Working Paper

TECHNOLOGICAL FORECASTING: AN INTRODUCTION TO MODELS AND METHODS WITH EMPIRICAL ILLUSTRATION FROM THE FOREST SECTOR

Sören Wibe

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WP-83-70

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A-2361 Laxenburg, Austria

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FOREWORD

The objective of the Forest Sector Project at IIASA is to study long-term development alternatives for the forest sector on a global basis. The emphasis in the Project is on issues of major relevance to industrial and governmental policy makers in different regions of the world who are responsible for forestry policy, forest industrial strategy, and related trade policies.

The key elements of structural change in the forest industry are related to a variety of issues concerning demand, supply, and international trade of wood products. Such issues include the development of the global economy and population, new wood products and substitution for wood products, future supply of roundwood and alternative fiber sources, technology development for forestry and industry, pollution regulations, cost competitiveness, tariffs and non-tariff trade barriers, etc. The aim of the Project is to analyze the consequences of future expectations and assumptions concerning such substantive issues.

The research program of the Project includes an aggregated analysis of long-term development of international trade in wood products, and thereby analysis of the development of wood resources, forest industrial production and demand in different world regions. The other main research activity is a detailed analysis of the forest sector in individual countries. Research on these mutually supporting topics is carried out simultaneously in collaboration between IIASA and the collaborating institutions of the Project.

This paper deals with methodology for technological forecasting and for estimating future demand of wood products. Special attention is paid to forecasting input coefficient for capital and labor as well as to the relation between per capita income and consumption of wood products. The situation both in developed and developing countries has been discussed.

Markku Kallio
Project Leader
Forest Sector Project

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TECHNOLOGICAL FORECASTING: AN INTRODUCTION TO MODELS AND METHODS WITH EMPIRICAL ILLUSTRATION FROM THE FOREST SECTOR

Sören Wibe

1. INTRODUCTION – AREAS FOR TECHNOLOGICAL FORECASTING

Two main approaches dominate the literature on technology and technological progress:

(i) The technical view and

(ii) The economic view

The technical approach is taken by engineers and, if we are dealing with past technology, by historians of technology. This technical approach is *concrete*, and means looking at the directly observable changes in organizational patterns within a firm or at the precise changes made in the way a machine is constructed. The history of technological change becomes the history of how humanity ingenuity made concrete changes in the working tools that were at hand. The story of technology's *impact* on society is the story of how men and women changed their way of living and working as a direct result of the concrete changes in the technological structure.

The economic approach implies an abstraction from the concrete technical details. Economists are not concerned with *how* things are done or *how* the way of doing it changes. Their interest is in the economic significance and the economic result. What matters for the economist in technological progress is the changing relationship between scarce input resources and scarce output and not how this change is accomplished. Scarce resources generally means capital, labor, and raw materials (including energy), i.e., units to which uniform prices can be attached. Prices and incomes are the core elements in the economists conception of technological progress: firms choose and develop new technology on the basis of price expectations. The overall effect of progress is the increase of efficiency and hence, an increase in real income. The impact of technological progress on society is, above all, analyzed with increased income as the strategic variable.

Technological forecasting can either focus on the technical foundation of progress or on its economic result. There is however, another dimension to technological forecasting, namely, the relationship between *products* and *processes*. Improvements in process makes possible the production of the same good at lower costs, while product improvements means producing better quality and an increase in product price. Of course there are interactions, but it is analytically convenient (and empirically relevant) to keep this difference in mind. Industrial sectors can be classified by whether they lower the cost of production or increase the product price.

2. A FORMAL PRESENTATION OF THE MODEL STRUCTURE

2.1 Process- or Supply-Side

Some formal analyses can clarify the viewpoints presented in the foregoing section. Let us start with *process*, and assume that we are dealing with an industrial sector that produces a good with only one quality. We denote the quantity of this good Q. Let us assume that we can describe the production process with the engineering variables $x_1, \ldots, x_n$, and simplify matters so that the total process can be described by an "engineering production function":[1]

$$Q = e(x_1, \ldots, x_n) \tag{1}$$

The engineering variables (e.g., length, speed, density, strength) usually have no uniform price attached. Let us therefore assume that we have m economic factors of production (capital, labor, etc.); $\nu_1, \ldots, \nu_m$. There are of course definite (efficient) relations between x and ν, and let us assume that we can write these relations:

$$\varphi_i(x_1, \ldots, x_n, \nu_1, \ldots, \nu_m) = 0 \quad i=1,\ldots,k \tag{2}$$

These relations are called *input functions* since they tell us the amount of economic resources (ν) needed to materialize a certain set of engineering variables (x).

If we solve the problem:

$$\begin{gathered} \mathrm{Max}Q = e(x_1, \ldots, x_n) \\ ST \\ \varphi_i(x_1, \ldots, x_n, \nu_1, \ldots, \nu_m) \quad i = 1,\ldots,k \end{gathered} \tag{3}$$

we obtain a relation between ν and Q:

$$Q = E(\nu_1, \ldots, \nu_m) \tag{4}$$

which is the *economic production function*.[2]

A change in the engineering function or in the input functions will result in a change in the economic production function. We see then that technological progress has two sources: changes in the production process itself (e.g., improvements in the organizational structure, etc.) or improvements in factor inputs (i.e., (2)). Changes in relation (2) include better education of labor, better quality in capital goods and so on.

Changes in the engineering relation, e, over time (t),de / dt is normally a function of the amount of research and development in the sector, possibly with some time lag. Let us denote this lagged quantity $RD(t)$. Progress is also normally affected by "learning by doing", so de / dt is dependent also on the flow of production $Q(t)$. We thus have to quantify a relation:

$$de / dt = H[RD(t), Q(t)] \tag{5}$$

Improvements in φ_i is normally not within the control of the sector. Improvements here are normally product changes for the sector that produces the inputs, notably the capital producing sector. The progress in the input-making sectors is also dependent on sales, and thus in the case of capital goods, on the *rate of investment* in the sector under study. Since this investment is dependent not only on $Q(t)$, but also on dQ / dt, we can deduce that total progress in the sector strategically depends on $RD(t)$, $Q(t)$ and dQ / dt[3]. It must, however, be added that progress is also connected progress in all the other sectors through the input functions (2).

Progress in the engineering or input function is transmitted to the economic production function. The change need not result in a change of technology used, since the improvements can affect only certain areas of the production function. However, the general result is to improve the relationship between ν and Q or, to put it in another way, *to shift the supply curve of the firm and/or the industry.*

2.2 Product- or Demand-Side

Let us now turn to *product innovations*, starting with the individual utility function. However, we shall assume that this function applies to the "characteristics" contained in economic goods and not to the economic goods themselves. In other words, we assume that the utility of a car is measured by its speed, safety, comfort and so on. Let us denote these characteristics $z_1, \ldots, z_k$ and we have utility U for an individual:[4]

$$U = U(z_1, \ldots, z_k) \tag{6}$$

The economic goods, which we can denote $Q_1, \ldots, Q_l$ "contain" these characteristics in different amounts, so that a given set of characteristics, z, can be obtained if a specific set of economic goods, Q, are bought and consumed. This means that we assume a relationship between z and Q;

$$z_j = g_j(Q, \ldots, Q_1) \qquad j=1,\ldots,k \tag{7}$$

If (7) are substituted into (6), we obtain the utility function with economic goods as variables.

Technological progress cannot change the utility function directly[5]. The relations that change are of course the goods-characteristics relations (7). An increase in quality j of good i means that $d(dg_j / dQ_i)/dt > 0$ (if z_j is a desirable characteristic). What happens is that the utility function in the economic goods shift, so that a given amount of utility is obtained at lower cost. This means (normally) that more quantity of the goods is demanded at a given price, so that the demand-curve shifts upwards.

2.3 Prices and Equilibrium

Assuming now that we can forecast the development of $e(x_1, \ldots, x_n)$ and $\varphi_i(x_1, \ldots, x_n, \nu_1, \ldots, \nu_m)$, we could correctly derive the economic production function. However, to know which point on the production function an investor will choose, we need to have additional information on the development of *prices*. The same holds for the demand side: Given the utility function and the goods characteristic relations (7), we can derive the utility function in economic goods. However, to know which quantities are actually consumed, we need to know the development of prices and incomes.

2.4 Summary of the Forecast Model

The model presented here is illustrated graphically in Figure 1. A forecast could start at either of the three levels indicated: 1) "technical level", implying a forecast (for the supply side) of the engineering production function and the input functions (and correspondingly for the demand-side) 2) the "economic level", meaning a forecast of the economic production function and/or of the input prices and at 3) the "equilibrium level", with the demand and supply relations or even with the equilibrium solution itself. The equilibrium solution means that a forecast is made of the time path for quantity sold (and/or inputs bought) without reference either to the technologies of the supply-side or the utilities of the demand-side.

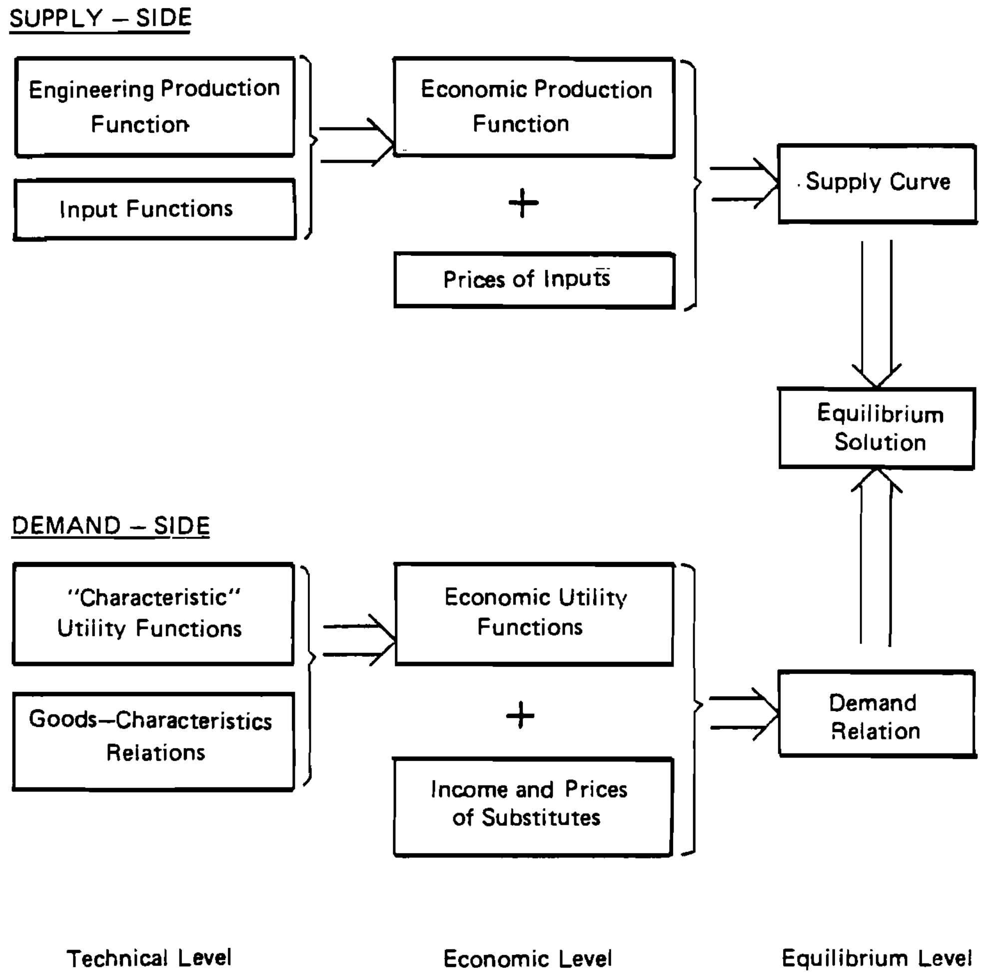

Figure 1. Graphical illustration of the Forecast Model.

3. METHODS FOR TECHNOLOGICAL FORECASTING[5]

The methods of technological forecasting tend to cluster into three principal categories:

(i) *Time series and Projections* which deal essentially with *trend forecasting*.

(ii) *Models and Simulations* which deal principally with interactions among events.

(iii) *Qualitative and Holistic Methods* which deal with the broad context of the future, including societal alternatives, patterns of values and so on.

When doing a forecast for, for instance, the forest sector, all three categories are relevant. We would like to know, e.g., the development of labor per ton pulp in production, the interactions between the forest sector and the rest of the economy and also if the society of the year 2000 will be more positive towards recycling than now[7]. In this presentation I will, concentrate on categories (i) and (ii) which are the methods for quantitative forecast. Descriptions of methods for category (iii) (such as the Delphi technique, etc.) can easily be found in standard text books (see note [6])

3.1 Time Series and Projections

3.1.1 Single-Valued Variables

The most common forecast by far a single-valued variable, x, dependent only on time t:

$$x = f(t) \tag{8}$$

The most common *form* of f is exponential, i.e., $x = ae^{b \cdot t}$, where a and b are parameters, estimated by statistical regression on historical data. x can be a ***process variable*** (e.g., the speed of a machine), a ***quality variable***, or an ***economic input figure***. The simple exponential growth curve is also widely used to forecast demand for a product (at a given price).

The exponential growth curve can be given some rationale apart from purely statistical inference. Let us assume that we are dealing with a positive variable and that a constant effort (in terms of money or scientists) is supplied in order to increase its value. It is then realistic to assume that

$$dx / dt = c_1 x(t) \tag{9}$$

(where c_1 is a constant), i.e., that the *growth* of $x(t)$ is proportional to $x(t)$. If $x(t)$ is taken to represent a ***given level of knowledge***, then it seems natural to assume that the chance of making progress (i.e., dx / dt) is, given the effort, proportional to the already achieved level.

The examples of these simple exponential growth curves are numerous: Martino (1975) gives the following examples:

(i) Productivity in ton miles/hour of civil and military aircraft (p.131-132).

(ii) Efficiency (in lumens per watt) of illumination sources (p.133).

(iii) Gross take-off weight of US single place fighter aircraft (p.134).

(iv) Top speed of US combat aircraft (p.135).

(v) Three engineering characteristics of US-built rocket engines (p.136-137)

(vi) Electric power production in US (p.138)

(vii) Installed horsepowers in US (p.139).

3.1.2 Single-Valued Growth with Limits

When an exponential curve is used, growth is without limit and $x(t)$ approaches zero or infinity when time approaches infinity. This may be realistic for certain cases or certain phases of a development, but it is certainly not the general case. In reality, we have all sorts of natural limits. For instance, when we discuss the development of engineering variables, we can distinguish the following limits:[6]

1) Energy input limits imposed by thermodynamical laws, e.g.,
   a) Energy limits for transformation of ore into metal.
   b) Carnot efficiencies of heat engines.
   c) Energy requirements for moving bodies.
2) Material input limits imposed by chemical laws, e.g.,
   a) Ore requirements for metals.
   b) Wood requirements for paper.

Some empirical examples of these are given in this chapter. However, other limitational facts do exist:

3) Absolute physical limits, e.g.,
   a) The speed of light.
   b) Zero pressure.
   c) Zero absolute temperature.
4) Limits imposed by the human body, e.g.,
   a) Acceleration limits (no more than 0.15 g for standing persons, no more than 5 g for seated, normal, persons).
   b) Maximum pollution concentration in plants, cities or on the earth.
5) Limits imposed by the physical property of material, e.g.,
   a) The strength of different materials.
   b) The insulation or conductive properties of materials

When we discuss the development of demand, we can easily identify "income-saturation" for different products, i.e., the point where the income elasticity is zero. (It is, for instance, highly unlikely that the per capita consumption of newspaper will ever exceed 150 kg/year, regardless of per capita income.) Also, when we discuss the substitution of one product or one process for another, we have a natural upper limit of 100% of market. In many cases, thus, we realize that a ***growth curve with a limit*** is the appropriate formulation for forecasting. The most common form of these functions is the logistic function. In our case

$$x(t) = \frac{\bar{x}}{1 + e^{a(t_0 - t)}} \tag{10}$$

where

$\bar{x}$ = upper limit of $x(t)$

a = the growth factor and

t_0 = the time when $x(t) = 1/2\bar{x}$.

The logic behind the logistic formulae is simple: Let us assume a positive variable and a constant effort to increase its value. Let us furthermore assume that we know that x has a definite upper limit $\bar{x}$. The assumption

$$dx/dt = a\cdot(\bar{x} - x(t))\cdot x(t) \tag{11}$$

is then not unrealistic. It means that we assume growth of knowledge (i.e., dx/dt) to be a product of (i) the *level of knowledge* ($x(t)$) and (ii) the *potential* knowledge ($\bar{x} - x$). If $x(t)$ is the share of total market and $\bar{x} = 1$ then $\bar{x} - x(t)$ indicates the remaining market to be explored.

The applications of the logistic curve are numerous. The logistic curve for market substitution was originally introduced by Griliches (1957) in a study of hybrid corn, and has since found many followers, of course, have refined the model to a considerable degree; e.g., Linstone et al (1976), Blackman (1974), Sharif and Kabir (1976), Ayres et al (1975), Sharif and Uddin (1975), Stapleton (1976), Blackman (1973), Marchetti (1979), Bowonder and Ronatgi (1975), Nabseth and Ray (1974). Some studies on single-valued process and product variables with growth limits can be found in Bright (1969, p.77-109) (articles by Ayres R.U. and Floyd, A.L.), Ayres (1969), Squire (1977)

3.1.3 Time Projections of Engineering and Economic Relations

Time projections of functional relations are not very frequent, and their most common application is to *economic production functions*. Forecasts based on *engineering relations* are very rare but they do exist. Cowing (1970), Pearl et al (1975). Eide (1979), Wibe (1980), Sahal (1976), and Alexander et al (1973). Projections departing from more complex models on the technical level at the demand side are even more rare. There do exist, however, on some attempts to measure the "utility" of certain characteristics, and to link these to the economic world: see Ayres et al (1975) and Cima et al (1973). The bulk of studies on time dependent *relations* is, however, on economic production functions. A short description of the basic concepts used when dealing with economic production functions could therefore be instructive: First, there is a difference between *ex ante* and *ex post* production functions. *Ex ante* refers to the technical possibilities of choice *before* the investment decision, ex post refers to conditions *after* that decision. The normal assumption is that firms have continuous substitution possibilities between factors of production ex ante, but that there are no substitution possibilities in ex post.

A second distinction is made between *average* (AP) and *best practice* (BP) production functions. BP refers to the most efficient existing technology. AP refers to the average of existing firms in a sector. Finally, there is a distinction between *firm* or *micro production functions* and *sectoral* or *macro functions*. The theoretical concept of the production function was based on firm conditions. Perhaps most satisfactory method of making forecasts is to study the development of the BP technology. However, there are great difficulties involved when estimating such a function. Two approaches can be followed. We can

(i) Estimate a function on the basis of existing production data, but with the restriction that

$$f(\nu^*) \geq Q^*$$

where ν^* is the observed vector of inputs, f is the estimated BP production function and Q^*, the level of output associated with input vector nu^*. The estimation procedure is described in e.g., Forsund and Hjalmarsson, (1976).

(ii) Estimate a function on the basis of *engineering data*

This method implies either that one simply ask an engineering consultant *or* that the economic relations are calculated from known engineering relations (see the survey by Wibe, 1982).

One could also obtain much information from studies of the *average* production function. The usual approach is to from a time series, cross-sectioned data base consisting of input and output figures for different firms and at different points of time. Technological progress is usually assumed to be neutral (of some kind) and the by far most common assumption is:

$$Q(t) = e^{at} \cdot f(\nu) \tag{11}$$

$(a > 0)$, i.e., that the production $[Q(t)]$ grows exponentially with time, given the input set ν. There exists a vast literature on the problem of modeling technical progress into economic production functions (see for instance, the bibliography in Puu and Wibe, 1980).

A third possibility is to start with the development of the *ex post structure* of the sector. This means that we should start with the *capacity distribution*, i.e., a function $g(\zeta_1, \ldots, \zeta_n)$ defined by

$$Q_G = \int\int\int_{G}, \ldots, \int g(\zeta_1, \ldots, \zeta_n) d\zeta_1, \ldots, d\zeta_n \tag{12}$$

where Q_G is the capacity located in area G in the $\zeta_1, \ldots, \zeta_n$ space, and $\zeta_1, \ldots, \zeta_n$ is the input coefficients (input per unit of output) of factors $1,\ldots,n$. The distribution function indicates the capacity of the firms with input coefficients within the space G. The movement of $g(\zeta_1, \ldots, \zeta_n)$ over time is an indication of the structural change within the industry and is a suitable starting point for forecasts.

3.2 Some Special Features with Time Series Projections

(i) Including the "Effort" and the Cost of Effort

Hereto we have assumed a "given effort". However, if we are dealing with forecasts for strategic planning, we must of course also include the *cost of effort*. In the case of the growth curve, we would for instance assume that the growth rate, a, was a function of the ***number of scientists***, N, working constantly on the subject, e.g.,

$$a = a_0 + a_1 \cdot g(N) \tag{13}$$

($a_0 \geq 0$ growth from e.g., learning by doing.) The effect of "effort" (i.e., cost) on the path of progress is discussed extensively in Fusfeld and Langlois (1982). The "learning by doing" effect is discussed in Arrow (1960) and illustrated empirically in Fusfeld (1970).

(ii) Including Probabilities ad Probability Distributions

A forecast is always associated with a certain ***probability***. What is predicted is normally the ***mean*** outcome. It is not difficult to model a probability distribution attached to this mean. We can for instance attribute a probability distribution to this mean with a standard deviation =0 at the time of the forecast and increasing over time. One could assume a probability distribution where the probability for the trend (mean) $\pm z\%$ at time T was π. Such probabilistic approaches are discussed and illustrated in Floyd (1969), Mitchell (1975), Dobrow and Malaya (1979), Cima et al. (1973), and Botez (1977).

(iii) Including Stepwise Increase in the Single-valued Variable. The analysis of "Breakthrough" and the Envelope Forecast.

It is not unusual that a variable develops in a stepwise fashion. Several examples can be cited [see Ayres (1968), (1969)] and we can use as an illustration the development of the Cornut efficiency for heat engines: There are two things that need to be examined in these cases:

(i) The envelope

(ii) The switch points between technologies

Let us assume that we are dealing with the process displayed in Figure 2. The first forecast that could be made is the envelope, i.e., the overall development. Second, we could forecast the development of the (latest) technology used. If we can detect an increasing distance between these two, it would indicate a relative saturation in today's technology, and a strategy for a radical break-through may be adopted.

It is not easy to forecast these break-throughs. However, one method based on probability has been suggested by Sahal (1976). The starting point is the probability distribution of inventions based on historical data. (For example, 50% probability of making an important innovation within 2 years, 60% within 3 years and so on.) This probability distribution could of course be attached to a distance between the envelope

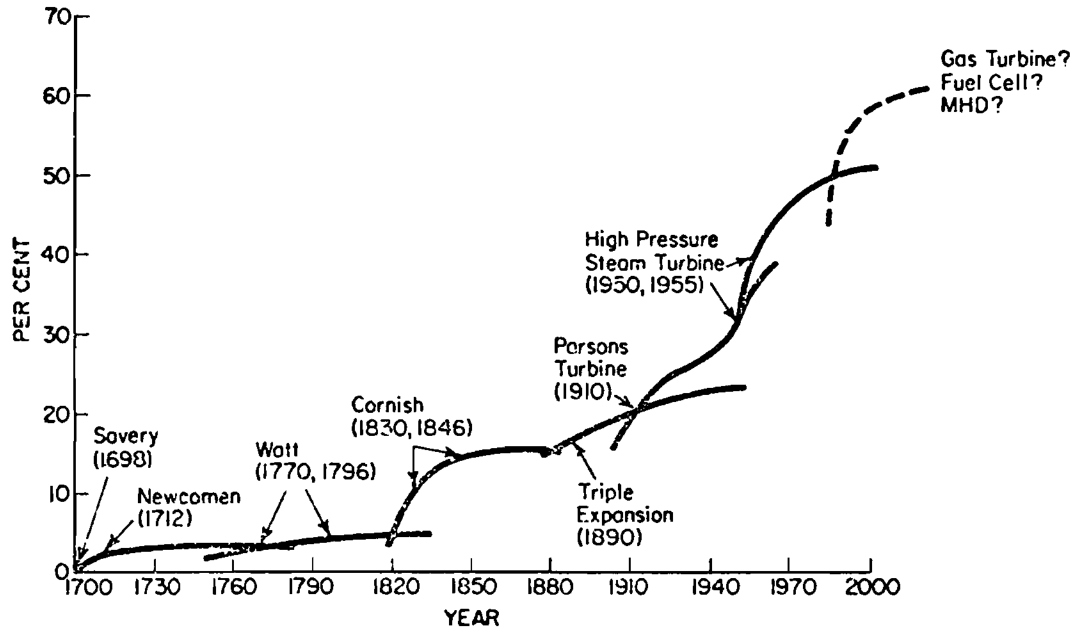

Figure 2. Efficiency of External Combustion Energy Conversion Systems. (*Source:* Ayres (1969)).

and the technology that is used today. (The probability curve can also be made dependent on research effort.)

4. FORECASTS OF LARGE SYSTEMS

4.1 Introduction

Forecasts of large systems are normally a very complicated matter, and one cannot easily identify clear methods. The most common approach is to build the system from many minor relations and forecast each variable separately. The system outcome is then nothing but the sum result of many individual (and interacting) variables, and no method or theory for the *system as such* is needed. However, in some cases there are the following special features attached to the use of system forecast: interacting probabilities, interacting economies, and global constraints.

4.2 Interacting Probabilities

A system usually consists of many interrelated subsystems. Each of these subsystems is associated with a *probability distribution* regarding future development. In order, for instance, to develop a new product, we have to develop three subsystems, A1, A2, and A3. The probability of "success" in each of these subsystems can be described by a function relating *time* and *research* effort (in value) to a probability figure. Suppose now that the subsystems have to be developed in a certain order, so that first A1, *then* A2 and finally A3 have to be developed. The probability of developing the total system P^T is the sum product of all subsystems probabilities

$$P^T = P^1 . P^2 . P^3 \tag{14}$$

Let us assume that we want to know the best strategy (i.e., lowest cost) for which the probability of the total system is 50% at year T. We would then (by iterations) choose the distribution of research efforts $C_1 + C_2 + C_3$ that fulfilled

$$\mathrm{Min} C_1 + C_2 + C_3$$

ST

$$P^T = P^1 . P^2 . P^3 = 0.5$$

$$T = t_1 + t_2 + t_3 \tag{15}$$

If several T's and probabilities are chosen, this would result in an "effective frontier" for the whole project, i.e., relation between overall research effort and time of development ***and*** probability of success. This method has been used to forecast the future of the tokamak fusion process (Vanston et al. 1977).

This basic model can be extended in several directions. Let us assume that the subsystems are not dependent on each other in time, so that they could be developed individually. The overall probability of success would be the same, but total time would now be $T = Max\ t_i \quad i = 1,2,3$. Another application of conditional probabilities in large systems has been suggested, based on Godet et al's (1976) ***cross-impact*** method of forecasting. Let us assume that we deal with three distinct "Events", E_1, E_2, E_3, which interact with a certain probability. Each event has its own probability. Let us assume we have the following scheme:

If this event occur	-- then the probability of this event is		
E_1	E_2	E_3	
E_1 (0.5)	-	0.8	0.2
E_2 (0.6)	0.9	-	0.8
E_3 (0.7)	0.3	0.5	-

A "non-occurrence" matrix is also constructed from this matrix using ordinary statistical definitions.[9] By using computer algorithms, the total dependent probability figures can be calculated. These new total figures could be used for scenario studies since they tell us "If event X takes place, what is the probability that event Y will occur?"

Finally, when using large systems to forecast a certain development the uncertainties involved must be underlined. When two events, each associated with a certain probability, interact, the most common case is that the overall probability is a product of the individual probabilities. Since large systems often include many such smaller parts, the system outcome (i.e., all smaller parts obtaining a trend value) is in most cases associated with an extremely small probability.

4.3 Interacting Economies

When studying a large system from an *economic* point of view, one must take into account the *interactions* that follow. For instance, if we study a firm, we can calculate the effects on output sold and inputs bought of a partial increase in wages or in some other price. But if we study the whole economy, we must assume that an increase in wages affects all sectors. The total outcome may therefore be radically different in these two situations: In the case of the firm, labor will most certainly be substituted for other inputs since the relative price has gone up while in the other case, we will probably end up with a more or less proportionate increase in all prices since labor is the only *primary* input and everything is directly or indirectly, produced by labor.

The interactions of an economy is normally modeled in an input-output system, showing the amount of commodity i it takes to produce one unit of product j. Given such a model, we can follow the changes throughout the system and analyze, for instance, what would happen to steel production when car production drops by z%. We can also calculate the "total content" (i.e., direct input *plus* + input in intermediates) of various resources, e.g., labor, energy, "knowledge" in end products, thus calculating the *overall* effects of, for instance, an increase in prices of primary resources. An input-output system may be used in several ways for forecasting purposes.

Let us assume that we can forecast the development of a technology, and that our prediction is that it will use $\zeta_i^t (i=1, \ldots, n)$ units of intermediate good i (per unit of output) in year t. Now we would also like to know something about the future cost of these intermediates. One way to calculate them is to assume that the absolute cost of good i, is

$$P_i = (1 + \alpha) \cdot w \cdot L_i \tag{16}$$

where w is the wage rate, L_i equals direct plus indirect labor content (=labor value) and α equals the profit margin. Since we are probably interested only in *relative prices* P_i / P_j , we find $P_i / P_j = L_i / L_j$ (if α and w are assumed to be constants). L_i can easily be calculated from an ordinary input-output table and tomorrow's value can thus be calculated from *tomorrow's* national input-output table. If we assume that tomorrow's table is today's best practice, we can obtain direct knowledge of tomorrow's technique directly from today's data.

4.4 Global Constraints

The third special feature of large systems is *global constraints*. The nature of these are quite obvious. If we forecast the development of an industry we need not take into account total labor supply, since the industry is small compared to the whole economy. On the other hand, if we forecast development of total GNP, labor supply constitutes one of the most important limitations. Some of these global constraints are:

(i) Total (active) population
(ii) Total amount of physical resources
(iii) Total possible environmental damage

It must also be remembered that many equilibrium conditions must be fulfilled on global level e.g.,

(i) Total export = total import
(ii) Total production = total consumption

5. AN EMPIRICAL ILLUSTRATION –SUPPLY AND DEMAND FORECASTS FOR THE FOREST SECTOR

5.1 Introduction

This section will present some forecasts relevant for the forest sector although the analysis is very rudimentary, and only simple relations and pieces of informations are used. Materials relevant for both supply (Section 5.2) and demand (5.3) forecasts are presented with special attention given to forecasting for developing countries.

5.2 Forecasting Paper and Pulp Technology

5.2.1 Labor Input Figures.

Labor input per unit of output decreases both as a result of technical progress and because of increasing scale. These two effects must be separated. Let us start with the relationship between labor input and scale. For a sulphate mill using the best 1965 technology, this relationship is shown as a solid line in Figure 3.[10] From other sources[11] we can obtain *point figures* (i.e., input figures for only one output level) for a new pulp mill at different times. These are displayed in Figure 3 together with the year of observation. Suppose now that the labor-scale relation has remained relatively intact, but shifted upwards (or downwards). Taking the points on the solid lines as 100%, we obtain percentage figures for 1969, 1977, and 1979. These *percentage* figures tell us the labor consumption at year *T* in percentage of 1965 best technology. These figures are displayed in Figure 4 together with a trend estimate. The trend indicates a drop in labor consumption (for all output levels) of about 20% in ten

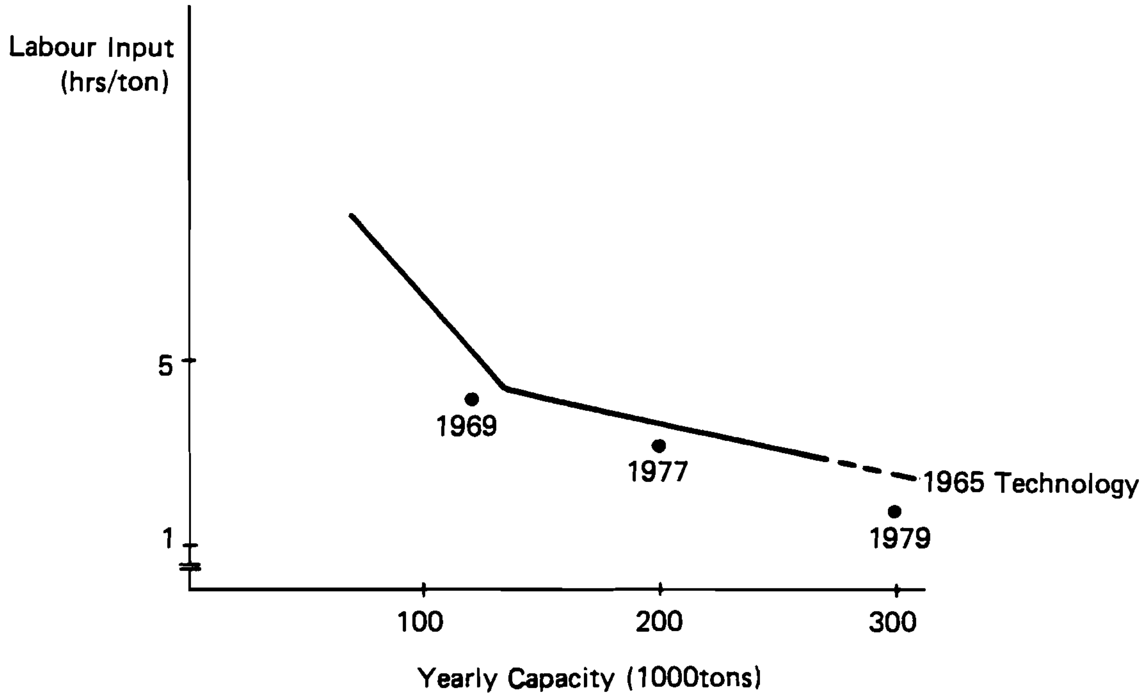

Figure 3. Labor Input for a Sulphate Pulp Mill.

years. This amounts to an annual average of approximately 2.2%. Thus, our forecast is

$$L_Q^t = L_Q^{1965} \cdot e^{-0.022(t-1965)} \qquad (17)$$

where

L_Q^t = labor input of a mill of capacity Q at year t

This means that labor input will be reduced by 50% in 31 years (at all levels).

5.2.2 Capital Input Figures

The foregoing analysis is not easily repeated for capital input. Here we must take into account the effects of rising prices since the capital quantity is a price-based measure. Let us start with the scale-relation. This is shown in FAO (1973) for every type of mill and every scale. If we study capital cost at one output level and for one specific type of mill, we would, in the case of constant prices, expect an *increase* in capital costs due to

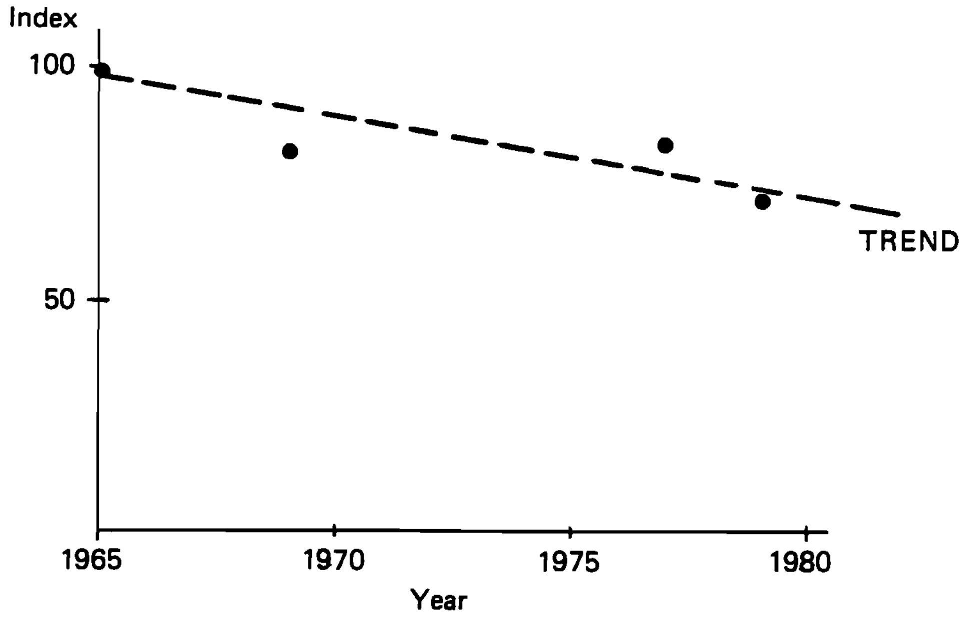

Figure 4. Labor input relative to 1965 technology as displayed in Figure 3.

(i) capital-labor substitution

(ii) capital-energy substitution

(iii) increasing anti-pollution equipment (especially 1970-1980)

On the other hand, we would expect a *decrease* in capital consumption due to technical progress (i.e., increased productivity in the capital producing sector). Let us for the sake of simplicity assume that

$$P_I(t) = W(t)L_I(t)S(t)A \tag{18}$$

where

$P_I(t)$ = price of investment good I at time t

A = constant

$W(t)$ = Wage rate

$L_I(t)$ = amount of labor needed at time t to produce the capital good

$S(t)$ = a factor expressing the effects of substitution

If we indicate growth rates with a dot (e.g.,$dw / dt / w = \dot{w}$) we have

$$\dot{P}_I = \dot{W} + \dot{L}_I + \dot{S} \tag{19}$$

($\dot{A} = 0$)

The growth of investment cost is the sum of (i) wage growth (ii) labor productivity growth in the capital producing sector and (iii) the rate substitution.

It seems quite obvious that the increase in *labor costs* ($\dot{W}$) the main factor behind the dramatic increase in investment costs in the forest sector. Since this affects all sectors and all products, the interesting measure for forecasts is $\dot{P} - \dot{W}$, i.e., the change in investment cost ***net*** of increases in wages. We have the figures shown in Table 2 for the period 1968-1980. Taking trend values (see Figure 5), yields:

(i) Pulp mills 1968-1976

$$\dot{P} - \dot{W} = -0.0127$$

(ii) Paper mills 1968-1980

$$\dot{P} - \dot{W} = -0.0307$$

Table 2. Index-series for investment in pulp and paper mills.

Year	Paper mill with 8.5m paper machine		Pulp mill (constant capacity)	Index for labor costs per hour (Sweden)
	Total Investment	Investment per capacity unit		
1968	100	100	100	100
1969	112	104	108	110
1970	122	114	120	120
1971	138	120	128	132
1972	150	127	140	145
1973	172	143	160	162
1974	194	168	189	194
1975	232	180	220	233
1976	264	193	240	276
1977	288	214	n.a	300
1978	332	232	n.a	333
1979	372	254	n.a	369
1980	412	279	n.a	400

Sources: Column 1 and 2 - Troil and Salama (1981); column 3 - United Nations (1978); Column 4 Statistisk Aersbok foer Sverige 1970-1980.

The sum effect of technical progress and substitution is thus to *decrease* capital cost per unit with ≈ 1.3% in the pulp and about 3% in the paper sector.[12]

There is every reason to assume that this development will continue since L_I , i.e., productivity development in the capital producing sector will probably continue as before. $\dot{S}$ will probably *decrease*, since the '70s witnessed a massive increase in capital due to (i) environmental legislation, and a drastic increase in energy prices. If the environmental legislation now remains the same, then the cost of capital need not *increase*; the same reasoning applies to energy prices. Since the effects of anti-pollution measures were only about 0.7% per year, we can fairly safely predict that capital cost will change about -4.5% for paper mills (-2.5 to 3.5% for pulp mills) plus an increase in wages in the next decade. There is thus little empirical support for the wide spread fear of exploding investment costs.

5.3 Costs and Technology for Developing Countries

The calculations made in 5.1 referred to new pulp and paper mills in developed countries. It is quite obvious that since production conditions differ in the developed and the developing world, forecasts have to include other factors when dealing with the latter group. This section will present some empirical material relevant to the special features for technology forecasts in developing countries. For comparison, I will concentrate on labor and capital input figures.

5.3.1 Labor Input Figures in Different Regions

While I have not found a report giving physical labor input figures for new plants in different parts of the world, there are indications that these are considerably higher than for developed countries.[13] A look at the Figure 6, *average productivity* of the pulp and paper sector, verifies this.

Average productivity in the pulp and paper sector is the vertical axis. (Measured as produced pulp *plus* paper/number of employed persons in the pulp and paper sector[14].) We find a clear linear relationship with

$$\ln(Prod) \approx -2.30 + 1.0 \cdot \ln(Y) \qquad (20)$$

(Prod = productivity tons/employee; Y = income/capita US$1969) or

$$Prod \approx 0.10 \cdot Y \qquad (21)$$

Productivity is thus linearly related to per capita income. As income in the developed countries is about ten times higher than in the developing ones, we have to calculate using an input figure about ten times higher than that for the world. The difference in plant size accounts for this huge difference as indicated in Figure 4.

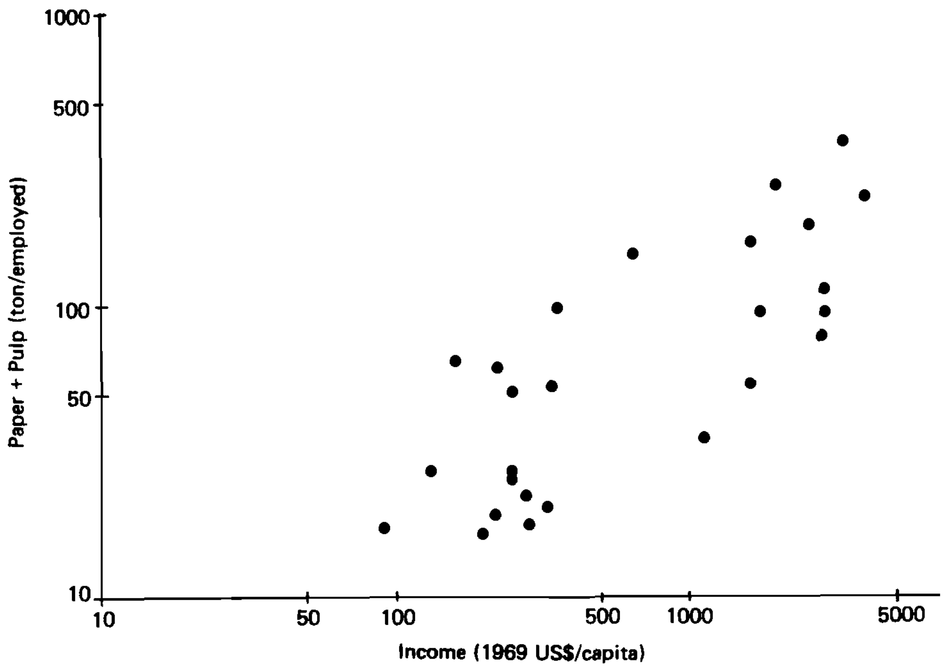

Figure 6. Average per capita income 1969 (US$/capita) in countries vs productivity in the pulp and paper industry (ton paper *plus* pulp per employee). Double-logarithmic scale.

The picture is not very clear, but a log linear relation (approximately $Y \approx e^{4.91} * (\text{plantsize})^{0.65}$) is not a bad approximation. The reasons for building small plants in the developing countries is of course (i) limitations in markets, transport and capital. limitations.

The point is that a forecast of technology (in this case labor input) has to rely on a forecast of income/capita. The safest assumption seems to be to rely on relation (20), together with the "shift-parameter" established in the preceding section.

5.4 Capital Input Figures in Different Regions

Contrary to what is commonly believed, expert opinions confirm that the cost of investment is *not* lower in developing countries.[15] The only quantitative information available here is from Troil and Salama (1981), where the figures shown in Table 3 are given. Capital cost is thus 50% higher in developing countries as compared with Europe

$$I^D = I^E \cdot (Y_D / Y_E)^{\alpha} \qquad (22)$$

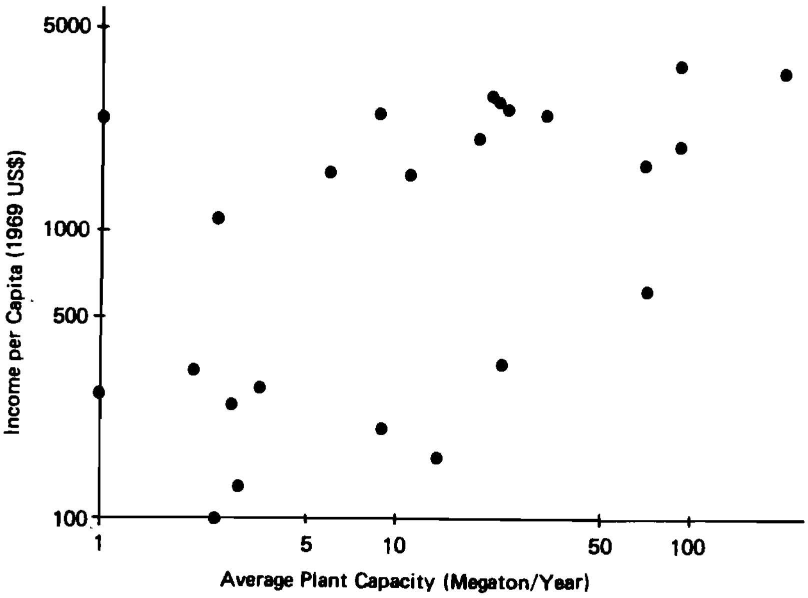

Figure 7. Average plant size in the paper and pulp industry vs national income per capita 1969. Double-logarithmic scale.

Table 3. Cost of investment in different regions.

	Europe	US (South)	Brazil	Developing Countries
Total cost of Investment	100	100	115	120
Infrastructure	5	5	20	30
Total cost	105	105	135	150

where

I^D = Investment cost (for a given plan) in developing countries

I^E = Investment cost in Europe

Y^D, Y^E, = Real per capita national income in developing countries (D) and Europe(E)

α = parameter < 0 ($\alpha \approx -0.17$ since $I^D = 1.5 \cdot I^E$ when $Y_D / Y_E \approx 0.10$).

The explanation for this is that it is probable that the cost for machines, infrastructure, etc. will be more similar when national income becomes more equal.

5.4.1 *Prices and Costs in Different Regions*

The cost of labor and wood differ significantly among regions in the world, as seen in the Table 4.[16] Assuming a consumption of $5m^3$ wood per ton of paper, this means that the Brasilian plant can operate with a labor input figure 23 hours/ton ***higher*** than a Swedish plant and still have about the same variable costs per unit. When forecasting those costs, the strategic variable should again be the per capita income since wages and costs of cutting, transportation, etc. are directly proportional to that variable.[17] However, the natural differences regarding, for example, climate, must be taken into account, so that different equilibrium prices for wood will emerge for the same wage and/or per capita income figure.

Table 4. Costs for labor and wood in different regions (approximate figures).

	Finland	Sweden	W. Germany	US	Canada	Brazil
Wood 1978 US $/m^3$	33	32	43	20	26	16
Labor cost US $/hrs	8.7	11.5	12.3	12.6	13.3	3.45

5.5 Some Comments on Demand Forecasts for Different Regions

Demand is one of the strongest forces influencing the path of technical progress. This is especially true for developing countries where the growth of national demand leads to an increase in plant size, thus adding scale effects to the overall gains in productivity. An important element in technological forecasting is therefore the demand projections. From the theory of individual consumer we have

$$C_i^j = f_i^j(Y_i, P^j, P^s) \qquad (23)$$

where

C_i^j = Person i's consumption of good j

Y_i = Real income of person i

P_j = Real price of product j, P^s = real price of a substitute (we assume that there is only two goods)

For *short run* studies, we can assume that Y_i is fixed, thus

$$C_i^j = g_i^j(P^j \cdot P^s) \tag{24}$$

However, when long-run development are considered, variations in income outweighs variations in prices, so

$$C_i^j = h_i^j(Y_i) \tag{25}$$

It is are worth noting that first, consumption is expressed as *consumption per individual* and second, income is *income per individual*. Forecasting the demand of a group of persons (e.g., a population within a region) of n persons is thus a question of *adding* n demand functions.

The implication is that when we want to forecast demand for a region, we would rather start with a relation between *per capita consumption* and *per capita income*, and multiply by population. Total growth of demand is obtained by forecasting (i) population growth; and (ii) growth of per capita income. Some material from the forest sector will provide an illustration. One very important question to be answered is whether the developing countries will have the same consumption pattern. as the industrial world has. If that is the case, we only need to establish the *global* relationship between per capita consumption and per capita income. Such relations have been established earlier. The findings indicated that

$$\bar{C} = A \cdot \bar{Y} \tag{26}$$

($\bar{C}$ = consumption of paper and paperboard per capita at national levels; $\bar{Y}$ = Income per capita at national levels.)

My findings do not support this formulation. In Figure 8a - 8d, I have plotted (in double-logarithmic diagrams) per capita consumption of different paper products against per capita income.[18]

I shall not comment on these figures separately, since they show more or less the same pattern. First, we have a segment with very low consumption and income figures (<1.0 kg capita, < 200-300 US$/capita) where there seems to be a very low casual relationship between the variables. This is what we would expect since things like schooling, infrastructure, population density etc. rather than per capita income determine demand at these low level (i.e., societies at very low income levels are so diversified that we cannot expect a simple and common relation). For levels with consumption >≈ 1.0 kg/capita we find a relation of about the same form:

$$\ln(\bar{Y}) = a_1 + a_2 \ln(\bar{C})^a \tag{27}$$

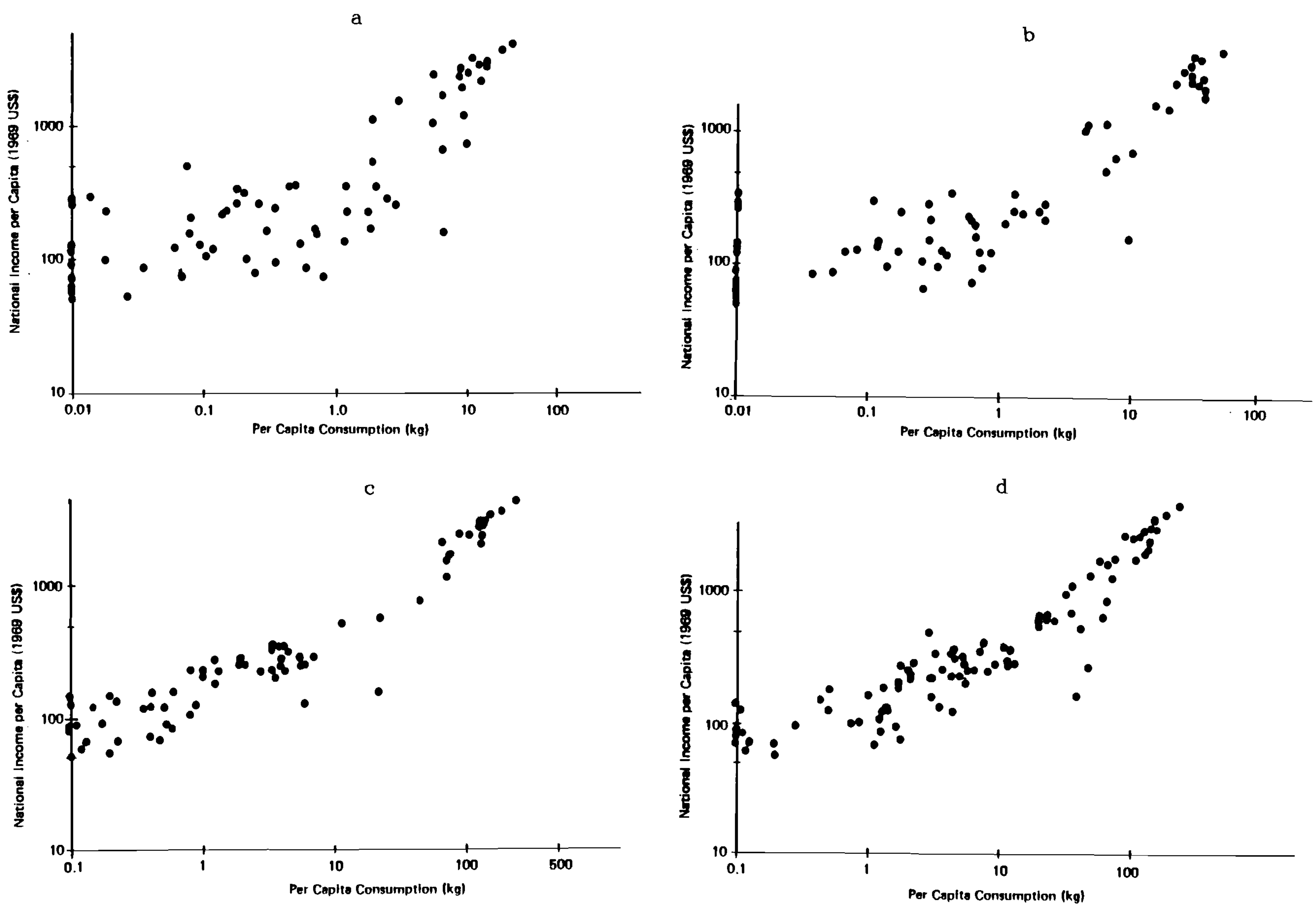

Figure 8. 1969 per capita consumption of different kinds of paper and paperboard (kg.) vs 1969 per capita income (US$) in different countries.

where a_1, a_2 and α are parameters with $a_2 > 0$ and $\alpha > 1$. As the elasticity of income, ε[19] is the log-derivative , we find that

$$\varepsilon = \frac{1}{a_2} \cdot \frac{1}{\alpha} \cdot \ln(\bar{Y})^{\frac{1}{\alpha} - 1} \tag{28}$$

where ε is the elasticity of income. Since $\alpha > 1$, we find that *the elasticity tends towards zero when income per capita increases.*

A formulation like (27) means that consumption per capita grows without limit when income increases. This is not realistic but we can easily introduce a consumption limit in our model. (The fact that $\alpha > 1$ is a support for such a limit.) A suitable formulation is

$$\ln(\bar{C}) = b_0 + b_1(\bar{Y})^{\beta} \tag{29}$$

with

$$\varepsilon = b_1 \cdot \beta(\bar{Y})^{\beta} \tag{30}$$

with

$$\varepsilon > 0, d\varepsilon / dy < 0, \lim_{Y \to \infty} \varepsilon = 0$$

The question now is whether or not the relations displayed in Figures 8a - 8d are stable. Do countries just move along this path when income rises? To answer this, Figure 9 calculates the figure corresponding to Figure 8d for 1979.

When compared with Figure 8d, one can see that the *curve has shifted upwards.* If the formulation

$$\ln\bar{C} = a_1 + b_i(ln\bar{Y})^{\gamma} \tag{31}$$

is used, then the shift parameter a_1 is *lower* in 1979 than in 1969. Translated to a non-logarithmic scale, this shift can be illustrated by Figure 10.

Apparently, the developing countries *do not* follow the path set by the already industrialized nations. They will at every given level of per capita income have a lower consumption of paper products, perhaps due to the "new" technologies available (e.g., radio and television as products competing with newsprint.) Thus, the appropriate demand forecast should in addition to the income forecast (i) forecast upper consumption limit; (ii) Measure and forecast the shift of the relations displayed in Figure 10.

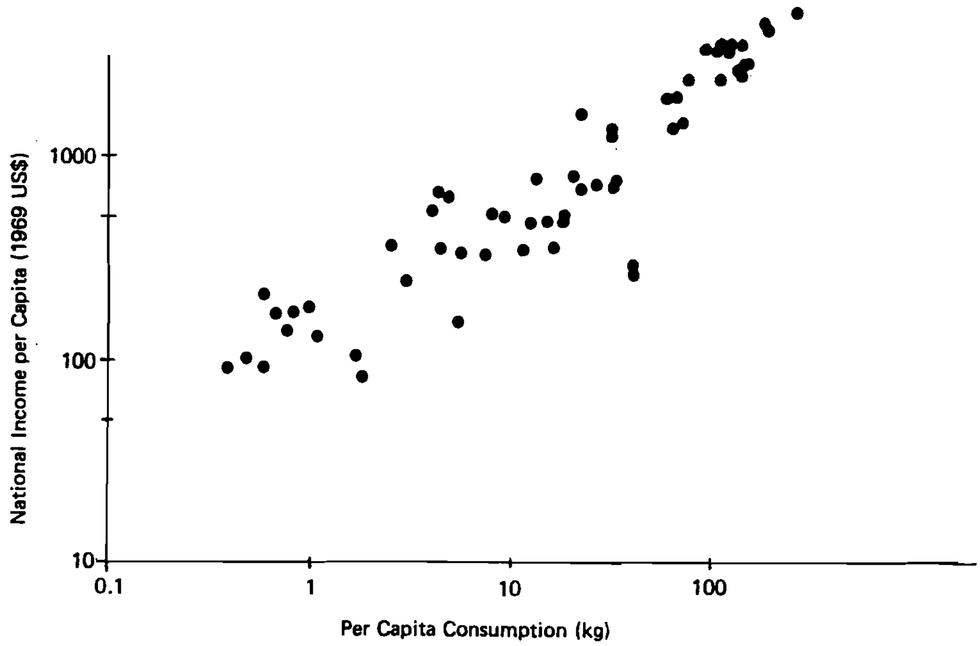

Figure 9. National income per capita, 1969 in US$, vs paper and paperboard consumption (double-logarithmic scale).[20]

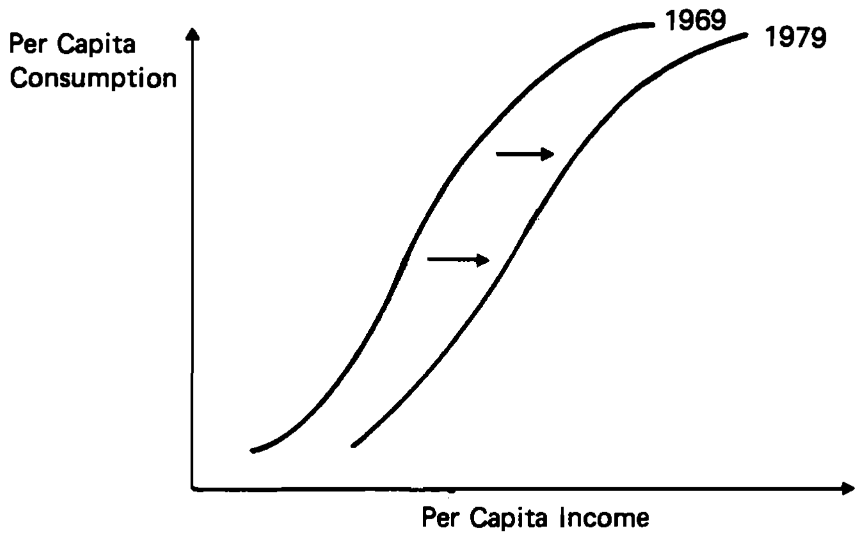

Figure 10. Graphic illustration of the shift of consumption-income relation between 1969-1979. (Observe linear scale)

NOTES

[1] This concept was introduced by Chenry (1949). For a modern survey, including several empirical examples, see Wibe (1982).

[2] This *transformation* from engineering to economics is studied in Wibe (1980) and summarized in Wibe (1982).

[3] For a study of this, relevant to the forest sector, see Wibe (1981).

[4] The utility function with *characteristics* as arguments was introduced by K. Lancaster in his path-breaking study (1971).

[5] The utility functions do of course change as an indirect result of technological progress.

[6] There exist several books dealing with methods of technological forecasting e.g., Jantsch (1967), (1972); Ayres (1969); Martino (1975); Bright (1968); Dodge et al. (1975). The ideas presented here are taken from all these books and from articles in "Technological Forecasting and Social Change".

[7] Since this latter aspect will affect the individual utility curves..

[8] Some of these can be found in Ayres (1968) p.81-82. They and their impacts are discussed extensively in Wibe (1982).

[9] See Stover (1973).

[10] Source: Wohlin (1969). Wohlins' figures are based on engineering evidence by Jaakko Pöyry.

[11] These sources are FAO (1973), United Nations (1978), and "Skogsindustrin..." (1979).

[12] The reason for this difference is that technical progress has increased the paper producing capacity of an 8.5m machine by 30% during the period. No such development can be found on the pulp side.

[13] See for example FAO (1973), UNIDO (1971).

[14] Sources: For national income, United Nations Statistical Yearbook. For pulp and paper production, FAO (1970). For number of employees, UN "The growth of world industry" 1973, ed. Vol.1 ISIC 3411: Pulp and paper etc." Figures relate to activities in 1969 (Exceptional cases 1970 or 1968).

[15] UNIDO (1971)

[16] "Skogsindustrin..." (1979)

[17] See FAO (1973), p.244.

[18] Sources: For consumption figures 1969, FAO (1973). For income, UN Yearbook.

[19] The definition of the income elasticity is

$$\varepsilon = \frac{dQ}{dY} \cdot \frac{Y}{Q}$$

where Q is quantity and Y income.

[20] Sources: For consumption figures 1979, I have taken Production + Import-Export from FAO (1980) . (I have chosen only those countries with positive production.) By comparing these figures with FAO (1973), I obtained average annual growth 1969-1979. Figures of average population growth and GNP growth (1970-1977) were obtained from the World Bank World Tables (2nd edition 1980). These average growth rates were assumed to prevail even 1978 and 1979. By combining these rates with the income-consumption figures for 1969 (see note 18), I obtained figures for 1979.

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