the year 2000. Thereafter, the impacts over time on US forest industries are shown.

Percentage increases in consumption relative to the base scenario in the year 2000 are shown in *Table 29.1*. As a general rule, in the strong-dollar scenario consumption in the US increases, whereas it decreases in Japan and Western Europe. The reason for this is that the decreasing production costs (in terms of US dollars) outside the US push down the general price level of forest products. Thereby the US consumption increases with a tendency to pull up prices. The resultant price effect in domestic currencies in Japan and Western Europe decrease consumption in these regions.

Consumption of mechanical products seems to be more sensitive to exchange rates than that of paper products. This is partly explained by differences in price elasticity for these product groups and partly by the differences in the share of capital costs as a fraction of total production costs. (Note that no regional differences in capital costs due to exchange rate changes were assumed.)

Changes in pulp consumption are, of course, derived from changes in production. The latter are summarized in *Table 29.2*. In general, US production decreases in the strong-dollar case, with particle board being the only minor exception. At the same time, consumption increases and therefore net imports must increase. Thus, the scenario supports the general hypothesis that the strong dollar attracts imports to the US and hinders exports. As expected, in the weak-dollar scenario, US production, consumption, and net imports deviate from the base scenario in the opposite direction, i.e., production and exports tend to increase while consumption and imports decrease.

Table 29.1 Percentage differences in consumption in the year 2000 between the strong-dollar and base scenarios and between the weak-dollar and base scenarios.

Strong-dollar scenario	*US*	*Japan*	*Western Europe*
Coniferous sawnwood	6	–7	–7
Nonconiferous sawnwood	51	–21	–41
Veneer and plywood	1	–7	–7
Particle board	4	–8	–13
Coniferous pulp	–6	3	0
Nonconiferous pulp	–3	–3	–6
Newsprint	3	–2	–9
Other printing paper	1	–2	–3
Packaging paper and board	0	–2	–3

Weak-dollar scenario	*US*	*Japan*	*Western Europe*
Coniferous sawnwood	–12	10	9
Nonconiferous sawnwood	–17	35	50
Veneer and plywood	–3	8	10
Particle board	–6	10	15
Coniferous pulp	22	–6	6
Nonconiferous pulp	20	–2	2
Newsprint	–5	7	11
Other printing paper	–2	4	4
Packaging paper and board	–2	2	3

Because the Canadian dollar tends to move closely in line with the US dollar, the results for Canada in the strong- and weak-dollar scenarios are qualitatively the same as those in the US case. There are exceptions though, such as the increase in printing paper production in Canada in the strong-dollar scenario, which is due to increased exports to the US.

For other regions the interpretation of results in these scenarios is not as straightforward as for the US and Canada. The simplifying factor in the US case is that in these scenarios we change the strength of the US dollar in the same direction with respect to *all* other currencies. The complication, in general, is that the strength of a particular currency with respect to all other currencies, not only the US dollar, counts, and the currencies move in many different directions. In Western Europe, for example, production in the strong-dollar scenario increases or decreases depending on

Table 29.2. Percentage differences in production in the year 2000 between the strong-dollar and base scenarios and between the weak-dollar and base scenarios.

Strong-dollar scenario

	US	*Canada*	*Japan*	*Western Europe*	*Northern Europe*
Coniferous sawnwood	-26	-26	75	-7	-10
Nonconiferous sawnwood	-10	-15	-30	0	-28
Veneer and plywood	-14	0	-4	-5	47
Particle board	1	4	-8	-9	-13
Coniferous pulp	-9	0	0	28	-7
Nonconiferous pulp	-17	-25	-5	0	23
Newsprint	-29	-8	5	13	8
Other printing paper	-1	12	-3	-6	-10
Packaging paper and board	-11	0	-2	1	4

Weak-dollar scenario

	US	*Canada*	*Japan*	*Western Europe*	*Northern Europe*
Coniferous sawnwood	0	13	-12	7	7
Nonconiferous sawnwood	9	21	56	113	43
Veneer and plywood	33	75	-16	-45	-40
Particle board	22	0	2	-3	14
Coniferous pulp	14	-20	0	100	11
Nonconiferous pulp	17	19	5	0	-29
Newsprint	7	31	-35	-28	-8
Other printing paper	22	12	4	4	-7
Packaging paper and board	30	0	-13	-33	16

the product. The result depends on the strength of Western European currencies with respect to currencies in regions that are major exporters of the product into Western Europe. For example, Canada is a major supplier of newsprint to Western Europe, so Western European production of newsprint increases in the strong-dollar scenario (decreases in the weak-dollar scenario) because the currency with respect to the Canadian dollar weakens (strengthens).

For coniferous sawnwood production in Western Europe, the changes are in the opposite direction. Part of the reason for this is the change in Western European consumption. In addition, in the strong-dollar scenario, the Nordic countries are the main exporters of coniferous sawnwood to Western Europe and their currencies are relatively weak compared with those of Western Europe. In spite of this, the Nordic production of coniferous sawnwood in the strong-dollar scenario decreases as well, because of the overall decrease in consumption. For example, exports to Western Europe decrease, but not as much as consumption decreases in Western Europe.

In Japan, there is a large shift from coniferous sawnwood imports to coniferous log imports and domestic sawmilling in the strong-dollar scenario. The opposite phenomenon may be observed, although somewhat weaker, in the weak-dollar scenario. The reason in the strong-dollar case is that the North American industry loses its competitive position in the sawnwood market, which results in an increasing export supply of roundwood, in this case to Japan.

The main changes in trade in coniferous logs and coniferous sawnwood for the strong-dollar case in the year 2000 are summarized in *Table 29.3*. In addition to the above results, we notice a reduction in log exports from Canada to the US (this was permitted in the base scenario) and a major increase in sawnwood trade.

Table 29.3 Net increase in trade flows (10^6 m^3/year) of coniferous logs and coniferous sawnwood in the strong-dollar scenario as compared with those in the base scenario in the year 2000.

Coniferous logs

	Importer					
Exporter	*US*	*Latin America*	*Western Europe*	*Japan*	*Other*	*Total*
Canada	–4.6			2.0		–2.6
US				22.5		22.5
Nordic Countries						0.0
USSR and Eastern Europe			–2.3			–2.3
Total	–4.6	0.0	–2.3	24.5	0.0	

Coniferous sawnwood

	Importer					
Exporter	*US*	*Latin America*	*Western Europe*	*Japan*	*Other*	*Total*
Canada	14.3	–0.1	–0.5	–24.0	–5.6	–15.9
US		–1.0			–4.1	–5.1
Nordic Countries			–0.3		–2.0	–2.3
USSR and Eastern Europe			–0.1	–1.0	–0.5	–1.6
Total	14.3	–1.1	–0.9	–25.0	–12.2	

As another example, Northern European printing paper production declines in both the strong- and weak-dollar scenarios. The main reason in the strong-dollar case is reduced consumption by the main export markets and in the weak-dollar case it is competition with the US, which expands its exports significantly.

Next, we discuss the impact of US dollar exchange rate variations on the US forest sector during the period 1990–2010 (*Table 29.4*). The overall phenomenon is as follows: in the strong-dollar scenario US production decreases and the impact becomes increasingly significant over time. The reason for the strengthening impact is the lack of investments that would otherwise replace depreciating capacity. This impact on investments causes a long delay before the full impact of the strong dollar on production can take place. In the weak-dollar case the situation is reversed.

Table 29.4 Relative changes (%) over time for US production in the exchange rate scenarios as compared with those in the base scenario.

Strong-dollar scenario

	1990	*2000*	*2010*
Coniferous sawnwood	–7	26	–28
Nonconiferous sawnwood	–4	–10	–13
Veneer and plywood	–9	–14	–21
Particle board	–9	1	4
Coniferous pulp	–7	–9	–13
Nonconiferous pulp	–16	–17	–16
Newsprint	–14	–29	–16
Other printing paper	–6	–1	0
Packaging paper and board	–7	–11	–17

Weak-dollar scenario

	1990	*2000*	*2010*
Coniferous sawnwood	0	0	–13
Nonconiferous sawnwood	–9	9	21
Veneer and plywood	6	33	57
Particle board	–4	22	24
Coniferous pulp	7	14	17
Nonconiferous pulp	7	17	22
Newsprint	–4	7	71
Other printing paper	1	22	45
Packaging paper and board	4	30	21

An exception to the general result is US particle board production, which tends to increase over time whether the dollar is strong or weak. The reason is that, due to relatively higher transportation costs, consumption, in general, is satisfied by domestic production and, furthermore, consumption in the US increases with the strengthening dollar. Somewhat similar is the situation with printing paper. In this case production is relatively stable in the long term; however, exports that took place in the base scenario are now shifted to satisfy the increasing domestic requirements. Note that in the weak-dollar scenario production may actually decline at first, due to the decreased domestic consumption in the US. Only in the longer term, after the trade impacts have occurred, does production start to increase again.

Finally, the relative impact of the US dollar exchange rate on US timber production is given in *Table 29.5.* In general, the early impact is relatively weak because of inertia in domestic industrial production, i.e., the existing capacity is employed to the extent possible. In the longer term, the impact becomes stronger, but tends to level off in line with stabilizing timber prices. Because the impact of exchange rate changes on timber prices is stronger for nonconiferous than for coniferous timber, so is the impact on US removals.

Table 29.5 Relative changes (%) from the base scenario in US timber removals in the strong- and weak-dollar scenarios.

Scenario		*1990*	*2000*	*2010*
Strong dollar	Coniferous	–5	–6	–6
	Nonconiferous	–11	–15	–14
Weak dollar	Coniferous	5	9	8
	Nonconiferous	4	21	23

29.3. Trade Liberalization

The trade-liberalization scenario assumes that all tariffs on forest products would be removed worldwide, beginning in 2000. All other conditions remain the same as in the base scenario. Removal of the post-Tokyo Round tariffs (see Chapter 24) implies a significant change in only two, large, consuming regions, Japan and Western Europe. In the base scenario, tariffs on forest products imports into these regions are:

(1) Japan:
  - (i) 7.5–15% for veneer and plywood, depending on the exporting region.
  - (ii) 8% for particle board from the developed regions.
  - (iii) 4–5% for all paper grades from the developed regions.

(2) Western Europe:
  - (i) 3.2% for pulpwood from the developed regions.
  - (ii) 11% for veneer and plywood from the developed regions.
  - (iii) 6–9% for all paper grades from the developed regions.

Given that these tariffs are relatively low, the effects of trade liberalization may be expected to be weak. However, this is not necessarily the case, as the following discussion demonstrates. In this discussion, the impacts of trade liberalization are illustrated by analyzing trade patterns in the year 2000 under the trade liberalization scenario as compared with those for the same year under the base scenario. The results of changes in trade after the year 2000 are essentially the same.

Changes in trade flows between the base scenario and the trade liberalization scenario are summarized in *Tables 29.6* and *29.7*. For products not reported there are essentially no changes. Percentage changes in production in four regions are shown in *Table 29.8*.

An obvious impact is the increase in imports into the regions where tariffs are removed. Examples are the increased imports of veneer and plywood into Western Europe by 1.5×10^6 m^3 and into Japan by 4.6×10^6 m^3 (*Table 29.6*), as well as the increases in newsprint imports into Western Europe by 1.1×10^6 ton and into Japan by 0.6×10^6 ton (*Table 29.7*). However, given all the interactions in the global forest sector, some of the changes that would be expected on the basis of reduced tariffs do not take place. For example, coniferous pulpwood imports into Western Europe decrease (by 1.9×10^6 m^3), even though the tariff is removed. The explanation is a complicated chain of interactions that involves changes in the whole production structure in Western Europe and elsewhere (see *Table 29.8*). Basically, coniferous pulpwood imports into Western Europe are reduced because of the reduced production of coniferous pulp, newsprint, and other printing papers in Western Europe. Pulp production, in fact, decreases faster than the decline in pulp consumption, so that there is an increase in coniferous pulp imports. As a result there is a shift in imports to Western Europe from the Nordic countries, with the decline in pulpwood imports being partially offset by an increase in white pulp.

Table 29.6 Increases in roundwood and veneer and plywood trade flows (10^6 m^3) in the trade liberalization scenario versus those in the base scenario for the year 2000. Exporters: 1, Canada; 2, US; 3, Nordic countries; 4, USSR and Eastern Europe; 5, Southeast Asia and Oceania; 6, Other regions. Importers: A, US; B, Western Europe; C, Japan; D, Other regions.

Coniferous logs	*A*	*B*	*C*	*D*	*Total*
1	-4.8				-4.8
2					
3					
4		0.6			0.6
5					
6					
Total	-4.8	0.6			

Nonconiferous logs	*A*	*B*	*C*	*D*	*Total*
1			-1.1		-1.1
2			-3.1		-3.1
3					
4					
5				-1.5	-1.5
6					
Total			-4.2	-1.5	

Coniferous pulpwood	*A*	*B*	*C*	*D*	*Total*
1	4.3				4.3
2			-0.6		-0.6
3		-2.4			-2.4
4		0.5			0.5
5			-0.2		-0.2
6					
Total	4.3	-1.9	-0.8		

Veneer and plywood	*A*	*B*	*C*	*D*	*Total*
1					
2			0.5	0.6	1.1
3		0.6	0.4	-.5	0.5
4			0.1		.1
5			3.1		3.1
6		0.9	0.5	-0.5	0.9
Total		1.5	4.6	-0.4	

Another phenomenon to be expected from the liberalization of trade is a shift in trade toward higher value-added products, e.g., from wood raw-material to processed goods. This is because existing tariffs are typically low or nonexistent on roundwood, but higher on processed goods, such as wood-based panels and paper. When the tariffs on processed goods are removed, these products may become competitive. Increased imports of processed goods will thus tend to reduce roundwood imports. For example, observe the log and plywood imports into Japan: the former decreases by 4.2×10^6 m^3 and the latter increases by 4.6×10^6 m^3 when the tariff on plywood is removed.

Finally, many indirect but significant changes in trade patterns occur. A trade flow that does not directly involve a tariff may nevertheless be effected by trade liberalization because of changes in supply that result from increases in exports as a consequence of tariff removals elsewhere. For example, consider the situation in Canadian exports. An overall increase in newsprint exports by 1.5×10^6 ton results in a decrease in pulp exports. However, the decrease in pulp export of 1.3×10^6 ton is only partly due to increased newsprint production (which necessitates increased pulp consumption). The other significant factor is that, because of price

Table 29.7 Increases in sawnwood (10^6 m^3) and pulp and newsprint (10^6 ton) trade flows in the trade liberalization scenario versus those in the base scenario for the year 2000. Abbreviations as in *Table 29.6*.

Coniferous sawnwood

	A	*B*	*C*	*D*	*Total*
1	3.3		0.4		3.7
2				-0.1	-0.1
3		-0.1		-0.2	-0.3
4					
5					
6					
Total	3.3	-0.1	0.4	-0.3	

Nonconiferous sawnwood

	A	*B*	*C*	*D*	*Total*
1			0.1	0.5	0.6
2		-0.4		0.3	-0.1
3					
4					
5					
6					
Total		-0.4	0.1	0.8	

White pulp

	A	*B*	*C*	*D*	*Total*
1	-1.0		-0.3		-1.3
2			0.2	0.1	0.3
3		0.4			0.4
4					
5					
6					
Total	-1.0	0.4	-0.1	0.1	

Newsprint

	A	*B*	*C*	*D*	*Total*
1	-0.1	1.1	0.6	-0.1	1.5
2					
3					
4					
5					
6					
Total	-0.1	1.1	0.6	-0.1	

Table 29.8 Increases (%) in production in the trade liberalization scenario relative to those in the base scenario in 2000.

	Canada	*Western Europe*	*Nordic countries*	*Japan*
Coniferous sawnwood	6	1	-1	-3
Nonconiferous sawnwood	13	37	0	0
Veneer and plywood	0	-17	25	-25
Particle board	0	2	0	-10
Coniferous white pulp	-14	-17	8	0
Nonconiferous white pulp	0	0	12	-13
Newsprint	10	-34	0	-12
Other printing paper	0	-7	0	0
Packaging paper and board	0	0	0	0

changes there are changes in roundwood trade and also in sawnwood production and trade. In particular, log exports from Canada to the US decline by 4.8 × 10^6 m^3 in favor of increased sawmilling in Canada and increased exports of sawnwood to the US. The increased supply of sawmill residues, then, permits an increase in pulpwood export to the US. This in turn reduces (and thus gives a lower pulpwood price) import demand in the US for processed pulp, so that pulp imports from Canada decline.

29.4. USSR Timber Exploitation

In this scenario, USSR roundwood exports are gradually allowed to increase over time up to two thirds of the domestic consumption of roundwood. In the base scenario, the corresponding share is one fifth. No changes in the production of forest products in the USSR, as compared with the base scenario, are assumed. No additional trade policy constraints are considered, either. Therefore, roundwood exports to Japan and China, for example, are allowed to increase (within the bounds of the trade inertia constraints — see Chapter 24) according to import demand as determined by the forest industries in these countries.

Table 29.9 shows the development of USSR timber exports over time. As compared with the base scenario, the USSR timber-exploitation scenario shows a dramatic rise in roundwood exports until the year 2010, after which exports continue to increases, but at a much lower rate. Given the real increase in roundwood prices, the increment in USSR export revenues amounts to about 10×10^9 dollars in 2010 under this scenario. This price increase occurs in spite of the large increase in roundwood exports (compared with the base scenario), because the two main importers of the additional USSR roundwood, Japan and China, have large deficits in roundwood supply.

Table 29.9 USSR timber exports in the base scenario and in the USSR timber-exploitation scenario (10^6 m^3/year).

	1980	*1990*	*2000*	*2010*	*2020*	*2030*
USSR timber-exploitation scenario	14	43	94	124	128	133
Base scenario	14	37	40	45	49	53
Increase	0	6	54	79	79	80

Changes in wood raw-material trade in the year 2000 are summarized in *Table 29.10*. The total increase of 54×10^6 m^3 worldwide consists of 61% coniferous logs, 22% coniferous pulpwood, 10% nonconiferous logs, and 7% nonconiferous pulpwood. Despite large increases in timber exports from the USSR to China and Japan, total imports into these countries change relatively little, i.e., imports in the base scenario from other regions

Table 29.10 Main differences in roundwood trade flows (10^6 m^3) in the year 2000 between the USSR timber-exploitation scenario and the base scenario. Exporters: 1, Canada; 2, US; 3, Latin America; 4, USSR; 5, Southeast Asia and Oceania. Importers: A, US; B, Western and Northern Europe; C, China; D, Japan.

Coniferous logs	*A*	*B*	*C*	*D*	*Total*
1	–0.3			–4.4	–4.7
2			–12.2	–4.5	–16.7
3			–3.8		–3.8
4		–1.0	25.3	9.1	33.4
5			–4.8		–4.8
Total	–0.3	–1.0	4.5	0.2	

Coniferous pulpwood	*A*	*B*	*C*	*D*	*Total*
1	–3.1				–3.1
2			–4.6	–2.6	–7.2
3					
4		1.5	5.4	4.8	11.7
5					
Total	–3.1	1.5	0.8	2.2	

Nonconiferous logs	*A*	*B*	*C*	*D*	*Total*
1				–1.3	–1.3
2			0.2	–0.3	–0.1
3					
4			1.7	3.8	5.5
5			–2.3	–1.5	–3.8
Total			–0.4	0.7	

Nonconiferous pulpwood	*A*	*B*	*C*	*D*	*Total*
1	0.7		–0.9		–0.2
2			–1.6		–1.6
3					
4		0.1	3.3	0.3	3.7
5				–0.1	–0.1
Total	0.7	0.1	0.8	0.2	

are pushed back by USSR exports in the USSR timber-exploitation scenario. The main losers as timber exporters are Canada, the US, Southeast Asia, Brazil, and Chile.

The major increase in USSR roundwood export supply assumed in this scenario is absorbed by

(1) Moderate increases in roundwood consumption in Japan and China.
(2) Reduced imports into these countries from other regions.

We may go one step further to see how the reduction in imports is absorbed by the exporting countries. As an example, according to *Table 29.10*, coniferous log exports from the US decline by 16.7 × 10^6 m^3. This is explained by

(1) A decrease of 6.1 × 10^6 m^3 in US coniferous log removals.
(2) An increase in US coniferous sawnwood production of 3.6 × 10^6 m^3.
(3) An increase in US veneer and plywood production of 2.0 × 10^6 m^3.

If we were to pursue this line of reasoning, we could establish how the increased sawnwood and panels production is explained. In this way we would end up with a large number of small, intricately linked changes that altogether absorb the entire increase in USSR roundwood exports.

29.5. Acid Rain

The impact of acid rain and other air pollution effects (which in the aggregate are commonly referred to as *acid rain* or *Waldsterben*) were studied by assuming that:

(1) Salvage harvests due to increased tree mortality would increase timber supply in Europe (excluding the Nordic countries and the USSR) during 1985–1995 by 20% of the timber removals in the base scenario.

(2) The annual forest growth, measured as a percentage of growing stock volume, would decrease by one third in the same part of Europe, starting in 1985 and continuing to the end of the projection period.

Note that no distinction is made in these assumptions between coniferous and nonconiferous timber. In reality, however, mortality and growth effects are likely to differ due to, for example, different renewal intervals of leaves. In addition, we have made no distinction in the quality of timber removed in salvage harvests as compared with that removed in normal harvests. This assumption is approximately valid only if dead trees can be harvested quickly enough.

As was pointed out in Chapter 27, it is assumed that the timber obtained from salvage harvests in Eastern Europe fully substitutes other removals so that the total timber removals for this region remain the same as in the base scenario. For this reason our discussion focuses on Western Europe.

In *Table 29.11* we summarize the results of the acid rain scenario on timber removals in Western Europe during the period 1990–2030, as compared with those of the base scenario. In the short term (1990), timber removals increase modestly (6%) as a result of the 20% increase in timber supply. This increase, however, represents less than one third of the timber removals from salvage harvests in Western Europe. The fact that removals increase by only 6% rather than the full 20% is due to the substitution of salvage harvests for some "normal" harvests. After 1995, by which time the tree mortality problem is assumed to have been controlled and the salvage harvest discontinued, the impact of decreased forest growth begins to appear in timber removals. Because the model adapts dynamically to the change in growth rate, the impact by the year 2000 amounts to only a 12% decrease in the total removals. This percentage gradually increases over time, reaching 23% in 2030. Given that the one third decrease in growth rate implies an equivalent decrease in sustainable yield, the decrease in timber removals asymptotically approaches a level of 33%. Because of

Table 29.11 Increases (%) in Western European timber removals in the acid rain scenario relative to those in the base scenario.

	1990	*2000*	*2010*	*2020*	*2030*
Coniferous	5	-14	-17	-20	-24
Nonconiferous	7	-8	-14	-18	-21
Total	6	-12	-16	-19	-23

differences in demand for coniferous and nonconiferous timber, the percentage reduction in coniferous removals is greater, by 2030, than the percentage reduction in nonconiferous removals.

Table 29.12 shows changes in consumption of various forest products in Western Europe as a consequence of the acid rain scenario. For final products (i.e., sawnwood, panels, and different grades of paper), the overall impact is negligible or small. Owing to a higher share of timber in production costs, the impact on mechanical products is somewhat stronger than on paper. In particular, there is a decrease of some significance in coniferous sawnwood and particle board consumption in the long term.

Table 29.12 Increases (%) in Western European consumption in the acid rain scenario relative to those in the basic scenario.

	1990	*2000*	*2010*	*2020*	*2030*
Coniferous logs	1	-14	-13	-15	-13
Nonconiferous logs	7	-13	-18	-22	-26
Coniferous pulpwood	3	-16	-19	-20	-22
Nonconiferous pulpwood	5	-6	-5	-6	-8
Coniferous sawnwood	0	-1	-5	-4	-5
Nonconiferous sawnwood	0	1	-2	0	0
Veneer and plywood	0	-2	-1	0	0
Particle board	1	-3	-3	-4	-7
Coniferous pulp	0	-4	-3	-14	-32
Nonconiferous pulp	0	-2	2	48	69
Newsprint	0	0	-3	-1	-1
Other printing paper	1	0	0	0	0
Packaging paper and board	0	0	0	0	-1

As shown in *Table 29.13*, changes in log production follow closely those in timber removals. However, changes in pulpwood production are somewhat distorted by changes in the production of residuals from sawmilling and in the production of veneer and plywood.

Table 29.13 Increases (%) in Western European production in the acid rain scenario relative to those in the base scenario.

	1990	*2000*	*2010*	*2020*	*2030*
Coniferous logs	6	−15	−17	−21	−25
Nonconiferous logs	7	−13	−19	−23	−26
Coniferous pulpwood	2	−13	−16	−18	−20
Nonconiferous pulpwood	7	−7	−12	−17	−19
Coniferous sawnwood	1	−14	−13	−15	−13
Nonconiferous sawnwood	14	22	−21	−52	−57
Veneer and plywood	−4	−26	−17	−16	−6
Particle board	7	−8	−5	−9	−14
Coniferous pulp	0	−56	−62	−78	−88
Nonconiferous pulp	5	0	0	−20	−30
Newsprint	0	−37	−31	−7	−3
Other printing paper	0	−1	6	72	100
Packaging paper and board	0	−2	−2	−1	−1

In the structure of the forest sector in Western Europe, there are several, major long-term changes. These changes cannot be understood without taking into account changes in consumption and trade simultaneously. In *Table 29.14* we indicate increases in net imports into Western Europe in physical units (10^6 m^3 and 10^6 ton). Note that a positive number may also refer to a decrease in Western European exports and a negative number to an increase in exports. We now briefly comment on production and trade of each product.

(1) *Coniferous logs*: the increment from salvage harvests is larger than the increase in consumption in 1990. As a result, imports from Eastern Europe and the USSR decrease by 2.5×10^6 m^3. In the long term, however, these imports increase again to compensate for the long-term reduction in growth rates. Owing to increases in sawnwood imports (see below), log imports remain at moderate levels.

(2) *Nonconiferous logs*: no changes in trade volume take place, i.e., the log-consuming industry adjusts completely to changes in domestic log supply.

(3) *Coniferous pulpwood*: in the short run, no significant effect can be observed. However, in the long term, pulpwood imports, especially from Eastern Europe and the Nordic countries, decrease due to decreasing pulp production.

Table 29.14 Increase in Western European net imports in the acid rain scenario relative to those in the base scenario (10^6 ton/year for pulp and paper, otherwise 10^6 m^3/year).

	1990	*2000*	*2010*	*2020*	*2030*
Coniferous logs	-2.5	-1.0	0.2	1.9	7.3
Nonconiferous logs	0.0	0.0	0.0	0.0	0.0
Coniferous pulpwood	0.3	-2.3	-5.0	-3.7	-4.9
Nonconiferous pulpwood	-0.5	0.1	2.8	5.1	6.6
Coniferous sawnwood	-0.6	5.8	4.0	5.8	4.6
Nonconiferous sawnwood	-2.1	-0.6	0.3	1.5	3.8
Veneer and plywood	0.2	2.1	1.8	2.0	0.7
Particle board	-1.2	1.5	0.8	1.7	2.6
Coniferous pulp	0.0	1.6	2.3	4.7	7.2
Nonconiferous pulp	-0.1	-0.1	0.1	2.1	4.7
Newsprint	0.0	1.3	1.8	0.5	0.2
Other printing paper	0.1	0.2	-0.6	-6.0	-13.1
Packaging paper and board	0.0	0.5	0.4	0.1	0.1

(4) *Nonconiferous pulpwood*: again, in the short term the impact is small. In the long term, however, the situation is reversed as compared with coniferous pulpwood: imports increase, in particular from the Nordic countries and Africa, due to slower decreases in pulp and particle board production than in the pulpwood supply in Western Europe.

(5) *Coniferous sawnwood*: after a slight reduction of imports from the Nordic countries, imports start to increase again in order to satisfy demand, which declines slower than does domestic production. The main exporters are Canada, the Nordic countries, and the USSR.

(6) *Nonconiferous sawnwood*: following a slight decrease in imports, increased imports are required in the long run, in this case from the US, to meet domestic consumption requirements.

(7) *Veneer and plywood*: there is an increase in imports from the Nordic countries, Eastern Europe, and Africa. However, owing to the recovery of domestic production, the increase in imports as compared with the base scenario declines in the long term.

(8) *Particle board*: after a decrease in imports from the US, a long-term increase takes place in imports from Latin America, the Nordic countries, and the USSR.

(9) *Coniferous pulp*: domestic production declines fast and at the same time consumption in paper production increases. As a result there is a major increase in pulp imports, mainly from the US, Latin America, and the Nordic countries.

(10) *Nonconiferous pulp*: the phenomenon is the same as for coniferous pulp, except weaker, because the decline in domestic production is less significant. The US is the main supplier of nonconiferous pulp.

(11) *Newsprint*: the decline in domestic production, which becomes less significant in the long term, is substituted by imports from Canada.

(12) *Other printing paper*: owing to long-term changes in capital allocation in the acid rain scenario within Western European forest industries, printing paper production increases drastically to satisfy the large domestic consumption needs. As a result, imports, which are drawn primarily from the Nordic countries, decline substantially.

(13) *Packaging paper and board*: only relatively minor changes take place in production and consumption, and therefore in trade, in Western Europe.

Finally, the price impacts of the acid rain scenario are summarized in *Table 29.15*. As was the case with the consumption of final products, the price impacts for these products are relatively minor. Given that the overall impact in the global forest sector is small, the price effects on pulp are relatively small as well. The main impact appears in the long-term prices of roundwood in Western Europe, which are directly traceable to the long-term reduction in timber supply.

Table 29.15 Changes (%) in Western European prices in the acid rain scenario relative to those in the base scenario.

	1990	*2000*	*2010*	*2020*	*2030*
Coniferous logs	-1	7	18	11	10
Nonconiferous logs	0	16	7	4	2
Coniferous pulpwood	-10	11	7	12	9
Nonconiferous pulpwood	-1	20	18	15	16
Coniferous sawnwood	0	3	11	7	6
Nonconiferous sawnwood	0	0	0	0	1
Veneer and plywood	0	5	2	0	2
Particle board	-2	5	5	6	7
Coniferous pulp	-1	5	4	7	5
Nonconiferous pulp	-1	-2	0	1	2
Newsprint	0	2	4	4	3
Other printing paper	0	1	1	2	2
Packaging paper and board	0	2	2	3	4

29.6. Climatic Warming

The impact on the global forest sector of climatic warming due to an increase in the CO_2 concentration of the atmosphere was studied under the following assumptions:

(1) Only the boreal regions (Canada, Finland, Sweden, and the USSR) are affected.
(2) These regions experience increases in both forest growth rates and forest land area due to elevated temperature levels associated with the increased CO_2.

For a detailed specification of the climatic warming scenario, see Chapter 27.

Since there would be an increased timber supply in the boreal regions, timber removals there increase substantially over time compared with those in the base scenario. The percentage changes are summarized in *Table 29.16*. The largest relative increases in timber removals are in Finland and the USSR, with Sweden the least affected. As a result of the lower prices

Table 29.16. Increases (%) in timber removals in the climatic warming scenario relative to those in the base scenario.

Coniferous	*1990*	*2000*	*2010*	*2020*	*2030*
Canada	0.0	2.1	8.5	20.3	33.3
Finland	0.5	4.0	17.7	32.1	55.1
Sweden	0.0	2.1	2.8	8.9	15.6
USSR	2.0	7.9	17.3	30.4	47.3
US	–0.6	–1.4	–2.8	–4.3	–6.3
Western Europe	–0.5	–2.2	–4.6	–6.6	–10.6
World total	0.4	1.4	4.0	9.2	14.5
Nonconiferous	*1990*	*2000*	*2010*	*2020*	*2030*
Canada	0.4	2.5	6.7	17.5	33.6
Finland	0.0	4.4	20.0	34.3	58.1
Sweden	0.0	2.9	9.4	19.6	30.5
USSR	2.0	7.9	17.3	30.4	47.3
US	–0.4	–0.9	–1.8	–2.9	–3.7
Western Europe	–0.5	–0.6	–0.9	–1.7	–1.1
World total	0.1	0.4	0.9	1.7	3.1

associated with the increased timber supply, removals in other regions decrease, as indicated for the US and Western Europe in *Table 29.16.* Owing to the species structure in the boreal forests, the impact is stronger for coniferous than for nonconiferous timber. In 1990 the increase is almost negligible, but strengthens gradually over time, producing a worldwide increase in removals by 2030 of 14% for coniferous and 3% for nonconiferous timber.

The relative increase in world consumption and decrease in US price levels in 2010 and 2030 as a result of climatic warming are given in *Tables 29.17* and *29.18*. As expected, the impact is stronger for coniferous than

Table 29.17 Increases (%) in world consumption of forest products in the climatic warming scenario relative to those in the base scenario.

	2010	*2030*
Coniferous sawnwood	5.3	22.0
Nonconiferous sawnwood	1.4	7.0
Veneer and plywood	0.7	0.7
Particle board	2.1	10.7
Newsprint	2.9	11.4
Other printing paper	0.9	4.8
Household and sanitary paper	0.6	1.4
Packaging paper and board	0.9	5.3

Table 29.18 Decreases (%) in US forest product prices in the climatic warming scenario relative to those in the base scenario.

	2010	*2030*
Coniferous logs	6.5	20.5
Nonconiferous logs	1.4	6.1
Coniferous pulpwood	14.9	61.5
Nonconiferous pulpwood	6.8	9.4
Coniferous sawnwood	0.0	10.3
Nonconiferous sawnwood	0.6	3.6
Veneer and plywood	0.3	3.2
Particle board	3.7	9.9
Coniferous pulp	7.7	24.5
Nonconiferous pulp	1.4	5.7
Newsprint	3.7	11.3
Other printing paper	2.2	7.1
Household and sanitary paper	2.3	6.4
Packaging paper and board	3.7	9.2

for nonconiferous products. Similarly, the impact is weaker for higher value-added products.

Finally, *Table 29.19* shows the relative increases in industrial production quantities for selected regions. (Note that USSR industrial production was assumed unchanged from the base scenario.) In Canada and Finland we observe a steady increase in all the product categories, with mechanical products and pulp exhibiting stronger increases in production than does paper. The entire increase in timber harvest in Finland is processed domestically and then exported. By comparison, Canada exports a major share of the increase in the form of logs, primarily to the US. Also, Sweden exports increasing amounts of pulpwood into Western Europe and consequently, in the long run, faces a decrease in pulp and paper production.

Table 29.19 Relative increases (%) in production quantities in the climatic warming scenario relative to those in the base scenario. Sawnwood and panels include all sawnwood and wood-based panels, white pulp includes coniferous and nonconiferous pulp, and paper includes all paper grades.

		1990	*2000*	*2010*	*2020*	*2030*
Canada	Sawnwood and panels	0	3	22	37	31
	White pulp	1	2	13	52	83
	Paper	1	4	6	8	19
Finland	Sawnwood and panels	1	12	15	36	63
	White pulp	0	15	58	127	98
	Paper	0	1	6	14	33
Sweden	Sawnwood and panels	1	3	5	14	25
	White pulp	0	4	7	−9	−5
	Paper	0	4	8	−24	−3
US	Sawnwood and panels	0	0	2	2	5
	White pulp	−1	−2	−3	−5	0
	Paper	0	0	2	6	8
Brazil	Sawnwood and panels	0	0	−1	−1	2
	White pulp	0	0	0	−2	−3
	Paper	0	0	0	−4	−10
Western Europe	Sawnwood and panels	0	0	0	7	9
	White pulp	0	0	0	−36	−56
	Paper	0	−1	0	−3	−12
Japan	Sawnwood and panels	0	8	2	9	8
	White pulp	0	0	0	0	6
	Paper	0	1	1	2	5

Production of mechanical products increases in Sweden, however. In the US, production generally increases as well, except for a slight decrease in white pulp production. This is partly due to increasing timber imports from Canada. Also, increasing timber exports from the US to China and Japan in the base scenario are pushed back in the climatic warming scenario by increasing USSR timber exports. Weakening competition in Brazil causes, in the long term, a slight decline in forest industries there. In Western Europe, owing to increased log imports, mechanical processing increases slightly. However, because of the increased supply of paper from the Nordic countries, production of pulp and paper declines relative to that in the base scenario. In Japan, because of increasing consumption and import supply of timber, production generally increases.

Thus, we see that an increase in timber supply in one set of regions — the boreal forest — has repercussions on timber and wood product prices and production levels throughout the world.

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THE GLOBAL FOREST SECTOR

An Analytical Perspective

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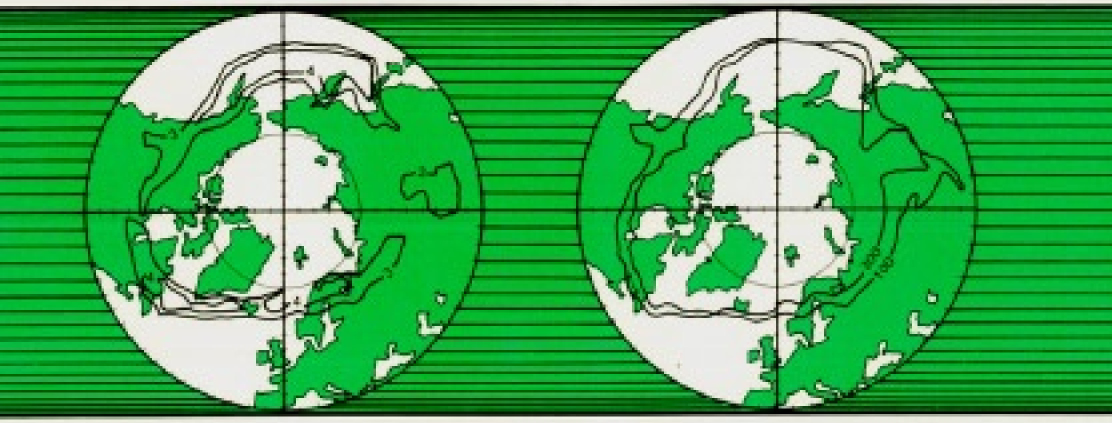
The book provides comprehensive background information on the global forest sector, and a state of the art exposition of forest sector modeling. There is detailed documentation of the IIASA global forest sector model and results of a set of scenario runs made with the model. The book includes sections of forest resources and timber supply, modeling of forest products, manufacture and demand, and information on international trade in forest products and recent advances in modeling trade.

This book is the work of internationally distinguished scientists and managers brought together by the IIASA Forest Sector Project to form a cooperating network. It is probably the first book of its kind ever written about the forest sector, and it is the culmination of five years' work on global forest sector modeling by more than 100 collaborators.



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