A LONG-TERM MACROECONOMIC EQUILIBRIUM MODEL FOR THE EUROPEAN COMMUNITY

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FOREWORD

MACRO is a long-term macroeconomic equilibrium model designed to reflect the aggregate economic structure of a group of countries or a region. The version of MACRO presented in this report was develop specifically for application to the member countries of the European Community (EC). Calibration and validation of the model for the EC region were undertaken as part of a study on "Long-Term Alternative Energy R&D Strategies", executed by IIASA under contract to the Commission of the European Communities (CEC) [Contract Nos. 541-79-ECI-OR(ERDS) and ECI-391-698-80-ÖR].

MACRO accounts for substitution processes between energy and other factors of production, assuming supply-constrained economic activity and emphasizing energy as the constrained input factor. The model can be used to calculate a macroeconomically optimal allocation of capital, manpower, and energy, as well as to check the consistency of assumptions about economic growth, structural economic change, and energy conservation.

The development of MACRO was guided by the need to check assumptions about long-term economic activity and energy requirements in the context of IIASA's research program on the global long-term energy problem [see Energy Systems Program Group of IIASA (1981) *Energy in a Finite World*: Volume 1, *Paths to a Sustainable Future*; Volume 2, *A Global Systems Analysis* (Cambridge, Massachusetts: Ballinger)]. MACRO may be implemented both as a component of a model set, such as the group of models constructed by the Energy Systems Program Group, or as a stand-alone model.

The present report is a doctoral dissertation, an unusual specimen among IIASA Research Reports. The author, a member of IIASA's Energy Systems Program, received a doctorate in Economics from the Universität Fridericiana (Technische Hochschule) of Karlsruhe, Federal Republic of Germany, for the research described in this report.

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Program Leader
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CONTENTS

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SUMMARY

As fossil fuel reserves become scarcer, the rising cost of energy imports, the diversion of capital to the energy sector, and the general drain of resources to energy-exporting countries will affect economic growth, employment rates, personal consumption rates, and investment behavior in energy-importing countries. Thus the problem of meeting energy requirements involves economic issues as much as the physical availability of resources. MACRO, a highly aggregated, long-term, two-sector general equilibrium model, was developed to examine the energy–economy linkage in the context of the global energy study undertaken by the Energy Systems Program Group of IIASA.

This report presents a version of MACRO calibrated for the European Community (EC), focusing on model structure, model validation and testing, and four applications to the EC region over a fifty-year planning period. The applications, based on a range of energy supply scenarios, examine such economic questions as the impact of rising energy costs on economic activity, the feasibility of common assumptions about price-induced conservation, and the impact of continued high levels of energy imports on the trade balance.

In essence, MACRO describes supply-constrained economic activity, using energy as the constrained input factor. The model is built around a constant elasticity of substitution (CES) production function, which represents substitution processes among capital, labor, and energy. MACRO differs from similar models of energy–economy interactions through its use of explicit factor functions and an empirically based procedure for estimating the CES production function's parameters. To overcome the problem of long-term extrapolations of econometric functions, which were estimated using data from a relatively short sample period, the model concentrates on slowly changing variables, including the capital: output ratio, investment and consumption rates, population, and the labor force. The model also contains exogenously determined "scenario parameters", which can be used to countervail short-term trends inherent in the estimated parameters, as well as to simulate policy measures.

Validation of model results against empirical data shows a satisfactory fit of model output to data for the EC over the period 1966–1976. The model has a slight tendency to underestimate developments during periods of rapid economic growth and to overestimate

the evolution of economic variables during periods of stagnation or recession. A second type of validation run, simulating an energy crisis in 1965, produces a good replication of the adjustment process that followed the 1973/1974 energy shock. The model results do not, however, account for the low employment rates and high market interest rates that characterized the 1970s.

The first long-term application of MACRO to the EC examines the economic impact of continued "business as usual" in the energy sector, i.e., unlimited availability of energy at reasonable costs, an unchanged energy demand–supply structure, and constant capital requirements per unit of production. This rather overoptimistic scenario constitutes a reference case for comparison with less favorable energy supply futures. The results of the MACRO run for Scenario 1 include a slowdown in the growth of gross national product and an accompanying decrease in secondary energy demand.

In Scenario 2, energy imports are assumed to be restricted, with correspondingly higher energy import prices. Compared with energy output for the "business as usual" scenario, model results indicate significantly lower economic growth rates, higher equilibrium energy prices, and a marked fall in the real wage rate.

The third scenario focuses on the compatibility of high economic growth rates with combined low growth in energy demand and high energy prices. The results of this "consistency check" indicate that the prices commonly assumed to induce a given level of energy conservation are considerably lower than the prices that would actually be required.

Scenario 4 analyzes the economic repercussions of the capital deepening that is associated with the creation of an advanced energy supply infrastructure. The impact of the energy sector's rapidly increasing capital: output ratio on interest rates and capital profitability is examined in two successive model runs: the first run, assuming no government intervention on the capital market, indicates that the energy sector would not be able to accumulate sufficient capital; the second run suggests that income tax increases could be used to reduce personal consumption and rechannel investments into the energy sector.

One model result common to all four scenarios is a deteriorating balance of trade for the EC over the next several decades. A final MACRO run suggests that if exports were increased sufficiently, the trade balance could be eliminated. However, this would require strong government measures to stimulate economic activity, especially during times of recession.

1 INTRODUCTION

Energy Transitions

Because the dynamics of any infrastructure are inherently long-term in nature, an analysis focusing on the implications of structural change requires a far look into the future, as well as into the past. The Energy Systems Program at the International Institute for Applied Systems Analysis has concentrated on the long-term aspects of the *energy* problem, specifically on the transition (or structural change) from the present global energy system, based mainly on fossil fuels, to a more advanced and, in the long run, sustainable system.

Several similar transition processes have been observed during the last two centuries. Figure 1, taken from Marchetti and Nakićenović (1979), shows the substitution of oil and gas for wood and coal during the nineteenth and twentieth centuries. Historically, these dynamic transitions within the energy sector have followed the development course of the entire economy: an adequate energy supply system has been a prerequisite for industrial development, economic growth, and human prosperity.

Until the middle of the nineteenth century, the world's energy supply was dominated by wood. When heavy machinery and power-assisted tools were introduced into production processes in northern regions of the globe during the industrial revolution, energy sources were needed that had a higher specific energy density and that could be more easily transported over long distances. Coal fulfilled these prerequisites and therefore penetrated into the energy market. Later, consecutive transitions to oil and gas took place for similar reasons.

Of interest to the energy analyst are the regularities characterizing past transitions. The market penetration curves of the new types of energy shown in Figure 1 have almost identical slopes. This observation suggests that the speed of introduction of new energy supply technologies (in fact a change in infrastructure) follows certain inherent laws. One may be directly derived from Figure 1 and applied to future structural shifts in the energy sector: each new technology has required from 70 to 90 years to capture 50% of the global

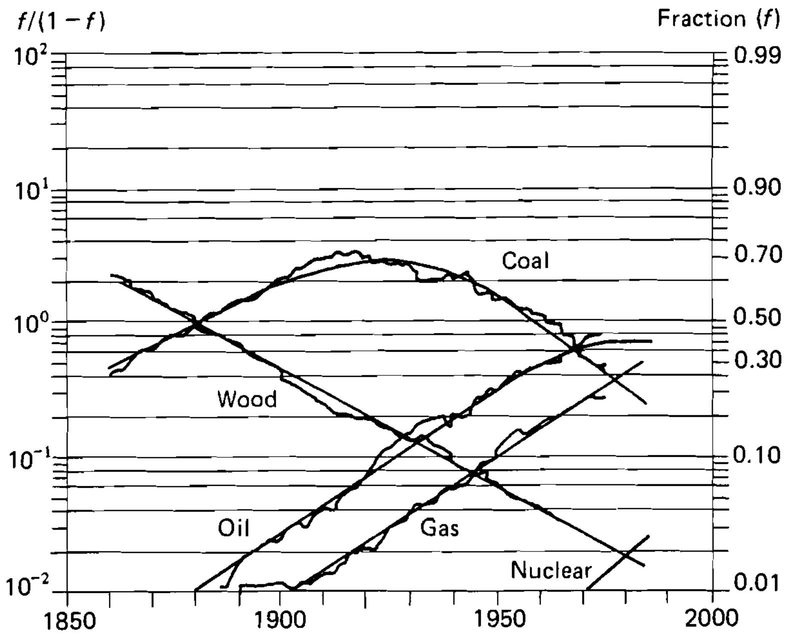

FIGURE 1 Global primary energy substitution. Logarithmic plot of the transformation $f(1-f)$ where f is the fractional market share. Smooth lines are model estimates of historical data; scattered lines are historical data; straight lines show the logistic model substitution paths.
SOURCE: Marchetti and Nakićenović (1978).

energy market, after achieving 1% penetration. On the level of a regional or a national economy, the time required to win a 50% market share is somewhat shorter – roughly 50 years. For this reason, in part, IIASA's Energy Systems Program foresees an energy transition period spanning at least the next 50 years.

The Energy Problem in a Global Context

In recent years, numerous national energy studies have assessed domestic energy demand and calculated energy supply strategies to meet the demand. These strategies describe in detail the domestic energy supply sector and the evolution required for its adaptation to the economy's future energy needs. Most of these studies indicate a gap between energy demand and energy supply; to close the gap, it has been common practice to refer to energy imports and to assume that unlimited amounts of imported energy will be available – without considering the feasibility of this assumption in the international context. When a global approach is taken, however, it is no longer possible to assume an imaginary source from which required imports can be obtained, or an imaginary market to which exports can be directed. Any really feasible long-term energy strategy automatically requires a balanced world trade market. The IIASA study is designed to examine the energy problem on this global scale.

Because energy resources, as well as energy supply and demand patterns, are not equally distributed throughout the world, the globe is divided into seven regions in the IIASA study; the composition of each region is not necessarily based on geographical proximity, but rather reflects similarities in economic structure, energy resource availability, or lifestyle patterns. (See Energy Systems Program Group of IIASA 1981.)

The IIASA Set of Energy Models

In the IIASA study, such attributes as economic activity, energy demand, domestic energy supply, and energy trade volumes had to be determined for each of the seven world regions, and interactions among the regions had to be described as well. This complex configuration required the handling and processing of a very large quantity of data and information within a consistent numerical framework. A set of mathematical models was developed for this purpose as part of the study; a full description of the design and application of the models to the seven world regions is given in Basile (1980) and Energy Systems Program Group of IIASA (1981).

Figure 2 illustrates the interactions and the information flows among the components of the model set. Within this set, the function of MACRO is to provide internal consistency between economic growth and such factors as energy demand and supply, energy imports, energy cost functions, and resource requirements (capital and labor) for the energy sector. The model may be used to examine the long-term effect of changes in the price or availability of energy on economic growth. Analysis of the short-term impact of sudden leaps in import prices or the effect of curtailed energy production on employment, inflation, and the business cycle are not model objectives.

The focus on global, long-term energy questions does not imply that short-term, national-level energy problems are not worth considering. Rather, the IIASA approach is meant to complement the numerous national studies that examine the next two decades in detail. Its long-term global features provide national and regional research groups with a means for checking their results in an international context, e.g., checking the consistency

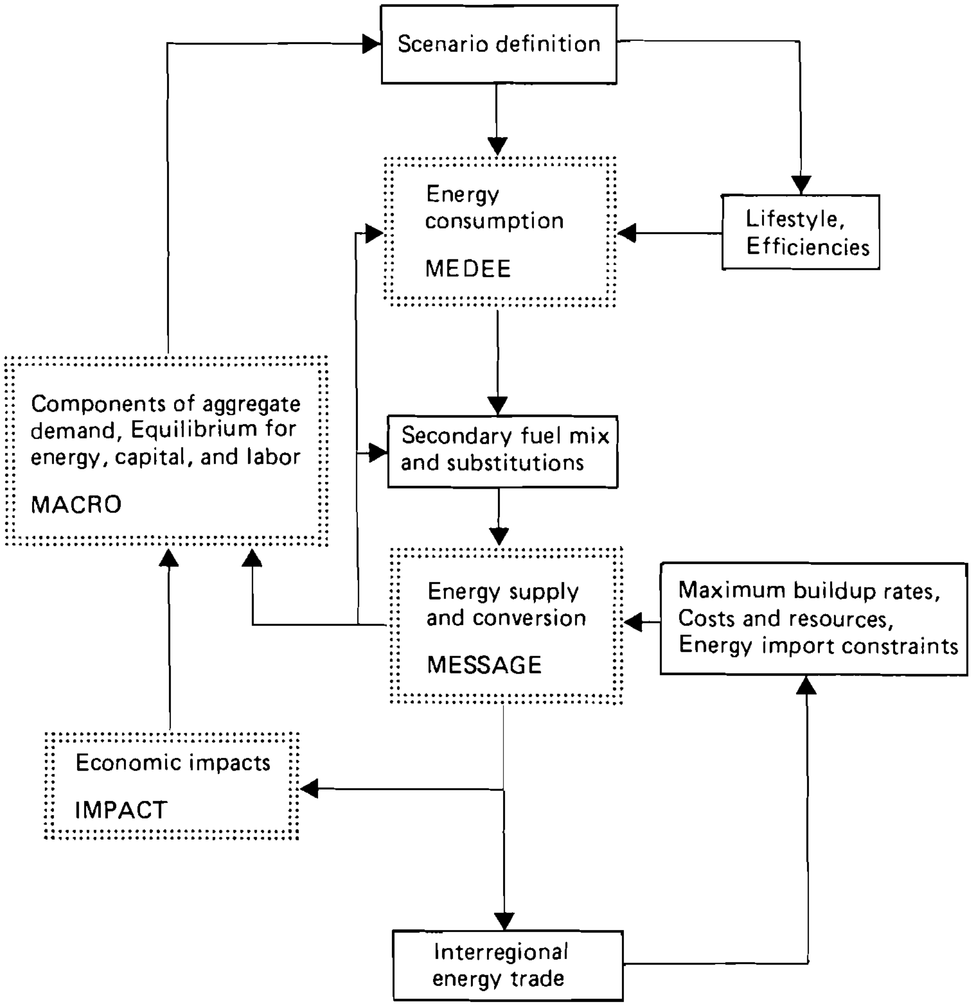

FIGURE 2 IIASA's set of energy models: a simplified representation.

of assumptions about energy trade, energy prices, or resource availability on the international energy market.

An Application of MACRO to the European Community

The need for such consistency checks became clear to the Commission of the European Communities' Directorate-General for Research, Science and Education (DG XII), when it began to examine the future energy supply options available to EC member nations. DG XII had developed, in collaboration with national research institutions, detailed energy demand and supply strategies for each of its member countries. As one might expect, the economic growth targets of each national economy – oriented to past experience and guided by a politically desirable evolution over time – resulted in ever-increasing demands for energy (CEC 1979). Aggregation of the energy import quantities associated with each national economy led inescapably to the question whether the energy import requirements are feasible in a global context.

Because the global approach of IIASA's Energy Systems Program was developed to examine just this type of question, DG XII requested that IIASA perform a case study of the EC region, focusing on competition for energy sources on the world energy market, oil import ceilings, and the impact of energy availability and prices on the economic growth of EC member nations.

The first step of the case study was to locate the EC region within the IIASA classification of world regions. The EC member countries[1] were identified as a part of Region III (Western Europe, Japan, Australia, New Zealand, and South Africa). It was then necessary to disaggregate Region III into "EC" and "non-EC" components, in order to make realistic assumptions about economic growth rates, aggregate energy resource availability, lifestyles, and other factors. If this had not been done, for instance, Australian coal and uranium would have been considered domestic energy resources for the EC region.

To perform this disaggregation, the models shown in Figure 2 had to be calibrated to the EC level. This was especially important in the case of the MACRO macroeconomic module; for some models it is sufficient to modify initial conditions, constraints, and input parameters. In the case of the macroeconomic module, however, one must redesign the model's internal structure, reestimate the parameters, and revalidate the model for any new application. As will be shown in subsequent sections, each of these steps was carried out in applying MACRO to the EC region.

The Objectives of MACRO

The need for a long-term macroeconomic model to examine the EC economy led to the development of the version of MACRO described in this report. Although the model is contemplated for use in energy analysis, it is not explicitly energy oriented. Rather, it is a basic macroeconomic model suitable for analyzing any economic sector characterized by long-term structural change. Briefly stated, MACRO has the following features: it is applicable for long-term analyses (up to 50 years); it is able to distinguish between a specific sector and the "rest of the economy" on an aggregate level; it is capable of capturing crucial problems arising between the sector of interest and the "rest of the economy"; it can test imposed normative structural changes; and it provides a "homomorphic picture" of the existing economic infrastructure.[2] An effort was also made to assure that MACRO is transparent to noneconomists.

The following sections of this report describe in detail the role of MACRO within the IIASA set of energy models, the model's mathematical structure, tests of model validity, and the results of four long-term applications of MACRO to the European Community. The report ends with a brief statement of model weaknesses and strengths.

2 MACRO'S POSITION WITHIN THE IIASA SET OF ENERGY MODELS

The conceptualization of any mathematical model depends on the larger setting in which it is to be used. Thus, MACRO is highly influenced by the other models with which it interacts in the IIASA set of energy models. A brief summary of each component of the model set, shown schematically in Figure 2, is given below.

Scenario Definition

Experience in mathematical modeling has shown the expedience of summarizing all assumptions and exogenous inputs used in model runs in the form of scenarios. Consequently, the modeling activity in the IIASA energy study begins with the definition of scenarios in terms of such variables as demographic development, evolution of productivity and technology, lifestyle development, and economic growth. Such scenarios are not predictions, but rather conceptualizations of the future status of the world, a nation, or a region. Thus, they delimit *a priori* the range of conceivable trajectories over a planning period. The scenario definition stage is shown at the top of Figure 2.

The MEDEE Energy Demand Model

Scenario projections of demographic and economic development, lifestyle, and other variables affecting energy consumption in a given region are basic inputs for the MEDEE[3] energy demand model (Lapillonne 1978). MEDEE considers energy-consuming activities in three economic sectors: transportation, household and services, and industry (which in turn is disaggregated into agriculture, mining, manufacturing, and construction subsectors). Gross regional product, broken down into its components (e.g., value added by industrial sector and investment shares) over time, serves as an essential scenario parameter for MEDEE runs. Other important inputs include the market penetration rates of advanced technologies, such as solar panels or district heat, which affect the mode of final energy consumption.

Simulation and accounting subroutines within MEDEE combine parameters describing future lifestyle changes with economic indicators to calculate the useful energy demand associated with each economic sector over the next 50 years. Useful energy includes categories such as space heat, water heat, high temperature heat for industrial processes, and specific electricity in the service sector. The model then evaluates various types of final energy demand on the basis of the penetration rates of district heat, electricity, or other modes of energy consumption. Substitutable uses of energy, including electricity, solar power, or fossil fuels for heating purposes, are important in this context. The composition of substitutable final energy demand is highly dependent on relative energy supply prices and is therefore subject to change as prices of alternative energy sources evolve differently.

The disaggregation of the final demand for fossil fuels among solid, liquid, and gaseous fuels is required as input to the energy supply model MESSAGE[4] (Agnew et al. 1979). This step is carried out exogenously to the IIASA set of energy models, as indicated by the box labeled "Secondary fuel mix and substitution" in Figure 2.

The MESSAGE Energy Supply and Conversion Model

MESSAGE is a dynamic linear programming model used to calculate cost-optimal energy supply strategies on the basis of MEDEE's energy demand results. In the model, selection among various primary energy sources is tightly constrained by energy resource availability, technological development, and the buildup rates of new energy production capacities (such as power stations, mines, and conversion plants). Resource constraints are represented by the availability of oil, gas, coal, and uranium in each region, further classified in ascending order of their extraction costs. In the case of the EC region, which is highly dependent on energy imports, resource constraints include availability of non-domestic energy sources, again split into different cost categories, or energy import restrictions.

Technological development is handled through specification of the points in time when new and advanced energy production and/or conversion technologies are introduced on a large scale. The buildup rates used in the model reflect the inherent lead times needed for structural change in the energy sector.

Briefly stated, MESSAGE provides the time trajectories of different primary fuels along the chain of conversion processes that lead to the various types of secondary energy demands derived from the final energy demands calculated by MEDEE. With the help of shadow prices, one can also use the model to calculate marginal costs for the supply of secondary energy, and in this way derive supply cost-prices for various energy sources. Thus, MESSAGE provides the cost-optimal mix of primary fuels to supply the energy demand of a given scenario, the required production and conversion capacities, energy import needs, and energy supply prices.

The IMPACT Model

MESSAGE outputs (fuel production and conversion capacity requirements) are fed into IMPACT[5], a dynamic input–output model with special emphasis on investment needs in the energy sector (Kononov and Por 1979). The model calculates direct and indirect capital requirements for a given energy strategy. (In this context, the term "indirect" means capacity and corresponding investment needs associated with energy-related industrial branches.) In addition, IMPACT accounts for materials, equipment and services, facilities, and manpower required by the energy sector and its related branches.

MACRO's Role in the Model Loop

MACRO's interactions and feedbacks with the other models in the IIASA model loop are shown in detail in Figure 3. MESSAGE provides time series of primary and secondary energy supply, energy imports, and energy supply costs. IMPACT supplies MACRO with the direct investment and manpower requirements of the energy sector.[6] For consistency, the scenario assumptions (indicated in the upper right-hand side of Figure 3) used in MEDEE runs must be identical with those used in MACRO runs. These assumptions concern demographic trends, productivity, changes in lifestyle, and number of working hours per week, to mention a few.

Given these inputs, MACRO then evaluates the impacts of energy import requirements and capital and manpower needs on economic activity. The model may be used to examine the following types of issues:

- What are the effects of steeply increasing energy import prices, and the accompanying transfer of income to oil-importing nations, on domestic investment behavior?
- What effects do energy price increases have on consumption rates, on the cost of capital (interest rates), on the labor market, and on the trade balance?
- What energy prices are needed to induce a given level of energy conservation?

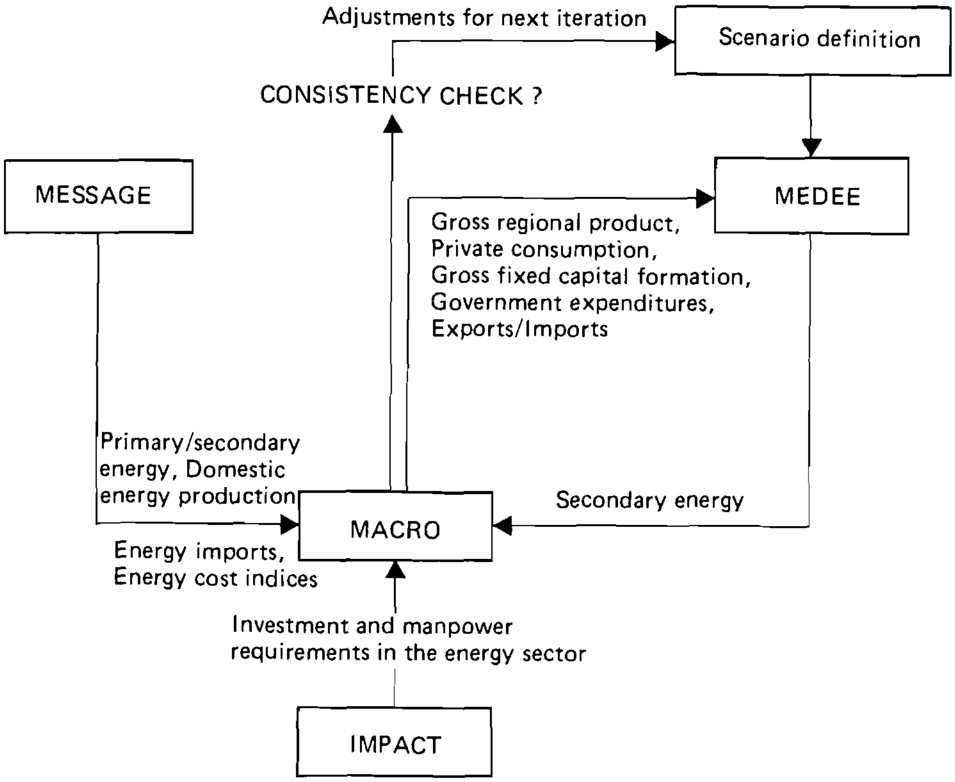

FIGURE 3 An overview of the flow of information between MACRO and other components of the IIASA set of energy models.

- Are the substitution effects of capital and labor efficient enough to permit the economy to operate with less energy and still sustain historically observed economic growth rates?
- Can sufficient capital be diverted to the energy sector in the future to create the necessary energy supply infrastructure?

Four scenarios, described in Section 8 of this report, illustrate the use of MACRO to examine such questions.

3 GENERAL MODEL STRUCTURE

MACRO as a General Equilibrium Model

MACRO is a numerically formulated macroeconomic model constructed to reflect the economy of the European Community. As a simple, highly aggregated, two-sector model, it belongs to a group of general equilibrium models often applied in long-term macroeconomic energy modeling.

As will be described in greater detail in the following section, MACRO is built around a constant elasticity of substitution (CES) function. Following the neoclassical approach, the model focuses on supply-constrained economic activity, with special emphasis on energy as the constrained input factor. In this framework the model represents substitution processes between energy and other factors of production.

The equilibrium feature of MACRO requires an adequate representation of factor demand and supply functions. Here the model adheres to the method used by Manne (1977) and Sweeney (1979), in so far as its factor demand functions are derived from the first-order optimality condition (which implies that production factors' marginal products are identical with their market prices, under the assumption that profit-maximizing behavior prevails in the production process). The model extends the work of Manne and Sweeney by implementing explicit factor supply functions, rather than just assuming that demand will create its own supply. In addition, the parameters of the CES production function are calculated on the basis of real time-series data, instead of being determined exogenously on the basis of judgment.

The components of final demand in MACRO are based on the definition of gross regional product. Following a quasi-Keynesian approach, they determine the aggregate levels of private consumption, government expenditures, and variations in exports and imports. The gross fixed capital formation component of final demand is derived from the equilibrium condition of a cleared capital market.

Use of MACRO for Long-Term Analyses

Traditionally, econometric models have been used for short-term econometric analyses covering approximately five years into the future. They are constructed on the basis of historical cross-sectional data by economic sector or time series of macroeconomic data covering a sample period of 30 years or more. Thus the sample period used to estimate and validate functional descriptions of various economic relationships is generally long compared to the prediction period.

In the case of MACRO, however, observations from a sample period of approximately 20 years have been used to construct a model with a 50-year planning horizon, and great care had to be taken in extrapolating, far into the future, econometric functions estimated over the relatively short sample period. One reason is that the user is not able to predict accurately the many exogenous or predetermined variables that must be specified to run the model; these include demographic trends, technological development, and relative prices. Another reason is that short-term trends, inherent in functions estimated on the basis of historical data, may not prevail in the future.

To overcome these difficulties, MACRO was constructed on the basis of certain important relations and variables whose values have been observed to remain fairly stable – within a certain range – in industrialized countries over several decades (Rogner 1977). Such slowly changing variables include the capital: output ratio, investment and consumption rates, population, and labor force participation. By concentrating on these "slow" variables, short-run fluctuations of "fast" variables (such as gross regional product, private consumption, or fixed capital formation) can be avoided. In addition, the number of exogenous variables is kept to a minimum in MACRO, in order to reduce possible inaccuracies introduced by their uncertain values.

In addition to "slow" variables, MACRO contains several exogenously determined scenario parameters labeled η. These can be used to countervail the short-term trends inherent in the estimated parameters. For example, a scenario parameter can be adjusted to change the export or import share of gross regional product to reflect rapidly increasing transfer payments to oil-producing countries. Scenario parameters also provide a means for simulating the evolution of the EC's economic structure (e.g., changes in the share of fixed capital formation within the gross domestic product).

"Slow" variables, together with ηs, make MACRO a useful tool for modeling both historical trends and imposed long-run normative changes, while guaranteeing consistency in a macroeconomic sense. The substitution of advanced, capital-intensive energy technologies for the present oil-based energy supply and demand infrastructure – which is conceivable and even likely – may well necessitate certain normative changes.

MACRO as a "Potential" Model

MACRO is a "potential" model in the sense that it represents maximum available output of the economy under optimal utilization of all input factors. Institutional policy is thus assumed to be effective in maintaining aggregate demand under sustained full employment. Small deviations from this principle might result from drastic changes in the availability of energy on the labor market, however, and the model has also been designed to reflect such disequilibrium situations.

One should bear in mind that MACRO was not developed to predict the future. Its main service is to examine a delimited set of plausible scenarios – represented by scenario parameters and exogenous variables – for the future.

4 THE BASIC MACRO MODEL

MACRO represents a simple two-sector economy, consisting of an energy sector and the rest of the economy (ROE). The energy sector itself consists of an energy import subsector and a domestic energy production subsector, whose activities are determined by the energy supply model MESSAGE. Energy supply is thus exogenous to MACRO, but certainly endogenous to the integrated set of models shown in Figures 2 and 3.

MESSAGE calculates the required energy import quantity E^{I} and its price p_I for input to MACRO. The domestic energy production sector is represented in MESSAGE by various cost functions for different types of energy production activities. The required energy import quantity E^{I} is equal to the difference between energy production and energy demand. Both subsectors charge against the output Y of the rest of the economy. In the case of the energy import subsector, income is transferred to the energy-producing countries; in the case of the domestic energy production subsector, resources from the ROE sector are used to produce its output E^{D}.[7]

It is important to note in this context that all energy is treated solely as an intermediate good. The portion of energy that usually satisfies final demand should be considered here as an intermediate means for achieving the final values of comfort, mobility, or sophistication. The output Y of the ROE sector may be either a final or an intermediate good.

The ROE sector requires as inputs a quantity of capital services K, a quantity of labor services L, and a quantity of secondary energy E. The output Y of the ROE sector is an aggregate quantity of goods and services that depend on the inputs K, L, and E. The relationship between K, L, and E can be represented by an aggregate production function of the economy $F(K,L,E)$.

If one assumes that production is based on profit maximization under perfect competition on all markets (capital, labor, and energy), then producers take the price of inputs as given and production levels are adjusted to the point where the marginal products of capital, labor, and energy are equal to their respective input prices. In a competitive economy this means, for instance, that the price of domestically produced energy is equal to the marginal costs of producing energy, which, in turn, is equal to the energy import price at an equilibrium stage. Labor and capital markets (supply and demand) require similar marginal conditions for market clearance. The factors capital and labor are rewarded by their marginal products, which equal the cost of capital p_K and the wage rate p_L, respectively.

4.1 Basic Relations within MACRO

MACRO is a very compact model, consisting of the ten basic relations presented below. A similar approach can be found in Manne (1977) and Sweeney (1979).

The gross regional product GRP is given by the sum of the output Y $[Y = F(K,L,E)]$ of the ROE sector [corrected for the charges against the economy of both the energy import sector E^{I} with its price p_I and the domestic energy production sector with its aggregate cost function $G(E^{\mathrm{D}})$] and the value added that is generated by the energy sector V^{E}:

$$GRP = F(K,L,E) - p_I E^{\mathrm{I}} - G(E^{\mathrm{D}}) + V^{\mathrm{E}} \tag{4.1}$$

$$E = (E^{\mathrm{I}} + E^{\mathrm{D}})cf \tag{4.1a}$$

$$Y = F(K,L,E) \tag{4.1b}$$

At this point in the discussion the contribution of the energy sector to GRP is set aside, and the profit-maximization behavior in the production process is applied only to the ROE sector. This appears reasonable, since one of the main purposes of applying MACRO is to analyze the impacts of various energy supply strategies on the evolution of the ROE sector, which in the past has produced more than 95% of total GRP. It is further assumed that the energy sector's contribution of value added to GRP is not necessarily based on the optimal allocation of capital and labor; such a case occurs when a reduction of dependence on energy imports becomes politically desirable.

It should be noted that the quantity E is secondary energy, while E^{I} and E^{D} represent primary energy. The parameter cf in eqn. (4.1a) is the conversion factor between primary and secondary energy. The essential assumption in eqn. (4.1) is the existence of the aggregate production function given in eqn. (4.1b).

For further analysis it is convenient to aggregate the two energy subsectors into one sector. The price of secondary energy $p_E(E)$ is then a weighted average of the price of imported and domestically produced primary energy, taking into account the costs of converting primary energy to secondary energy as provided by MESSAGE. Equation (4.1) then takes the form

$$GRP = F(K,L,E) - p_E(E)E + V^E \tag{4.1c}$$

It is assumed here that the price of energy p_E is a function of the amount of secondary energy required by the economy. This reflects the fact that available primary energy import volumes from energy-exporting countries depend implicitly on their profit function π_O:

$$\max \pi_O = p_I(E)E^I - c(E)E^I$$

where the term $c(E)$ implicitly represents their assumed energy extraction cost function.

The explicit profit-maximization assumption for a competitive economy (in this model the ROE sector) may be expressed as

$$\max \pi = F(K,L,E) - p_E(E)E - p_L L - p_K K \tag{4.2}$$

The aggregate production function $F(K,L,E)$ is subject to a number of specific restrictions (see Allen 1967). The production function is continuous and twice differentiable; the partial derivatives $\partial F/\partial x_i = F_i$ ($x_i = K,L,E$) are interpreted as the marginal products F_K, F_L, and F_E, respectively, and the marginal productivity of the inputs K,L, and E are $\partial F/\partial x_i = F_i > 0$, with F_i decreasing as the input of x_i increases. This implies that $\partial^2 F/\partial x_i^2 < 0$ or that there is a decreasing marginal rate of substitution. The marginal rate of substitution R is derived from the production function [eqn. (4.1b)] by taking the total differentials – assuming a constant product isoquant [$Y = F(K,L,E) = \text{constant}$]. Any variation along such an isoquant, such as would be caused by a change in the structure of relative prices of input factors, results in

$$\mathrm{d}Y = \mathrm{d}F(K,L,E) = F_K \mathrm{d}K + F_L \mathrm{d}L + F_E \mathrm{d}E = 0$$

For a constant output Y and assuming that K is substituted for L and that $\mathrm{d}E = 0$, the marginal rate of substitution R from any given $K: L$ ratio is

$$R(K,L) = -\mathrm{d}K/\mathrm{d}L = F_L/F_K \tag{4.3}$$

which is the absolute value of the slope of the isoquant at point (K,L) (see Figure 4).

Further restrictions concern the "constant returns to scale" feature and the requirement that the production function be linear and homogenous. If a production function is subject to these restrictions, then the necessary conditions for π in eqn. (4.2) to be a maximum are $\partial \pi/\partial x_i = F_i - p_i = 0$. It follows from the assumption that production is adjusted to the point where the input factors are rewarded their marginal products (which are equal to their corresponding real market prices) that $F_i = p_i$. Therefore, according to eqn. (4.2)

$$\partial \pi/\partial E = F_E - \partial p_E(E)E/\partial E - p_E(E) = 0 \tag{4.4}$$

$$F_E - p_E(E)[1 + \partial p_E(E)E/\partial E p_E(E)] = 0 \tag{4.4a}$$

The first-order optimality condition of the profit-maximization assumption pertaining to energy contains an energy price elasticity term ϵ_1; this is due to the assumed dependence

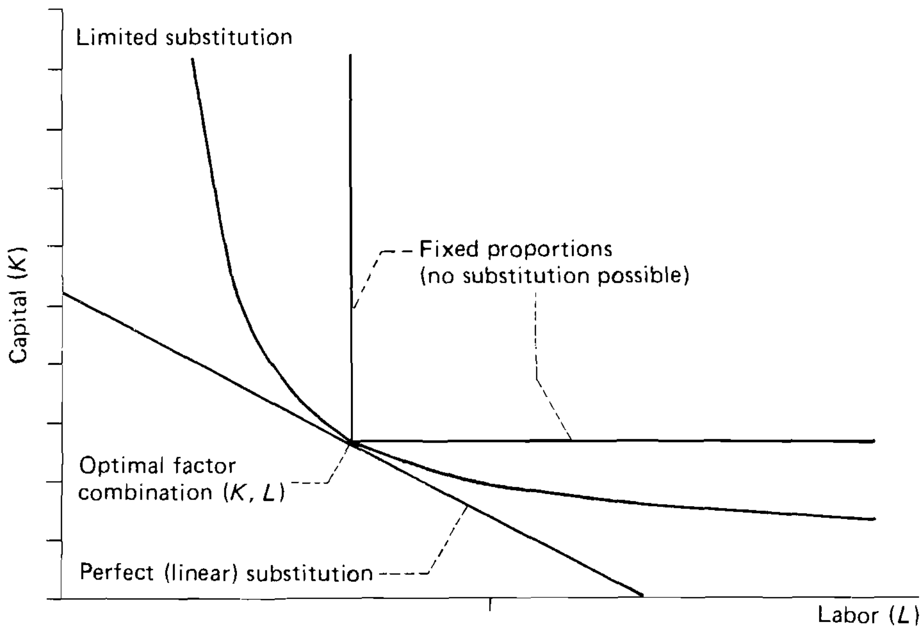

FIGURE 4 Idealized factor substitution curves. Each curve (isoquant) defines combinations of capital K and labor L that produce constant output.

of the domestic energy price on the absolute amount of energy demand, as well as on the export price pattern of energy-exporting countries.

$$F_E - p_E(E)(1 + \epsilon_1) = 0 \tag{4.4b}$$

$$\partial \pi / \partial L = F_L - p_L = 0 \tag{4.5}$$

$$\partial \pi / \partial K = F_K - p_K = 0 \tag{4.6}$$

Renormalization of eqns. (4.4)–(4.6) for K,L, and E results in input demand functions for capital, labor, and secondary energy, respectively.

In an equilibrium stage of an economy, the demand for input factors has to be met by supply. In the IIASA model loop, supply of secondary energy E^S is an output of the MEDEE/MESSAGE models. Labor supply L^S essentially depends on the demography *POP* of a region (overall population, age distribution, and labor force participation) and the real wage rate or price of labor:

$$L^S = g(POP, p_L) \tag{4.7}$$

The supply of capital stock K^S for the present period equals the capital stock of the previous period plus the gross fixed capital formation *INV*, corrected for consumption of fixed capital *DEP*:

$$K^S = K(-1)^S + INV - DEP \tag{4.8a}$$

Capital supply or gross fixed capital formation is a function of gross regional product *GRP*, the cost of capital p_K, and the real trade balance *TB*:

$$INV = f(GRP, p_K, TB) \tag{4.8b}$$

In industrialized economies like the EC, the investment or savings ratio $s = INV/GRP$ has remained remarkably stable for decades. The generally observed fluctuations of s due to business cycles can thus be neglected, using a long-term perspective. It is quite a common concept in economics to use *GRP* and the cost of capital (interest rate plus the rate of depreciation) in the functional determination of the share of *GRP* that adds to the existing capital stock (after correction for depreciation). In addition to *GRP* and p_K, the term *TB* (the real trade balance) has been introduced into eqn. (4.8b), since over the long term steeply increasing energy import prices will charge against *GRP* by increasing transfers of economic resources from the EC region to the energy-exporting countries (also see Klein et al. 1979).

For the past two decades, the nominal trade of the EC region has been almost balanced (or slightly positive); thus

$$p_X X - p_M M = 0 \tag{4.9}$$

where X represents exports, M represents imports and p_X and p_M are their corresponding prices. If one divides the nominal trade balance by the export price p_X and labels the difference *TB*, one obtains:

$$X - Mp_M/p_X = TB \tag{4.9b}$$

This relation measures exports X less the cost of imports Mp_M, calculated in terms of export prices.

The oil-pricing policy of energy-exporting countries during the post-1973 period had a slightly unfavorable effect on the magnitude of *TB* for the EC economy. As long as the ratio of import prices to export prices (p_M/p_X), i.e., the reciprocal of the terms of trade, is greater than unity, the value of *TB* is negative. A negative trade balance indicates a drain of resources to energy-exporting countries caused by unfavorable terms of trade (a direct consequence of rising energy import prices).

It is reasonable to assume that real losses of income will negatively affect the propensity to save within the EC economy; this in turn will have a feedback effect on overall economic activity, by slowing down the *GRP* growth rates. This may be considered a "quasi"-negative multiplier effect.

With the help of the above equations, the model can now clear capital, labor, and energy markets by adjusting p_K, p_L, and p_E to the equilibrium levels of K, L, and E. After such an iterative adjustment process, the total change in *GRP* can be calculated analytically by taking the total differentials of eqn. (4.1), using eqns. (4.4)–(4.6):

$$\Delta GRP = -E^{\mathrm{I}}\Delta p_I - E^{\mathrm{D}}\partial G(E^{\mathrm{D}}) + p_L\Delta L + p_K\Delta K \tag{4.10}$$

In eqn. (4.10) the changes in *GRP* are expressed as the sum of weighted changes in imported energy and its import price, in domestically produced energy, in the domestic energy cost function $\partial G(E^{\mathrm{D}})$ characterizing the domestic energy production sector, as well as in capital and labor deployment.

4.2 The Aggregate Production Function

The aggregate production function $Y = F(K,L,E)$, outlined above, must now be specified in more detail. This function uses the input factors, capital K, labor L, and energy E, to produce gross output Y. Gross output in such a configuration includes the output of energy as an intermediate input factor, in addition to the real value added that is contributed by capital and labor.[8] Any change in the relative price structure of capital, labor, or energy leads to the substitution of input factors in the production of output Y, as well as to changes in real value added or *GRP*. This double effect is a well-known problem in identifying real value added, since the output of any commodity or economic sector is determined by the inputs of a number of other commodities or sectors. Some of these inputs are the primary inputs of capital and labor, while others are intermediate goods like materials or energy, as in the case of MACRO.

Statistical bureaus usually begin constructing national accounts by calculating the money or nominal value added that constitutes the difference between the nominal values of gross output and intermediate inputs. Real value added is then derived by deflating the nominal flows and calculating the difference between the resulting real quantities. This "double deflating" method unavoidably incorporates a wide range of inconsistencies, due to variations in absolute and relative prices across time and space.

Arrow (1974) suggests an alternative approach to measuring real value added; he argues that the "most natural meaning" of this quantity arises from the wish of economists to estimate production functions. It is the need to attribute a special role to the primary input factors of capital and labor and to construct an aggregate term for these factors that calls for measuring real value added. But such an aggregation of capital and labor can only be justified as long as their use in production is separable from that of other inputs, i.e., energy. If one assumes separability of primary input factors and energy, the measurement of real value added can only be pursued if the production function $Y = F(K,L,E)$ takes on the special nested form

$$Y = \Phi\,[E, V(K,L)] \tag{4.11}$$

where real value added V of the ROE sector is a function of only capital and labor. Leontief (1947) noted that the condition for separability is given if the marginal rate of substitution between capital and labor in the production of output Y is independent of energy. In practice, this means that capital and labor produce the intermediate good V, which, combined with energy, then produces gross output Y.

This approach has one important inherent consequence: energy does not appear in the production function for real value added. Therefore, the real value added that is associated with the ROE sector only responds to changes in energy inputs if such changes affect the level of capital and labor inputs. It is essential to keep this consequence in mind, and to use factor supply and/or demand functions to capture the feedback between changes in energy costs and real value added.

4.3 The CES Production Function

A production function with the characteristics of eqn. (4.11) belongs to the class of production functions with constant elasticity of substitution (CES functions) proposed by Arrow et al. (1961). The authors based their theoretical work on the empirical observation that, within a given industry, value added per unit of labor varies by country, with the wage rate accounting for profit-maximizing responses of producers to given factor prices. Application of the linear relationship between the logarithms of output Q, or value added per unit of labor Q/L, and the wage rate w produced a good fit to the empirical data[9].

$$\ln(Q/L) = \ln a + \sigma \ln w \tag{4.12}$$

where a and σ are parameters that will be discussed below.

Given the existence of this relationship between wages and output per unit of labor, Arrow et al. asked what sort of production function could be used to rationalize it. The form of the production function given in eqn. (4.12a) is based on the assumption that the aggregate producer technology can be represented by a continuous, quasi-concave, and nondecreasing function of the type

$$Q = f(K,L) \tag{4.12a}$$

or

$$Q/L = h(K/L,\ 1) \tag{4.12b}$$

Assuming the identity of factor prices of capital and labor with their marginal products (or competitive factor markets), it is convenient to replace the wage rate w in eqn. (4.12) with the first-order optimality condition for labor in eqn. (4.12b). Arrow and his colleagues used this procedure to arrive at a differential expression of the following kind:

$$\ln\left(\frac{Q}{L}\right) = \ln a + \sigma \ln\left[\frac{Q}{L} - \frac{K}{L}\frac{\partial(Q/L)}{\partial(K/L)}\right] \tag{4.13}$$

Taking the antilogs and solving for $\partial(Q/L)[\partial(K/L)]^{-1}$, one may substitute the term β for $1/(\sigma - 1)$. Further rearrangements and transformations lead to the following CES production function, which is homogenous of degree one:

$$Q = \gamma\,[\delta K^{-\beta} + (1-\delta)L^{-\beta}]^{-1/\beta} \tag{4.14}$$

where

$$\beta = (1-\sigma)/\sigma \quad \text{or} \quad \sigma = 1/(1+\beta) \tag{4.15}$$

In eqn. (4.14) δ fixes the distribution between input factors, while β represents the substitution parameter. The elasticity of substitution σ, derived from β as shown in eqn. (4.15), is defined as follows [see also eqn. (4.12)]:

$$\sigma = \partial \ln(K/L)/\partial \ln R$$

R is defined as in eqn. (4.3):

$$R\,(K,L) = -\,\mathrm{d}K/\mathrm{d}L = F_L/F_K \tag{4.16}$$

In eqn. (4.14) γ changes output Q for any given set of inputs K and L in the same direction and proportionally. In this context, γ has been referred to as the neutral efficiency parameter. Although any technical progress causes a shift in the production function, the marginal rate of substitution for each prevailing K:L ratio remains unaffected as long as a change in efficiency is solely reflected by γ.

β is the substitution parameter. Its connection to the elasticity of substitution was discussed above. δ is the so-called distribution parameter. For any given value of σ, δ determines the functional distribution between the input factors. Taking the additional required characteristics of a production function into consideration (i.e., it should have positive marginal products for all inputs and should be subject to diminishing returns in varying proportions), one can easily derive the permissible ranges of the parameters in eqn. (4.14). It is obvious that output Q will be positive if $\gamma > 0$ and as long as $0 < \delta < 1$ (positive values of the input factors being a prerequisite). The substitution parameter β ranges from $-1 < \beta < \infty$ ($\beta = 0$ being excluded), allowing σ to range from $0 < \sigma < \infty$ ($\sigma \neq 1$). The value -1 for β implies an infinite elasticity of substitution; the value 0 leads to a Cobb–Douglas function (see Arrow et al. 1961).

In general, one assumes production isoquants to be downward sloping and convex to the origin, with an asymptotic approach to the L and K axis. Inclusion of this assumption in the application of a CES production function then dictates that σ is in the range from $0 < \sigma < 1$ or that $\beta > 0$.

4.4 The CES Production Function in MACRO

MACRO contains a CES production function encompassing secondary energy E, capital K, and labor L in the nested image shown earlier in eqn. (4.11):

$$Y = \Phi\,[E, V(K,L)]$$

Explicitly, the production function takes the following form:

$$Y = \gamma\,[\delta E^{-\beta} + (1-\delta)\,V(K,L)^{-\beta}]^{-1/\beta} \tag{4.17}$$

The ROE sector's value added V itself is determined by a Cobb–Douglas production function with the unit elasticity of substitution between its factor inputs, capital and labor. In eqn. (4.18) $1 - \alpha$ represents the share of payments to capital and α is the share of payments to labor[10]:

$$Y_{\$70} = \gamma[aE^{-\beta} + b(\theta K_{\$70}^{1-\alpha} L^{\alpha})^{-\beta}]^{-1/\beta} \tag{4.18}$$

In eqn. (4.18) the distribution parameter δ has been replaced by parameters a and b due to the difficulty of avoiding dimensional errors in the measurement of the variables involved. Allen suggests that the individual magnitudes of parameters a and b do not necessarily need to add to unity, since they are determined by the unit chosen for measuring gross output Y[11].

The parameter α was derived from the product exhaustion requirement, i.e., the identity between GRP and aggregate compensation of labor plus payments to capital.

$$GRP_{\$70} = p_L L + p_K K_{\$70} \tag{4.19}$$

or

$$\alpha = p_L L/GRP_{\$70} \tag{4.20}$$

Available data for the EC region suggest a value of 0.661 for α.

The term θ in eqn. (4.18) represents the neutral efficiency parameter of the Cobb–Douglas production function. This efficiency parameter must be clearly distinguished from γ; the latter reflects shifts, due to technical progress, in producing output Y, with secondary energy E and value added V as input factors.

The parameter β and the distribution ratio a/b in eqn. (4.18) were estimated using the neutrality condition of the efficiency term γ in eqn. (4.14). Taking the first derivatives of eqn. (4.17) with respect to energy E and value added V, and adopting the ratio F_E/F_V (equivalent to the price of energy over the price of value added), one arrives at the following expression:

$$F_E/F_V = p_E/p_V = (a/b)(V/E)^{\beta+1} \tag{4.21}$$

If one rearranges eqn. (4.21) and takes the logarithms, one obtains

$$\ln(p_E E/p_V V) = \ln(a/b) + \beta \ln(V/E) \tag{4.22}$$

This form is easily estimated using ordinary least-squares techniques (OLS) (Johnston 1972). The estimates of the parameters β and δ vary considerably for different sample periods, due to the greater weight of the post-1973 period relative to the total sample period. The best statistical fit, although by no means satisfactory, is obtained for the time spans of equal length before and after the disruption of the energy system in 1973/1974, i.e., for the period 1970–1978:

$$\ln(p_E E/p_V V) = -2.547200 - 1.824001 \ln(V/E) \qquad (4.23)$$
$$(-6.691) \quad (-20.764)$$

$R^2 = 0.8455$, $se = 0.0588$, $d = 1.972$

From the values in eqn. (4.16) it follows that $\sigma = 0.3541$, $a = 0.0723$, and $b = 0.8877$.

Allen (1967) has provided another approach to estimating the elasticity of substitution; here σ is estimated independently of the distribution parameter δ (a and b, respectively):

$$\ln\left(\frac{E_1/V_1}{E_2/V_2}\right) = \sigma \ln\left[\frac{(p_V/p_E)_1}{(p_V/p_E)_2}\right] \qquad (4.24)$$

Given values for E/V and p_V/p_E at two points in time on the production function, one can derive estimates for σ. Application of the 1967 and 1978 values yields $\sigma = 0.388286$, $a = 0.067$, and $b = 0.897$. Values of σ for other sample periods range from 0.31 to 0.40, i.e., for the period 1970–1978 $\sigma = 0.3571$, and for the period 1970–1976 $\sigma = 0.3215$.

The difference in the values for the elasticity of substitution between the period 1970–1976 and the period 1970–1978 is mainly explained by the slowdown in overall economic activity within the EC region. The average real growth rate dropped from 3.2% per year (1970–1976) to 2.6% per year (1976–1978). Underutilization of existing capital stock and the tendency to curtail or to stop production in business sectors with low profit margins caused secondary energy use per unit of value added, i.e., energy intensity, to drop below historically observed values. In 1970 energy intensity was 1.418×10^{-3} tce/\$, while in 1978 it was 1.235×10^{-3} tce/\$.

Economic theory suggests that elasticities are higher in the long run than in the short run, due both to the inability of the infrastructure to adjust immediately to changing prices and to the hope that such changes will only be temporary. It is questionable whether a value of σ at the 0.4 level can be achieved on a permanent basis, since the reduction of economic growth rather than higher energy prices has been its dominant determinant. The devaluation of the US dollar has kept the deflated energy price for Europe at its 1976 level. If the economy recovers from its present slowdown in activity, energy intensity will rise and the elasticity of substitution will drop again.

The values produced using Allen's estimation procedure, i.e., 0.388 for σ, 0.067 for a, and 0.897 for b, are adopted as reference values in MACRO. Other values for σ, such as 0.25 or 0.40, which span the range of σ as calculated by various other estimation procedures, are employed in the model for further analyses.

Continuing our discussion of the derivation of parameters, the productivity term γ is estimated from the following relation:

$$\ln(Y_{\$70}/Y^*_{\$70}) = \ln\gamma + rTIME \qquad (4.25)$$

The OLS estimation process then yields:

$$\ln(Y_{\$70}/Y^*_{\$70}) = -0.06774 + 0.01046\,TIME \qquad (4.26)$$
$$\qquad\qquad\qquad (5.26) \qquad (10.08)$$

$R^2 = 0.9096, se = 0.0108, d = 0.988$

where

$$Y^*_{\$70} = [aE^{-\beta} + b(\theta K^{1-\alpha}_{\$70} L^{\alpha})^{-\beta}]^{-1/\beta} \qquad (4.27)$$

Now it is possible to present the fully estimated production fucntion

$$Y_{\$70} = \gamma\,[aE^{-\beta} + b(\theta K^{1-\alpha}_{\$70} L^{\alpha})^{-\beta}]^{-1/\beta} \qquad (4.28)$$

with the following parameter values:

γ = 0.9345 exp (0.01046*TIME*)
a = 0.067083
b = 0.897028
β = 1.5754223
α = 0.660561
θ = 0.85710 exp (0.029519*TIME*)

The fit of the estimated CES production function to empirical data for the sample period is shown in Figure 5.

The lack of sufficient observations on the substitution of energy and value added, as well as the relatively small share of energy inputs to total output (in monetary terms), lead to questionable estimates of the elasticity of substitution. Hogan and Manne (1977) suggest that if the assumption of the approximate independence of output Y from energy E holds, then *the long-run price elasticity of energy demand and the long-run elasticity of substitution are virtually identical.*

Nordhaus (1975) and the Federal Energy Administration (1976) have studied long-run energy demand elasticities. Their findings indicate a range of 0.2–0.6 for the long-run demand elasticity, which corresponds to the elasticities estimated for the EC.

5 THE COMPREHENSIVE MACRO MODEL

5.1 Equilibrium Demand for Capital, Labor, and Energy

The explicit demand equations in MACRO for capital K, labor L, and energy E – the input factors of the aggregate production sector – have been adopted as outlined above in the general description of the basic model [see eqns. (4.4)–(4.6) in Section 4]. Renormalization of the first-order derivatives of K, L, and E of the aggregate CES production function [eqn. (4.28)] permits derivation of the factor demand equations for the ROE sector.

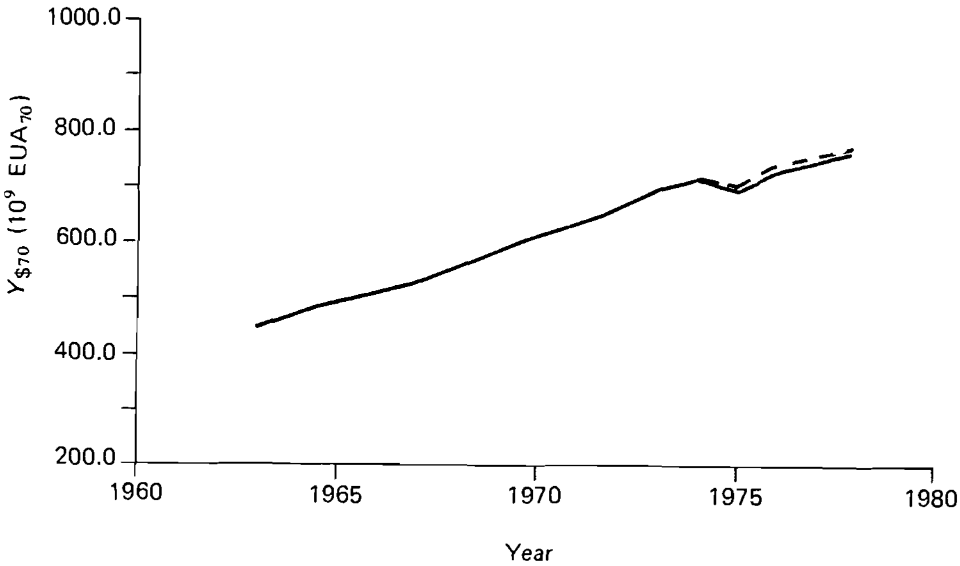

FIGURE 5 Goodness of fit of gross output $Y_{\$70}$: - - - - , estimated values; ——— , actual data for EC region, 1964–1978.

When one adds the requirements for capital K^{E}, labor MH^{E}, and secondary energy E^{E} of the energy sector, as calculated by IMPACT and MESSAGE/MEDEE, to the endogenously determined factor demand of the ROE sector, one obtains total demand for the factors of production.

Derived demand for secondary energy in ROE:

$$E^{\mathrm{D,R}} = [p_E(1+\epsilon_1)\gamma^{\beta}a^{-1}]^{-1/(\beta+1)}Y_{\$70} \tag{5.1}$$

Total demand for secondary energy:

$$E^{\mathrm{D}} = E^{\mathrm{D,R}} + E^{\mathrm{E}} \tag{5.1a}$$

Derived demand for capital in ROE:

$$K^{\mathrm{D,R}}_{\$70} = (1-\alpha)\gamma^{-\beta}bV^{-\beta}_{\$70}Y^{\beta+1}_{\$70}p_K^{-1} \tag{5.2}$$

Total demand for capital:

$$K^{\mathrm{D}}_{\$70} = K^{\mathrm{D,R}}_{\$70} + K^{\mathrm{E}}_{\$70} \tag{5.2a}$$

Derived demand for labor (expressed in total manhours[12]) in ROE:

$$MH^{\mathrm{R,D}} = \alpha\gamma^{-\beta} b V_{\$70}^{-\beta} Y_{\$70}^{\beta+1} p_L^{-1} \tag{5.3}$$

Total demand for manhours:

$$MH = MH^{\mathrm{R,D}} + MH^{\mathrm{E}} \tag{5.3a}$$

5.2 Equilibrium Supply of Capital, Labor, and Energy

Having obtained the total demand for capital, labor, and secondary energy, the next step is to define the equilibrium supply of these production factors for the entire economy. The energy-related demand (equaling supply) of these factors is determined by MESSAGE and IMPACT, and therefore has to be considered an exogenous input to MACRO. The difference between total factor supply and energy-related requirements may be taken as the supply of capital, labor, and energy of the ROE sector (also see Section 5.3).

The general form of the supply equations for capital, labor, and energy were discussed in detail in Section 4. The estimated supply equations used in the model, together with goodness of fit and autocorrelation statistics, will now be provided. The figures in parentheses under the equations show the corresponding t-statistic for the estimated parameter. The values for the correlation coefficients R^2, corrected for degrees of freedom, the Durbin–Watson statistic d, and the standard error of estimate *se* are also listed below each equation.

The relatively high correlation coefficients and low standard errors indicate that most of the equations provide a good fit to the data. In assessing the goodness of fit, it should be noted that many of the Durbin–Watson statistics are too low. This implies positive autocorrelation, and, hence, upward biases in the estimates of the correlation coefficients and t-statistics and downward biases in the estimates of the standard errors. However, a model's usefulness is determined by the simultaneous solution of all its equations: the accuracy of the simulation as a whole over the sample period provides an indication of a model's goodness of fit.

The supply of capital is calculated via the supply of gross fixed capital formation [see eqns. (4.8a) and (4.8b)]. Application of the capital stock identity [eqn. (4.8b)] yields the desired supply of capital stock.

Gross fixed capital formation:

$$\begin{aligned} INV_{\$70}^{\mathrm{S}} = \underset{(27.02)}{0.176\, GRP_{\$70}} + \underset{(7.56)}{0.706\, TB} + \underset{(11.64)}{13.795\, p_K} - \underset{(9.76)}{106.150} \end{aligned} \tag{5.4}$$

$$R^2 = 0.993,\ se = 1.118,\ d = 1.576$$

Equation (5.4) states that – other factors being constant – a unit change in gross regional product increases the supply of gross fixed capital formation $INV_{\$70}$ by 0.176 units. If the price of capital p_K[13] moves in either direction, $INV_{\$70}$ will change in the same direction by a factor 13.79 times the amount of the price of capital. In this sense eqn. (5.4) can be considered a savings function rather than a pure investment function.

The positive sign of the trade balance parameter ensures the intended reduction in the supply of capital in cases where unfavorable terms of trade lead to a transfer of domestic income to countries that export energy or other raw materials. Figure 6 shows the good fit of eqn. (5.4) to actual data.

The functional image of total supply of labor is given in eqn. (5.5). Here labor is measured in terms of numbers of workers. In order to compare supply of labor with demand for labor, one has to convert labor availability into manhour equivalents, as shown in eqn. (5.10).

Total labor supply:

$$L^S = -0.302(POP - POP > 65) + 7.745 p_L + 159.705 \qquad (5.5)$$
$$\quad (-1.26) \qquad\qquad\qquad (3.06) \qquad (3.31)$$

$$R^2 = 0.923, \ se = 0.347, \ d = 1.45$$

Labor supply is a declining function of active population (roughly the population under retirement age) and is positively correlated with the real wage rate. Demographic forecasts based on age distribution studies of the EC countries predict a diminishing labor force participation rate, i.e., a decline from 44.5% in 1975 to about 30–35% 50 years from now. The negative sign of the population parameter therefore seems plausible. The wage rate parameter, however, appears somewhat high.

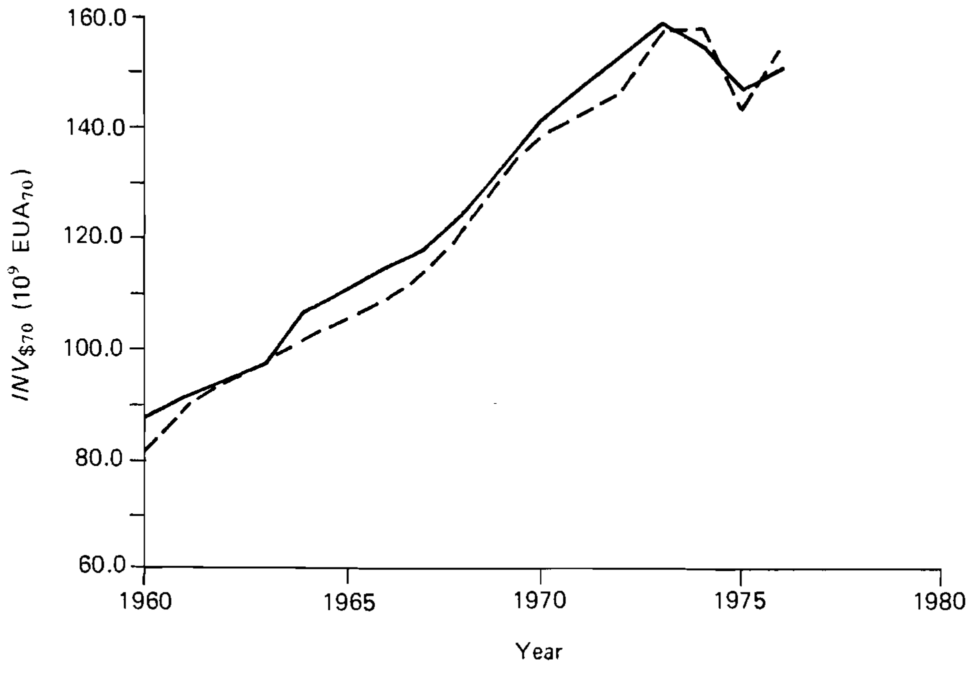

FIGURE 6 Goodness of fit of gross fixed capital formation $INV_{\$70}$: - - - - , estimated values; ——— , actual data for EC region, 1960–1978.

Although the statistical fit of these aggregate data is quite satisfactory (see Figure 7), it may turn out to be necessary in the long run to manipulate the parameters of the labor supply function. Because eqn. (5.5) has been estimated on the basis of a relatively short sample period (1960–1977), it is likely that the estimated parameters reflect short-term trends characteristic of the prosperous economic development that took place during the years before 1973. Above-average productivity gains during that period allowed real wages to grow steadily, at rates higher than overall economic growth. This short-term trend undoubtedly cannot persist in the long run.

To complete our discussion of the equilibrium supply of capital, labor, and energy, secondary energy supply E^S must be specified. As mentioned above, it is an output of the MEDEE/MESSAGE models.

5.3 Basic Identities in MACRO

Identities Between the Energy Sector and the Rest of the Economy

A complete economic model requires a number of identities to guarantee consistency between aggregate demand and supply. In MACRO the breakdown of the economy into two sectors – energy and rest of the economy – must be carried one step further, i.e., some basic identities also need to be disaggregated. An example of such an identity is that gross fixed capital formation $INV_{\$70}$ equals the investment requirements of the energy sector $INV^E_{\$70}$ and those of the ROE sector $INV^R_{\$70}$.

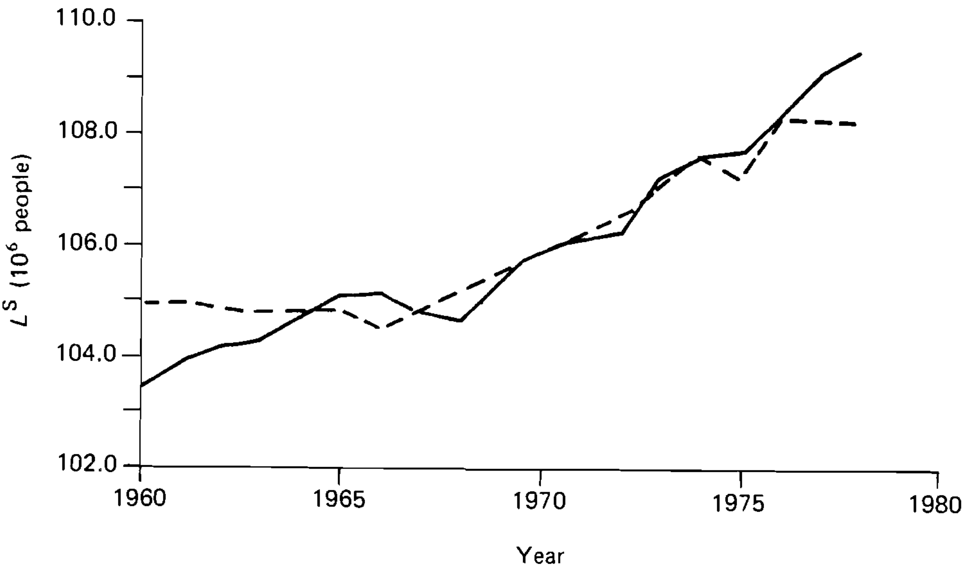

FIGURE 7 Goodness of fit of total labor supply L^S: - - - -, estimated values; ——, actual data for EC region, 1960–1978.

Investment in ROE:

$$INV^{R}_{\$70} = INV^{S}_{\$70} - INV^{E}_{\$70} \tag{5.6}$$

The investment requirements of the energy sector are determined by the IMPACT model. The capital stock identity for each sector is then given by

Capital stock in ROE:

$$K^{R}_{\$70} = K(-1)^{R}_{\$70} - \delta^{R} K(-1)^{R}_{\$70} + INV^{R}_{\$70} \tag{5.7}$$

Capital stock in energy sector:

$$K^{E}_{\$70} = K(-1)^{E}_{\$70} - \delta^{E} K(-1)^{E}_{\$70} + INV^{E}_{\$70} \tag{5.8}$$

The δs above represent the capital depreciation factor. MACRO uses the value 4.24% for δ^{R} and 3.0% for δ^{E}. Total capital stock is the sum of capital stock for the energy sector and capital stock for the ROE sector.

Total capital stock:

$$K_{\$70} = K^{R}_{\$70} + K^{E}_{\$70} \tag{5.9}$$

A similar breakdown was necessary for the labor market. Labor, as used in the production function, is measured in units of manhours. Labor force participation therefore has to be adjusted for hours worked per week *HOURS*, which is one of the important scenario variables (exogenous inputs) in MACRO. Equation (5.10) determines total labor supply for the EC economy. The manhour requirements of the energy sector MH^{E} for a given energy strategy are provided by IMPACT and are thus exogenous to MACRO.

Total availability of manhours:

$$MH = 52\, L^{S}\, HOURS \tag{5.10}$$

Manhours allocated to ROE:

$$MH^{R} = MH - MH^{E} \tag{5.11}$$

MH^{R} represents the maximum manhours available to the ROE sector. This quantity is considered to be the residual of total manhour supply, an approach used as well in the determination of investment (capital) supply. This way of determining capital and manhour supply for the ROE sector is useful, because capital- and/or labor-intensive energy production technologies cause a drain of resources and primary input factors from this sector. It is thus possible to investigate the effects of capital-intensive energy supply strategies on the overall economy. The assumption underlying this approach is that the use of capital and labor is more efficient in the ROE sector than in the energy sector.

Higher capital and/or labor inputs associated with constant physical outputs (measured, for instance, in terms of kWh) certainly decrease the efficient use of these inputs.

Gross Regional Product and Income Identities

The basic equation in the macroeconomic model is the definition of real gross regional product $GRP_{\$70}$. $GRP_{\$70}$ is the constant value [expressed in European Units of Accounts (EUA) at 1970 prices and exchange rates] of all goods and services produced by labor in the EC member countries, and of property supplied by their residents. Three additional definitions of GRP are used in the model. First, it equals total purchases of goods and services (aggregate demand), which has the following components: personal consumption ($C_{\$70}$), gross fixed capital formation $INV_{\$70}$, government purchases of goods and services $G_{\$70}$, and net exports of goods and services $X_{\$70} - M_{\$70}$. The purpose of the demand side of MACRO is to produce a consistent set of estimates for these variables under different assumptions. The estimates should be consistent both with assumed behavioral relationships for consumers and producers and with the *GRP* and the disposable income identities.

Second, *GRP* equals the sum of payments to factors of production. Finally, the third *GRP* identity stems from the aggregate production or supply function of MACRO. Total output Y must be corrected for payments to the energy sector that are not part of value added. Since output $Y_{\$70}$ represents the output of the ROE sector only, the value added produced by the energy sector $V^{\mathrm{E}}_{\$70}$ has to be added to $Y_{\$70}$.

Definitions of real GRP:

$$
\begin{aligned}
GRP_{\$70} &= C_{\$70} + INV_{\$70} + G_{\$70} + X_{\$70} - M_{\$70} \\
GRP_{\$70} &= p_L MH + p_K K_{\$70} \qquad (5.12) \\
GRP_{\$70} &= Y_{\$70} - p_E(E)E + V^{\mathrm{E}}_{\$70}
\end{aligned}
$$

Real national income $NI_{\$70}$ is the total income paid to the factors of production (labor and property). One must deduct all the nonfactor charges from $GRP_{\$70}$, i.e., indirect business taxes and surplus of government enterprises minus subsidies *TAXES* (converted into constant values by means of the general deflator p) and capital consumption allowances $DEP_{\$70}$. To finally secure a balance, it is also necessary to account for a statistical discrepancy. In eqn. (5.13) the term *RES* (residual) represents the statistical discrepancy and the error associated with conversion to constant monetary units, as well as the surplus of government enterprises minus subsidies.

Definition of real national income:

$$NI_{\$70} = GRP_{\$70} - DEP_{\$70} - TAXES/p - RES \qquad (5.13)$$

Disposable income $YD_{\$70}$ equals national income $NI_{\$70}$, corrected for income taxes *TAXDIR* and government transfer payments to persons *GT*. Income taxes and government transfer payments are measured in current values, and therefore it is necessary to apply the deflator p to convert to constant 1970 values. To simplify the model, corporate retained earnings are included in personal disposable income.

Definition of real disposable income:

$$YD_{\$70} = NI_{\$70} - TAXDIR/p + GT/p \tag{5.14}$$

Personal consumption expenditures or private consumption $C_{\$70}$ equals national income $NI_{\$70}$ minus investments $INV_{\$70}$ plus aggregate depreciation $DEP_{\$70}$.

Definition of private consumption:

$$C_{\$70} = YD_{\$70} - INV_{\$70} + \delta^{R}K(-1)^{R}_{\$70} + \delta^{E}K(-1)^{E}_{\$70}$$

and (5.15)

$$\delta^{R}K(-1)^{R}_{\$70} + \delta^{E}K(-1)^{E}_{\$70} = DEP_{\$70}$$

An explicit consumption function [where private consumption is a distributed lagged function of disposable income and previous levels of consumption of the type $C_{\$70} = f(YD_{\$70}, \Sigma^{4}_{t=1} C(-1)_{\$70})$] has been omitted from MACRO for two reasons. First, lags are not appropriate for this equilibrium model. Second, the long-term application of MACRO makes it necessary to reduce econometrically estimated relations to a minimum, in order to keep the model transparent and simple, and in order to exclude short-term trends as much as possible. Furthermore, in the long run the consumption identity provides for equality of investments and savings; this is not the case when a distributed lagged function is used. As an alternative, MACRO provides a simple consumption function connecting private consumption to disposable income, where the marginal propensity to consume is 0.816.

$$C_{\$70} = \underset{(51.637)}{0.81602}\, YD_{\$70} + \underset{(1.145)}{8.1631} \tag{5.15a}$$

$$R^2 = 0.997, \; se = 0.3853, \; d = 2.145$$

Taxes and the Government Sector

As shown in eqn. (5.16), a renormalization of eqn. (5.12), the government sector $G_{\$70}$ is the residual of the components of aggregate demand. In conjunction with eqns. (5.18), (5.19), and (5.20), one can use this equation to examine the implications of different tax policies on aggregate demand and the budget.

Government purchases:

$$G_{\$70} = GRP_{\$70} - C_{\$70} - INV_{\$70} - X_{\$70} + M_{\$70} \tag{5.16}$$

The government's budget identity $SUR_{\$70}$ (surplus or deficit) contains tax revenues $(TAXDIR/p + TAXES/p)$ on the income side, and government expenditures on goods and services $G_{\$70}$ plus government transfer payments to persons GT/p on the expenditure side. There is no restriction requiring a balanced budget in MACRO. The government's budget identity is a useful instrument for monitoring the effects of different energy strategies on the magnitude of budget deficits or surpluses.

Government budget:

$$SUR_{\$70} = TAXDIR/p + TAXES/p - G_{\$70} - GT/p \tag{5.17}$$

Indirect business taxes and nontax liability *TAXES* include taxes for sales, property, inspection fees, fines, royalties, and donations. The term does not include taxes on corporate income. The estimated indirect business tax function has an average tax rate of 10.6% on real GRP. η_1 is the first of four explicit scenario parameters labeled η, which are included in MACRO to allow for normative changes of parameters estimated on historically observed time series.[14] For example, in eqn. (5.18) any value of η_1 other than 1 will influence the government budget as well as the overall level of private consumption given in the real disposable income identity [eqn. (5.15)]. Taxation policies favoring a desired energy strategy can therefore be analyzed in detail.

Indirect business tax function:

$$\underset{}{TAXES} = \underset{(25.2)}{\eta_1 0.106pGRP_{\$70}} + \underset{(5.9)}{16.85} \tag{5.18}$$

$R^2 = 0.975$, $se = 5.16$, $d = 0.29$

The income tax function used in MACRO has a surprising result. It is impossible to estimate corporate and personal income tax functions without taking tax rate changes over time into account. The total income tax *TAXDIR* function, however, applies to the entire 1960–1978 period. During these years, the average income tax rate was 33% of national income; changes in tax structures seem to have affected only the relative share of each tax category, leaving the total fairly constant. The scenario parameter η_2 in eqn. (5.19) may be interpreted similarly to η_1 in eqn. (5.18).

Income tax function:

$$TAXDIR = \underset{(66.9)}{\eta_2 0.33pNI_{\$70}} - \underset{(5.5)}{14.19} \tag{5.19}$$

$R^2 = 0.996$, $se = 4.76$, $d = 1.39$

The main determinants of government transfer payments are the number of retired persons and the compensation given to unemployed persons. The level of government transfer payments to persons is linked to per capita consumption in current terms. This allows the welfare system to participate in the improvement of economic production and prevents recipients of transfer payments from suffering income losses through inflation.

Government transfer payments to persons:

$$GT = 2.637(POP > 65 + UNEMP) + 82.101p(C_{\$70}/POP) - 87.337 \quad (5.20)$$
$$(2.52) \qquad (13.92) \qquad (-3.47)$$

$R^2 = 0.998,\ se = 3.17,\ d = 1.33$

Demography

The occupied population is obtained by dividing the demand for manhours by the number of annual hours worked. The difference between labor supply (labor force participation) and the occupied population yields the unemployment level.

Occupied population:

$$POPOCC = 1000MH^{\mathrm{R,D}}/(52HOURS) \quad (5.21)$$

Unemployed population:

$$UNEMP = L^{\mathrm{S}} - POPOCC \quad (5.22)$$

The Trade Sector

The importance of the trade balance equation for capital formation was discussed in Section 4. The levels of exports and nonenergy imports in MACRO are linear functions of gross regional product in current prices and are meant to reflect historically observed trade patterns. It is obvious that such simple relationships, lacking a connection with the level of world production and relative world prices, are not capable of identifying in full past determinants of exports and imports. The scenario parameters η_3 and η_4 make these relations useful in their present form, by allowing modelers to manipulate the trade sector according to their long-term perceptions of future world trade. Furthermore, such a configuration of relations encourages linkage with other more detailed trade models (i.e., models for the seven IIASA regions). In such cases exports and imports are totally exogenous to MACRO.

Trade balance:

$$TB = X_{\$70} - (p_x/p_m)^{-1}M_{\$70} \quad (5.23)$$

Exports:

$$p_x X_{\$70} = \eta_3 0.287p0.01GRP_{\$70} - 36.871 \quad (5.24)$$
$$(28.0) \qquad (5.9)$$

$R^2 = 0.981,\ se = 10.28,\ d = 1.30$

Nonenergy imports:

$$p_{NEI} M^{\mathrm{N}}_{\$70} = \eta_4 0.240p0.01GRP_{\$70} - 26.184 \quad (5.25)$$
$$(28.1) \qquad (5.0)$$

$R^2 = 0.981,\ se = 8.56,\ d = 1.48$

Requirements for energy imports in physical terms [tons of coal equivalent (tce)] are an output of the MESSAGE model. The factor 14.29, based on a price of US$2.75 per barrel of oil in 1970, is used to convert tce into constant 1970 monetary units.

Energy imports:

$$M^{E}_{\$70} = 0.0143/E^{I} \tag{5.26}$$

Total imports:

$$M_{\$70} = M^{E}_{\$70} + M^{N}_{\$70} \tag{5.27}$$

The import price index is determined by the energy import price index p_I^{index} (output from the MESSAGE model) and the nonenergy price index, weighted according to their quantities. Optionally the nonenergy import price index p_{NEI} may be exogenously determined (i.e., determined outside the model loop) or linked to MACRO's overall price index.

Import price index:

$$p_M = 100(M^{E}_{\$70} p_I^{\text{index}} + M^{N}_{\$70} p_{NEI})/(M^{E}_{\$70} + M^{N}_{\$70}) \tag{5.28}$$

The Energy Sector

MACRO obtains information on the investment and manpower requirements of the energy sector from IMPACT. Primary, secondary, and imported energy is provided by MESSAGE. MACRO combines the IMPACT output to calculate the energy sector's capital stock [see eqn. (5.8)] and real value added. Furthermore, MACRO transforms the energy import quantities into monetary terms and then uses them as variables in the determination of total imports and the trade balance [see eqn. (5.27) or eqn. (5.23)].

The energy sector's real value added can be determined in two ways: first, by applying the equilibrium prices and remuneration of labor and capital by means of the production exhaustion requirement; second, by using a Cobb–Douglas production function, which assumes diminishing returns to scale. This strong assumption is based on the expectation that the capital : output ratio of the energy sector will rise. Bauer et al. (1980) state that capital requirements will increase in all energy subsectors, not only in electricity generation. Production of synthetic fuels through coal liquefaction or gasification as a substitute for oil is especially capital intensive. Further, the characteristics of oil at the turn of the century will be quite different from the low cost, clean, and easily manageable fuel we have used during past decades. In the twenty-first century, oil will have to be extracted from dirty sources such as oil shale and tar sands, using complex and capital-intensive processes. Strict environmental protection standards will increase the capital requirements of the energy sector.

Production exhaustion requirement for the energy sector:

$$V^{E}_{\$70} = p_L MH^{E} + p_K K^{E}_{\$70}$$

Production function (Cobb–Douglas) for the energy sector:

$$V^{\mathrm{E}}_{\$70} = 1.83(K^{\mathrm{E}}_{\$70})^{0.485}(MH^{\mathrm{E}})^{0.267} \quad (5.29)$$

The parameters in this production function are derived from the share of payments to the primary input factors capital and labor. The equation is calibrated for the reference year 1970.

Prices in MACRO

Real prices for capital, labor, and energy are derived from the assumption that the production factors are rewarded their marginal products [see eqns. (4.2) to (4.6)]. Renormalization of eqns. (5.1)–(5.3) for p_K, p_L, and p_E yield real equilibrium prices for capital, labor, and energy, respectively.

An interesting indication of the influence of higher energy prices on the overall price level p is given by eqn. (5.30). The exogenously supplied implicit price deflator for the real value added of the ROE sector p_V is combined with both the energy price (calculated within MACRO) and the amount of energy supply (provided by MESSAGE):

$$p = (V_{\$70}\, p_V + Ep_E(E)p_E^{\mathrm{index}})/(V_{\$70} + Ep_E(E)) \quad (5.30)$$

6 MODEL VALIDATION AND TESTING

6.1 Validation against Historical Data

One test of a model's validity is to compare model results with actual data for a sample period. The degree to which the simulation output matches historical observations provides an indication of the model's "goodness of fit". In an equilibrium model of the MACRO type, of course, complete accuracy cannot be achieved. The assumption of an economy in equilibrium – in reality, an exceptional circumstance – forces the model to achieve an artificial equilibrium level in its solution for each time period.

Furthermore, because MACRO is a quasi-*potential* model, it postulates full utilization of all factors of production (including full employment) at the equilibrium level. This is likely to lead the simulation to slightly underestimate actual data for boom periods, when aggregate demand usually exceeds aggregate supply. The simulation may be expected to adhere best to actual developments during periods of continuous and smooth growth, when gains in productivity are distributed between factors of production so as to keep the spending of income in a constant relation to overall output, without noticeable inflation or unemployment. During periods of stagnation or recession, model output is likely to overestimate actual data.

Existing economic and demographic statistics, especially those compiled by the Statistical Office of the European Communities,[15] were used to compare model output with empirical data over the 1965–1976 period. In these validation runs, the values of all exogenous variables[16] were set equal to historical values. Figures 8–10 show model results compared with actual data for components of aggregate demand, secondary energy demand,

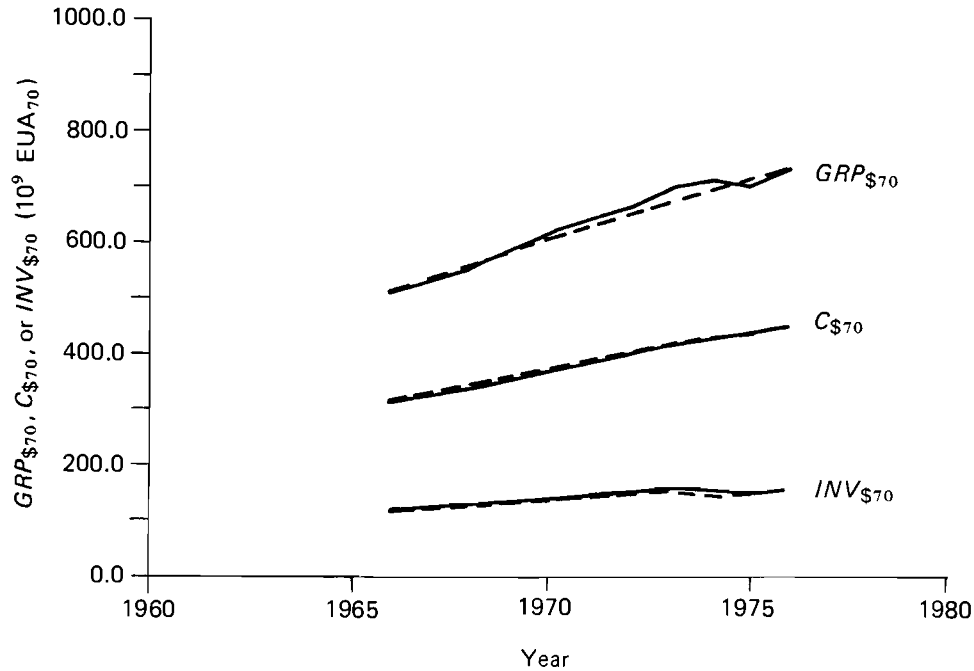

FIGURE 8 Validation of MACRO results for gross regional product $GRP_{\$70}$, personal consumption expenditures $C_{\$70}$, and gross fixed capital formation $INV_{\$70}$: - - - -, model results; ——, actual data for the EC region, 1966–1976.

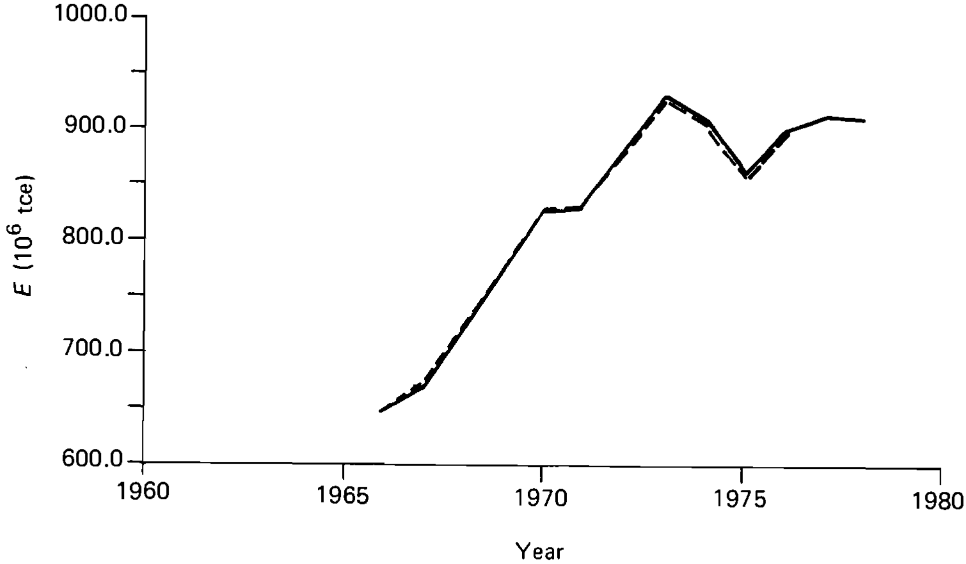

FIGURE 9 Validation of MACRO results for secondary energy demand E: - - - -, model results; ——, actual data for the EC region, 1966–1976.

FIGURE 10 Validation of MACRO results for total labor supply L^S: - - - -, model results; ——, actual data for the EC region, 1966–1976.

and labor supply. In general, MACRO results for the 10-year period provide a satisfactory fit to actual data, despite the fact that the model is designed for longer-term analysis.

As may be discerned from Figure 8, the model solution for gross regional product $GRP_{\$70}$ conforms quite well to actual values between 1966 and 1976. However, the model underestimates actual developments during the period 1972–1974, when the EC economy was definitely not in equilibrium. The model results overestimate the historical trend during 1975 and 1976, when a recession produced a slowdown in economic activity: the solution values only weakly indicate the noticeable drop in economic activity that occurred in 1975.

Similar patterns can be found in the cases of gross fixed capital formation $INV_{\$70}$ and private consumption $C_{\$70}$, also shown in Figure 8. For secondary energy demand E, the solution values closely replicate the considerable energy demand reduction that occurred in EC member countries after 1974 (see Figure 9). For labor supply L^S, model results were also in line with actual values during the sample period, as illustrated in Figure 10.

6.2 Simulation of a 1965 Energy Crisis: A Test Case

In another type of test run, the model's predetermined (i.e., exogenous) variables were given values that simulated an energy shock to the EC region. The results of the run showed possible economic responses to the imposed disturbance. In concrete terms, the test case examined the impacts on the EC economy that could have occurred if energy-exporting countries had curtailed oil production and instituted new oil-pricing policies in *1965* instead of 1973/1974.

The purpose of this test case was twofold. First, as a type of *ex post* validation, it checked whether the model's response to the artificial imposition of a crisis situation replicated the aftermath of the real 1973/1974 energy shock. Second, it permitted examination of economic and social adjustment to the shock over the time span of a decade, rather than just for the years that have passed since 1974.

An analytical framework for the analysis of the economic adjustment process is presented below. Then the values of the exogenous variables used in the test case are specified, to show how the crisis situation was simulated in the model runs. Finally, MACRO results for the test case are presented, showing in quantitative terms the adjustment of the EC economy to the energy shock.

Economic Adjustment to an Energy Crisis: An Analytical Framework

Fried and Schultze (1975) have distinguished three phases within the adjustment process. In the initial phase, rapidly increasing oil import prices raise the general price level, and, simultaneously, cause a transfer of income from consumers to producers of energy. An immediate consequence is a fall in aggregate demand and a lower level of national employment in the oil-importing countries. In turn, the oil-exporting countries accumulate a large fraction of their sudden profits from the oil sales as an unspent financial surplus, lacking a domestic infrastructure in which to spend the income.

In the second, or "transition phase", the oil-producing countries start to recycle their oil revenues by gradually increasing purchases from oil-importing countries. At the same time, oil-importing industrialized countries revitalize their domestic energy production facilities in response to the higher market price of energy (i.e., submarginal energy resources and production technologies become economically competitive). Substitution of other types of energy for imported oil, as well as price-induced conservation among energy consumers, gradually decrease industrialized countries' demand for oil and other energy products.

In the third phase, energy consumers complete their adjustment to higher energy prices by consuming less energy at higher costs. The increasing volume of exports to energy-producing countries, combined with higher domestic energy production costs, continue to keep economic growth lower than the level that would prevail in the absence of the energy pricing and production policies of the oil-producing countries. The sectoral generation of value added shifts from domestic consumer goods to export goods and services, as higher energy prices reduce domestic budgets for consumer goods, and as economic resources (exported goods and services) are drained to energy-producing countries.

During this final phase, full employment can be regained, accompanied by increased mobility between economic sectors. The final consequences of the adjustment process are slightly reduced growth in the standard of living and a reduction in overall welfare development – represented by a reduction in real wages.

Specification of Exogenous Variables in the Test Case

Exogenous variables in MACRO were specified as follows to simulate an energy crisis situation. The 1975 level of energy imports to the EC region was restricted so as not to exceed the 1966 level. Domestic energy production was set equal to historically observed levels. As shown in Figure 11, this assumption led to a reversed U-shaped development curve for energy imports during the period 1966–1976. Energy import prices were assumed to leap by 20% annually, causing the domestic market price of energy to increase by roughly 12% per year – equivalent to a 4.5% annual increase in real terms for the 10-year period.

The growth rate of productivity was assumed to decline, in comparison with historically observed developments, since the drain of economic resources associated with the higher energy import bill would reduce the incentive of private business to invest in new plants and equipment. This was assumed to lead to a one-third reduction in the growth rate of labor productivity over the period 1966–1976.

Impact of the "1965 Energy Crisis" on the EC Region

MACRO runs based on the above assumptions have produced quantitative measures of the impacts of an assumed 1965 energy crisis in the EC region. These include estimates of the trade balance, the growth of the gross regional product, the real wage rate, the development of the per capita consumption rate, and the level of employment that result from the imposed disturbance. Analysis of the values of these variables over the period 1966–1976 provides a picture of the dimensions and speed of the adjustment process.

The macrodynamic impact of the 1965 energy crisis is closely connected to the unfavorable change in the terms of trade caused by the higher energy import prices. Figure 12 contrasts the EC region's actual oil bill (in deflated terms) for the 1966–1976

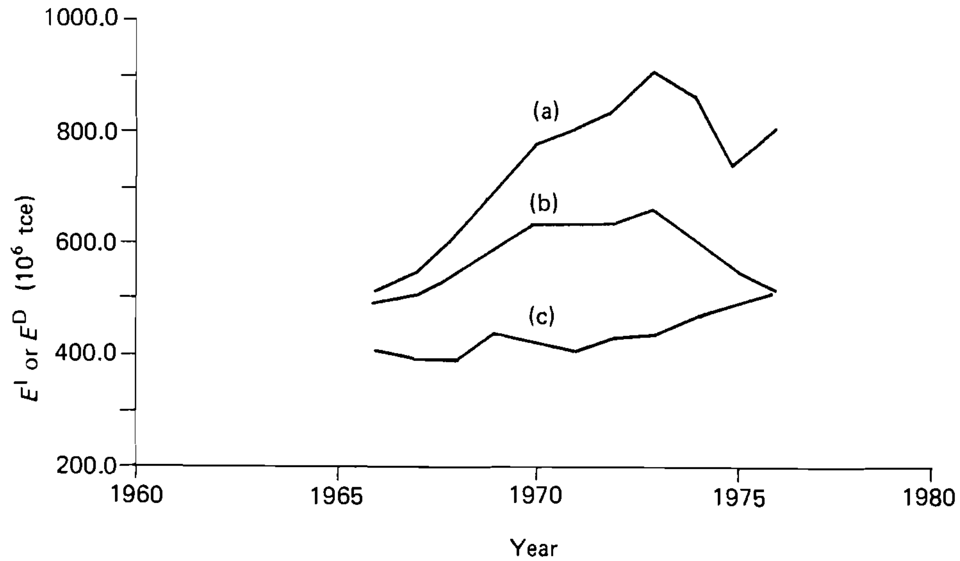

FIGURE 11 Comparison of energy imports E^I assumed in the "1965 Energy Crisis" Scenario (curve b) with actual data for the EC region (curve a), 1966–1976. Curve c shows the region's actual domestic energy production E^D.

period with the bill in the "1965 Energy Crisis" Scenario. The cumulative difference between the results of the test case and actual data for the 10-year period amounts to 102.1×10^9 European Units of Accounts (EUA), corresponding to a 156.5×10^6 tce difference in the total quantity of imported oil. Figure 13 shows the development of the trade balance [cf. eqn. (4.9b)] resulting from the imposed oil-pricing policy.

The real loss in income associated with the higher energy prices negatively affects the savings rate, leading to reduced economic growth rates and a fall in the profit rate. This, in turn, has a negative multiplier effect on capital formation. The capital stock of an economy increases slowly over time whenever net capital formation is positive and decreases when net capital formation is negative. Thus, although the effects are not felt immediately, higher energy prices keep the rate of capital formation below historically observed levels and ultimately slow the growth of capital stock. As energy prices increase, the relatively high inelasticity of capital stock temporarily depresses the interest rate by approximately 5% for a period of several years before it regains its original level.

In quantitative terms, the GRP growth rate drops from 3.68% per year to 2.57% per year over the time frame of the test case, as indicated by Figure 14. The transfer of real income from consumers to producers of energy and cost-propelled inflation are reflected in the disproportionate decline in the per capita consumption rate, which drops from 3.6% to 1.9% per year (in real terms).

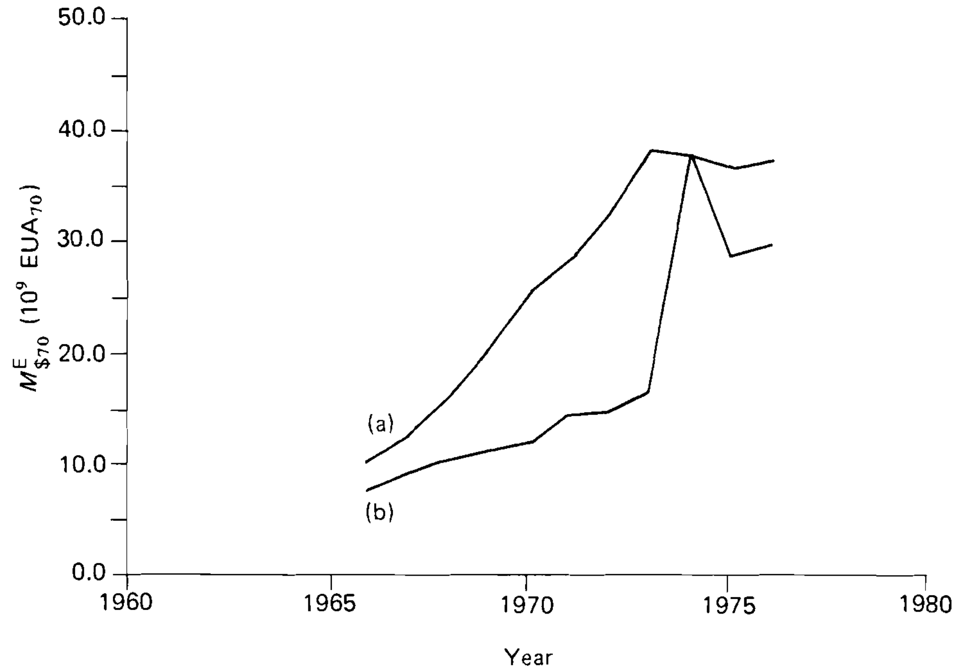

FIGURE 12 Comparison of the oil import bill $M^{E}_{\$70}$ calculated in the "1965 Energy Crisis" Scenario (curve a) with actual data for the EC region (curve b), 1966–1976.

FIGURE 13 Comparison of the trade balance *TB* calculated in the "1965 Energy Crisis" Scenario (curve b) with actual data for the EC region (curve a), 1966–1976.

The level of regional unemployment rises from about 2.0×10^6 people in 1965 to 6.7×10^6 people in 1968, corresponding to an unemployment rate of 6.4%. By 1976, the processes of substitution and adjustment of capital and labor for energy reduce the unemployment rate to less than 2.5%. Supply of labor is kept fixed at its actual value in the model run; otherwise the model's equilibrium feature would have adjusted the supply of labor to meet demand via the wage rate, and actual unemployment would have been disguised.

As shown in Figure 15, the high level of employment at the end of the test period is accompanied by a significant diminution in real wage rates. In real terms, the annual wage increase is cut from 3.9% to 2.8%. Although this allows demand for labor to return to precrisis levels, the EC economy cannot recover fully by the end of the test time frame and return to business as usual.

In general, the response of the EC economy to the simulated 1965 energy crisis follows the adjustment process described by Fried and Schultze.[17] Reduced energy import availability, combined with rapidly increasing energy import prices, reduces demand for capital or the incentive to invest within the EC region. In turn, the downward adjustment in the equilibrium quantity of capital slows the growth of gross regional product and causes unemployment to increase. Then, as climbing energy prices lead to increasing

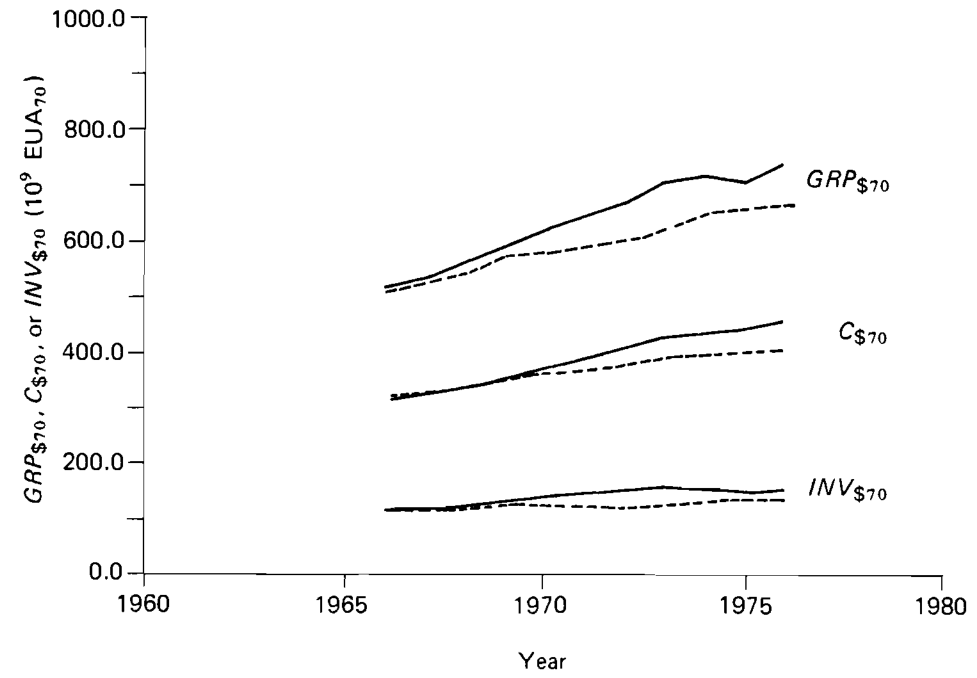

FIGURE 14 Comparison of the gross regional product $GRP_{\$70}$, personal consumption expenditures $C_{\$70}$, and gross fixed capital formation $INV_{\$70}$ calculated in the "1965 Energy Crisis" Scenario (- - - -) with actual data for the EC region (———), 1966–1976.

substitution of labor for energy-intensive production technologies and products, energy demand slows and demand for labor grows. By 1975/1976 full employment is reestablished, but at the cost of a significantly reduced real wage rate.

A comparison of the results of the MACRO run with actual events following the 1973/1974 energy shock shows that the model replicated the decline in gross regional product, the negative balance of payments, and the drop in investments, but did not account for the increased unemployment rates and the high market interest rates.

7 ASSUMPTIONS FOR THE LONG-TERM APPLICATION OF MACRO

MACRO was developed to study the energy–economy linkage in a regional context, specifically in the context of the European Community. This requires specification of the future framework of the region's economy, in terms of variables and parameters not handled endogenously in MACRO. For example, one crucial subset of variables concerns demographic developments over the next 50 years. Other information needed to run MACRO up to the year 2030 involves determination of such factors as relative prices for nonenergy products and overall evolution of productivity.

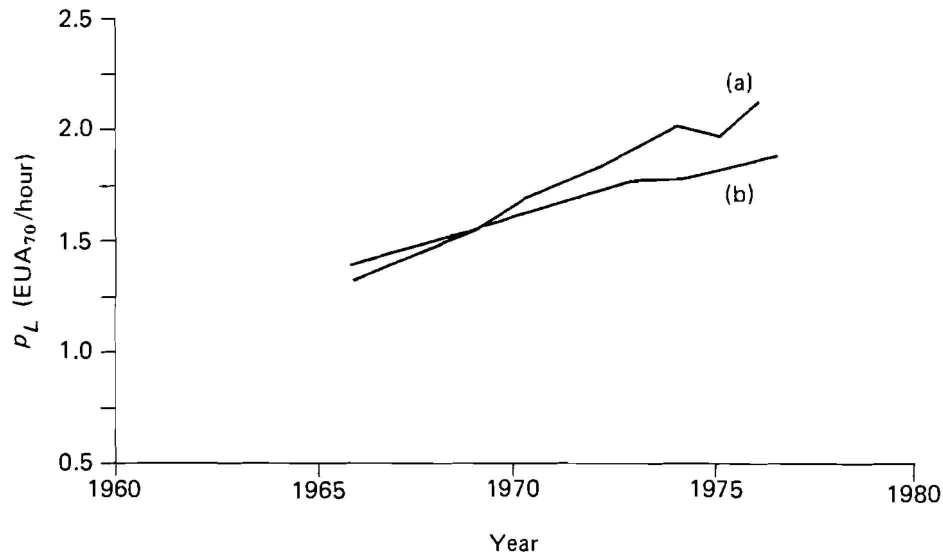

FIGURE 15 Comparison of the real wage rate p_L calculated in the "1965 Energy Crisis" Scenario (curve b) with actual data for the EC region (curve a), 1966–1976.

7.1 Demography

The European Community is an industrialized region characterized by low and gradually declining population growth. During the period 1950–1975, its population grew steadily at 0.72% per year, compared to a prewar annual growth rate of more than 1.4%. A large fraction of the present population growth rate may be traced to persons from member states of the British Commonwealth who have emigrated to the United Kingdom, to inhabitants of former French colonies who have emigrated to France, and to "guest workers" from the Balkans and Turkey who are employed in the Federal Republic of Germany – rather than to native Europeans inhabiting EC countries. Over the next 50 years industrialization of the immigrants' low-income home countries will lessen their incentive to move to the high-income EC region. It is thus to be expected that the EC region will attain, asymptotically, a quasi-zero population growth rate by the year 2030. The population projection underlying the MACRO runs is the same as that used in a study published by the Commission of the European Communities, which in turn was partly based on the IIASA set of energy models (CEC 1980).

The fraction of the population over 65 years of age has increased substantially over the last decades, due to improved health care and welfare systems, as well as to declining fertility rates. In 1960, 10.7% of the total population was over 65; by 1975 this share had risen to 13.3%. Figure 16 shows the development of total population and the population aged over 65, as assumed in the MACRO runs. The population growth rate for the 2000–2030 period is about 0.22% per year, while the share of the population of retirement age amounts to 16.7%.

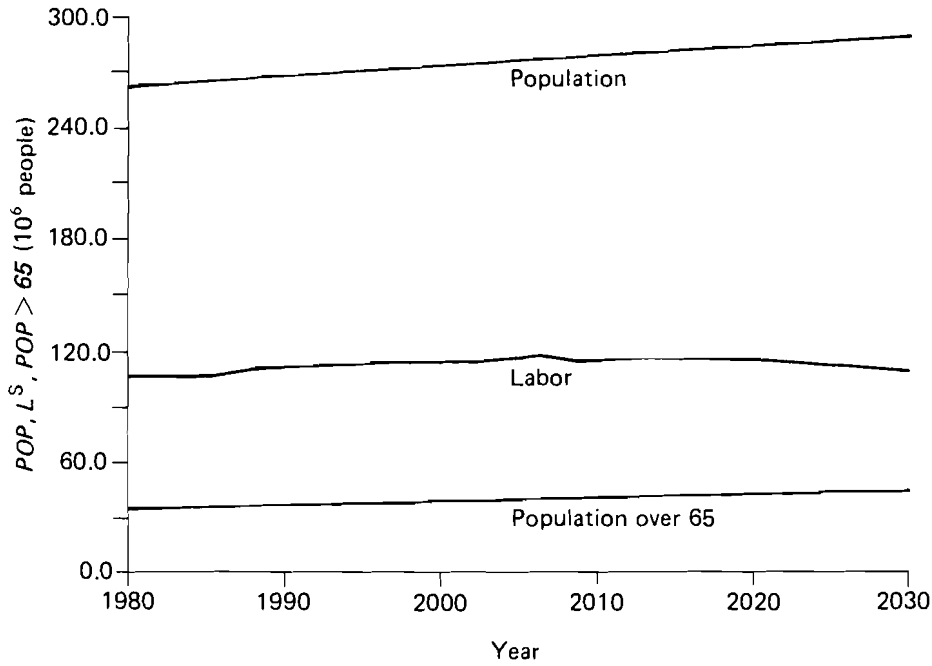

FIGURE 16 Projections of total population *POP*, labor force L^S, and the population over 65 *POP > 65* used in MACRO runs for the EC region, 1980–2030.

Like the population growth rate, labor force participation has shown a retrogressive tendency during the past 20 years. In 1960 44.5% of the total population was in the labor force; by 1970, this fraction had dropped to 42.1%, and by 1975 it amounted to only 41.6%. This trend is assumed to continue in the scenarios developed by IIASA researchers for the European Community, resulting in a final labor force participation rate of 35% in 2030, as indicated in Figure 16.[18]

The exogenous specification of labor is not, however, a strictly binding restriction in MACRO. Because the equilibrium and price adjustment feature of the model determines labor supply and demand endogenously, the exogenously determined supply of labor serves only as a rough guideline. The long-term application of the econometrically estimated labor supply function given in eqn. (5.5) is limited by the inherently short-term trends prevailing in the 17-year sample period. Over a planning horizon of 50 years, these short-term trends may push labor supply unreasonably far above or below the exogenously given trend. In this case the parameters in eqn. (5.5) have to be manually adjusted to keep the endogenously calculated labor supply within reasonable bounds – at about the levels shown in Figure 16.

Another exogenously determined scenario variable[19] is the evolution of average working hours per week. Technical progress has not only allowed real wages to grow steadily over the last decade, but has also permitted the shortening of the number of working hours per week. Trade unions constantly negotiate for the reduction of the number of working hours to achieve a more humane working environment. In the light of the increasing substitution of electronic devices for labor-intensive activities and the major shift of labor requirements from production to control tasks, a decline from 44.4 working hours per week in 1970 to 32.3 hours per week by 2030 was assumed in MACRO runs.

7.2 Relative Prices

It is practically infeasible to determine relative prices exogenously for a 50-year period in the future. Nevertheless, inputs needed for MACRO include the specification of price indices for the value added that is produced by the ROE sector, for exports, and for nonenergy imports. The best one can do to supply these inputs is to assume the continuation of historically observed time trends of various price deflators and to perform a straightforward extrapolation of these trends. The price deflator for the ROE sector has doubled every 15–20 years since World War II, corresponding to an annual growth rate of 3.5–4.7%. Increasing energy prices are to be expected for at least another 20 years, so a 5% growth rate until the turn of the century for the value-added deflator appears reasonable. After the year 2000 a reduced rate of 3.5% has been applied, corresponding to the lower boundary of the historically observed trend. As a preliminary approach, exports and nonenergy import prices have been linked to the development of the *GRP* deflator. Inclusion of a more detailed model, to serve as a vehicle for improving the price representation of foreign sectors within the IIASA set of energy models, is under discussion.

7.3 Productivity

The estimated growth of the first productivity term θ, introduced in eqn. (4.27) to calculate value added in the ROE sector, came to 2.95% per year during the 1960–1978 sample period. This growth rate was assumed to prevail until 1990 and then to decrease slightly. By the turn of the century, the growth rate of productivity is assumed to be 2.5% per year, and by the end of the planning horizon (2030), this rate has decreased to 2.0% per year. Of course, the values assumed for this productivity parameter are quite arbitrary and reflect a somewhat conservative view of future economic and technical development. The evolution of the productivity term represents one of the most important scenario variables, serving as a means for manipulating the model to reflect an individual's personal view of the future. (This also holds for all other exogenous variables.)

The growth rate of the second productivity term γ was assumed to remain at 1.146% per year until the turn of the century, and then to gradually approach zero growth by 2030. This decline in productivity is meant to reflect, in part, the increasing environmental constraints negatively affecting the capital : output ratio in many sectors of the economy. Capital and the efficiency of capital continue to be dominant factors in determining overall productivity.

The downward trend in productivity also reflects the change in the age distribution of the population. The increasing proportion of people over 65 will lead to a more service-oriented economic structure – representing a break from the past industrialized society in the direction of a postindustrialized economy. In the OECD's "Interfutures" study (OECD

1980), the term "change in values" is used to represent the change in the population's attitude toward the past composition of the social product (*GRP*). According to this study, such changes in values are likely to occur in response both to changes in the environment and to changes in conceptions of the significance of man's existence. The decline in the average number of working hours per week can definitely be interpreted as a significant shift away from a purely production-oriented society.

8 FOUR SCENARIOS FOR THE EUROPEAN COMMUNITY

The four scenarios presented below depict a range of energy futures for the European Community. Scenario 1 is characterized by unlimited availability of energy at reasonable costs. It represents a return to historically observed economic growth patterns – as if the 1973/1974 energy crisis had only been a short-term market disruption. Scenario 2 is a more realistic reference scenario, assuming tight constraints on energy availability and steadily increasing energy prices. Scenario 3 focuses on energy demand, examining the feasibility of strong assumptions about price-induced energy conservation. Finally, Scenario 4 considers the EC's future energy supply infrastructure, which is likely to be marked by high capital requirements.

These scenarios are used in this section as the setting for examination of specific energy-related macroeconomic questions. For instance, the MACRO applications described below focus on such issues as the impact of restricted energy imports on economic growth; the implications of reduced energy availability for the development of gross domestic product, wages, the trade balance, and other economic variables; the compatibility of high economic growth rates with low growth in energy requirements and high energy prices; and the impact of capital deepening in the energy sector on the rest of the economy. These are issues with which the European Community is currently grappling and thus illustrate MACRO's capacity to provide input for discussions of economic policy.

8.1 Scenario 1: A Reference Case

Assumptions

Scenario 1 may be called a *business as usual* case. It is assumed that the EC economy will not face energy import shortages in the future, i.e., that the present 55–60% energy import share within total energy supply will be sustained. Thus, energy is supplied in sufficient quantities and at prices comparable to those prevailing in the 1974–1976 postcrisis period. It is furthermore assumed that the foreign trade sector will continue to operate as historically observed. The world export market absorbs excess domestic production and required imports are available without limit – implying perfect market conditions. The current energy supply and demand structure thus remains unchanged, as do capital requirements per unit of production capacity.

Essentially, conditions characterizing the period 1960–1973 are extrapolated to the years after 1980. The period 1974–1979 is considered a transition phase, during which economic disruptions caused by the steep increase in energy prices in 1973/1974 are resolved. By the end of the decade, when the economy has fully readjusted to the higher energy price levels, a new level of economic equilibrium is achieved. The energy-producing countries' 1973/1974 oil policy is thus taken to be a one-time interference in the world energy market.

The scenario specification also includes skewing of the age distribution to the older age groups and slowing of improvements in productivity.

Results

What, then, are the macroeconomic implications of the energy future defined by these assumptions? MACRO's output, in the form of indicators of economic development over a 50-year planning horizon, are summarized in Tables 1 and 2. As may be expected from the scenario specification, this scenario is characterized by a gradually declining economic growth rate. During the period 1985–2000, the growth rate of the gross regional product equals 3.9% per year; by the period 2015–2030, it has dropped to 2.6% per year.

In line with the economic mechanism built into MACRO, the effects of the 1973/1974 oil curtailments and the subsequent steadily increasing energy import prices encourage implementation of energy-conserving technologies through the substitution of capital and labor for energy. The impact of this substitution process on energy intensiveness (defined as the ratio of secondary energy to gross regional product), however, only becomes apparent 10–20 years later. If energy intensiveness in 1970 is set equal to 100, then this index drops to 77.3 by the year 2000 and to 74.8 by 2030 (see Table 1). These improvements in energy intensiveness cause secondary energy demand in ROE to grow at a lower rate than in the past.

TABLE 1 Results of the MACRO run for Scenario 1: values of selected variables over time.

Variable	Year				
	1970	1985	2000	2015	2030
Gross regional product (10^9 EUA at 1970 prices and exchange rates)	618.2	1061.4	1875.3	2958.6	4358.2
Secondary energy (10^6 tce)	830.8	1218.8	1948.0	2942.5	4281.3
Investment rate (%)	22.8	21.9	20.9	19.5	18.8
Energy intensity (1970 = 100)	100.0	85.4	77.3	74.0	74.8
Price of energy [EUA/tce (deflated)]	30.4	60.2	64.8	74.8	71.3
Capital: output ratio	3.59	3.53	3.31	3.19	3.13

TABLE 2 Growth rates of selected variables, by time period, in Scenario 1 (% per year).

Variable	Time period			
	1960–1973	1985–2000	2000–2015	2015–2030
Gross regional product (at 1970 prices and exchange rates)	4.5	3.9	3.1	2.5
Secondary energy	4.6	3.2	2.8	2.5
Consumption per capita	3.7	3.6	3.0	2.4
Secondary energy per capita	3.8	3.0	2.6	2.3

The energy–GRP elasticities corresponding to these levels of energy intensiveness are 0.82 for the period 1985–2000 and 0.97 for the period 2000–2030. The slowdown in the rate of improvement of energy intensiveness after the turn of the century results from unconstrained energy supply, for this hinders the innovation process from progressing beyond the necessary levels imposed by the first-order optimality condition of the production function.

Although Scenario 1 is admittedly highly artificial, it provides a reference point for assessing the degree to which the other scenarios deviate from a simple continuation of business-as-usual into the future. The difference between the results for Scenario 1 and those of the other scenarios show the economic impact of less optimistic assumptions for the energy future, including restricted energy import quantities and high energy prices.

8.2 Scenario 2: A Constrained Energy Supply Case

Assumptions

In Scenario 2 some assumptions used in Scenario 1 have been modified to produce a reference case based on a more realistic view of the future. This view is characterized by reasonably optimistic assumptions about the implementation of energy conservation measures and improvements in energy efficiency.

The most important difference between Scenarios 1 and 2 concerns energy availability. In Scenario 2, energy import quantities are assumed to be restricted and energy import prices are correspondingly high. It is postulated that by the year 2030 no more than 45% of primary energy requirements can be met by imports. At the same time, the energy import price index is assumed to increase at the high rate of 7.5% per year until the turn of the century, when it begins a gradual decline to 5% per year by 2030. Domestic energy production is constrained to a maximum annual growth rate of 2.5%. Assumed levels of energy imports and domestic energy production over the scenario time frame are shown graphically in Figure 17.

Capital requirements per unit of production capacity in the energy sector are assumed to rise from the present value of 0.27 EUA/watt to 0.62 EUA/watt by the year 2030. Demographic and productivity assumptions are held constant in Scenarios 1 and 2.

Results

The results of Scenario 2 are summarized in Tables 3 and 4. Reduced quantities of energy imports, together with the constrained expansion of domestic energy production, have significant negative consequences for the EC economy, causing GRP growth rates to fall well below those attained in Scenario 1. By 2030, secondary energy supply is reduced to 59% of that available in Scenario 1, while the value of GRP at an equilibrium stage represents only 81% of the value calculated for Scenario 1.

The braking effects of reduced energy supply on economic activity are partly offset by substitution of capital and labor for energy. The capital : output ratio is a good indicator of such substitution: technical progress and sufficient energy supply allow this ratio to decrease from 3.59 in 1970 to 3.13 in 2030 in Scenario 1; in Scenario 2 it reaches a value of only 3.28 by 2030.

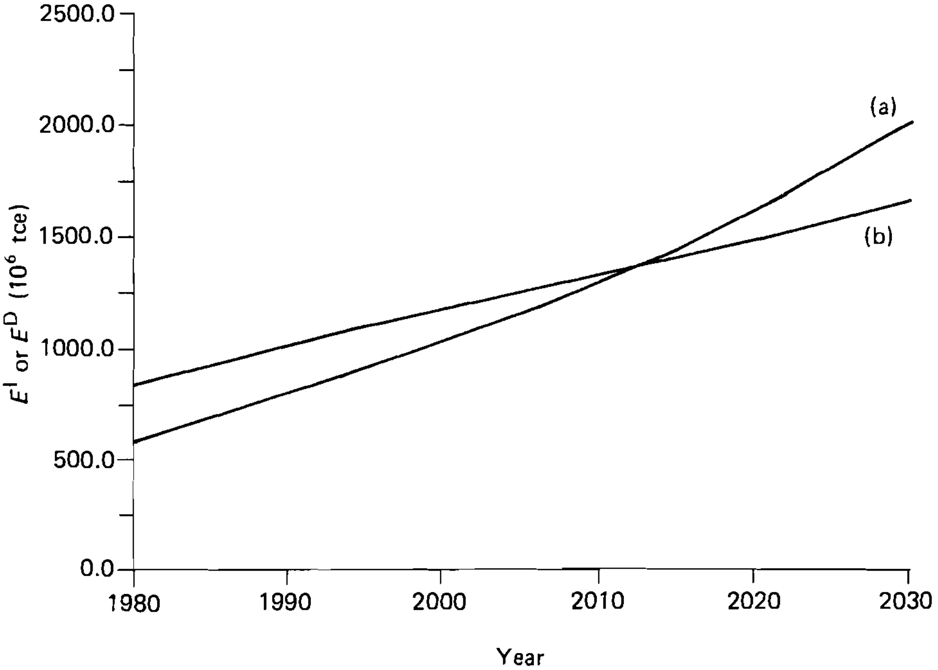

FIGURE 17 The development of energy imports E^I (curve a) and domestic energy production E^D (curve b) assumed in Scenario 2, 1980–2030.

TABLE 3 Results of the MACRO run for Scenario 2: values of selected variables over time.

Variable	Year				
	1970	1985	2000	2015	2030
Gross regional product (10^9 EUA at 1970 prices and exchange rates)	618.2	1035.0	1734.8	2558.0	3521.2
Secondary energy (10^6 tce)	830.8	1118.8	1510.2	1948.8	2514.9
Investment rate (%)	22.8	21.6	20.5	19.0	17.7
Energy intensity (1970 = 100)	100.0	80.4	64.8	56.7	53.2
Price of energy [EUA/tce (deflated)]	30.4	59.6	63.0	165.2	200.4
Capital: output ratio	3.59	3.58	3.38	3.33	3.28

TABLE 4 Growth rates of selected variables, by time period, in Scenario 2 (% per year).

Variable	Time period			
	1960–1973	1985–2000	2000–2015	2015–2030
Gross regional product (at 1970 prices and exchange rates)	4.5	3.5	2.6	2.2
Secondary energy	4.6	2.0	1.7	1.7
Consumption per capita	3.7	3.3	2.6	2.0
Secondary energy per capita	3.8	1.8	1.5	1.5

Reduction of the secondary energy demand to match a given level of energy supply is performed in MACRO by adjusting the price of energy to its equilibrium level. Comparison of Table 1 with Table 3 shows that the deflated price of energy in 2030 is a factor of 2.68 higher in Scenario 2 than in Scenario 1. The energy price in 2030 corresponds to an annual growth rate of 3.2% above overall inflation.

Although scenario assumptions hardly affect labor requirements in Scenario 2, they do result in a reduction in real wages. As may be seen in Figure 18, the real wage rate drops from 14.5 EUA/hour in 2030 in Scenario 1 to 12.1 EUA/hour in Scenario 2 to permit maintenance of full employment. Full employment is not a surprising result, for MACRO's equilibrium feature does not allow underutilization of labor unless otherwise specified.[20]

The effects of steadily increasing energy prices on the trade balance become noticeable only after the year 2010 in Scenario 2. Before the turn of the century, higher energy import prices are directly offset by the physical reduction in energy import quantities. After the year 2010, the slowdown in overall economic activity increases the share of the energy import bill relative to the bill for nonenergy imports. Together with declining export volumes (in relative terms), this results in a negative trade balance. The unfavorable trade balance in turn lessens the incentive of private business to invest in new plants and equipment and has a negative multiplier effect on economic output. As shown in Table 3,

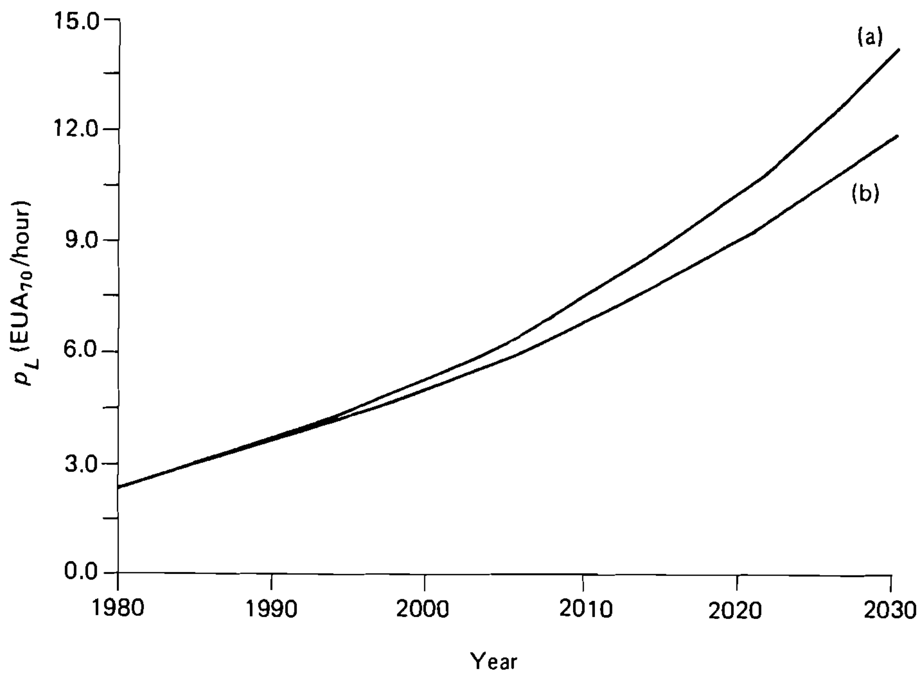

FIGURE 18 Comparison of the real wage rate p_L calculated in Scenario 1 (curve a) with that calculated in Scenario 2 (curve b), 1980–2030.

this sequence of impacts results in a low investment rate of 17.7% in 2030. (Export quantities are not adjusted to produce an equilibrated trade balance in this scenario.)

The results of Scenario 2 clearly indicate the negative effects of reduced energy inputs on economic growth, as well as the strong influence of higher energy prices on the economy. But one should bear in mind that, due to the structure of MACRO, substitution processes between factors of production are solely regulated by their market prices. Other factors that encourage substitution, such as institutional measures or innovations introduced independently of energy prices, are not considered in the model.

8.3 Scenario 3: Energy Demand versus Energy Prices – A Consistency Check

Within the IIASA model loop, the level of future energy demand is derived from MEDEE, and the costs and prices to satisfy this demand are calculated in MESSAGE and IMPACT. MACRO may be used to provide a check on the consistency of various assumptions used in these models at different points in the modeling exercise. Scenario 3 addresses this vital question, focusing on the consistency between energy demand lowered through strong conservation assumptions and associated energy prices.

The Nature of Energy Conservation

However high the uncertainties, estimates of future energy needs must be made to evaluate the implications of alternative future energy supply systems and to study the probable dynamics of the energy–economy linkage, including economic adjustment to scarcer and more costly energy. The range of future energy requirements calculated in various long-term studies is quite large [see Workshop on Alternative Energy Strategies (1977), World Energy Conference (1978), and CEC (1980)]; since assumptions about demographic and economic development are often nearly identical in the studies, differences in estimated future energy demand stem from diverse views of the potential of energy conservation.

Energy conservation does not have to be associated with energy curtailments or energy shortages. Rather, it implies careful and intelligent use of energy, leading to improvements in energy efficiency. In general, it is useful to distinguish between *price-induced* and *lifestyle-induced* conservation.

In the case of price-induced conservation, lowered availability of energy and accompanying price increases may lead to the substitution of capital, labor, and expertise for energy, thus decoupling the historically close relationship between GNP and energy use. The process of adjustment to lowered availability of energy in a competitive economy is mainly governed by the price of energy. Increases in price can depress the equilibrium economic output – since any price-induced deviation from the optimal input profile constitutes a shift away from the previously achieved optimum – unless other factor prices decrease concommitantly. If wage rates are lowered, firms are encouraged to replace energy-intensive production technologies with labor-intensive methods. The multiplicative effect of augmented labor input can even increase GNP [see eqn. (4.10)].

Lifestyle-induced conservation spans a wide range of human activities and involves fundamental changes in values (see Section 7.3). For instance, private households may decide to allocate their budgets to less energy-intensive activities and thus cut down on energy used for private travel. The trend of movement into large urban areas could also conceivably be reversed as part of a growing general aversion to large-scale technologies. In addition, energy use may be affected by saturation effects concerning the material goods that underlie the standard of living of the industrialized world. These changes in values imply a structural change from a production-oriented to a more service-oriented economy. Shifts in a region's age distribution may also contribute to this structural change.

The Characteristics of Scenario 3

Scenario 3 was developed to study the consistency between MEDEE-generated estimates of energy demand and underlying assumptions about energy prices. Case 2 of the CEC's study "Crucial Choices for the Energy Transition" (CEC 1980) provided a good starting point for the consistency check, for MEDEE had been used to calculate energy demand for the case, under strong assumptions of energy conservation.[21] Underlying assumptions concerning lifestyle-induced conservation and improvements in energy efficiency were considered correct; the focus in the consistency check was rather on the validity of the price-induced conservation assumptions used in the demand calculations for Case 2.

Briefly stated, the consistency check involved using the level of energy demand estimated in the CEC's Case 2 as input to MACRO, calculating the associated equilibrium price level, and, finally, comparing the price yielded by MACRO with that assumed in Case 2. As will be shown below, the results of the consistency check in fact revealed that the price assumptions underlying Case 2 were *not* consistent with the levels of energy demand calculated for the case.

The feature of Scenario 3 that distinguishes it from Scenario 2 is then the use of the energy demand calculated in the CEC's Case 2 as an exogenous input. (Actually, to suit MACRO's requirements, the energy demand had to be converted to secondary energy supply; but because MACRO is an equilibrium model, supply is taken to equal demand.) As illustrated in Figure 19, this assumption results in a markedly lower level of energy supply in Scenario 3 than in Scenario 2. All other assumptions are held constant in the two scenarios.

Scenario Results

MACRO's response to the assumptions used in Scenario 3 is shown in Tables 5 and 6. The low level of energy availability pushes the price of energy up to 301.8 EUA/tce by the end of the scenario time frame. This is equivalent to an annual increase of 9% in current terms, bringing the price of a barrel of oil up to 64 US dollars (at 1970 US prices and exchange rates). At this price equilibrium level, economic output is about 12% below that of Scenario 2. The investment rate of private business concurrently drops to 16.3% of GRP, certainly a reaction of producers to the transfer of income to energy-producing countries. The energy intensiveness index in Scenario 3 drops by approximately 6 percentage points to 47.5 (1970 = 100) by 2030.

The energy prices calculated by MACRO for Scenario 3 are clearly higher than those assumed in the CEC's Case 2. The iterative procedure built into MACRO, which permits it to find an equilibrium between a given quantity of available energy and the internally calculated energy demand, yielded a 3.7% annual growth rate for the real equilibrium energy price of secondary energy over the period 1975–2030. Corresponding current

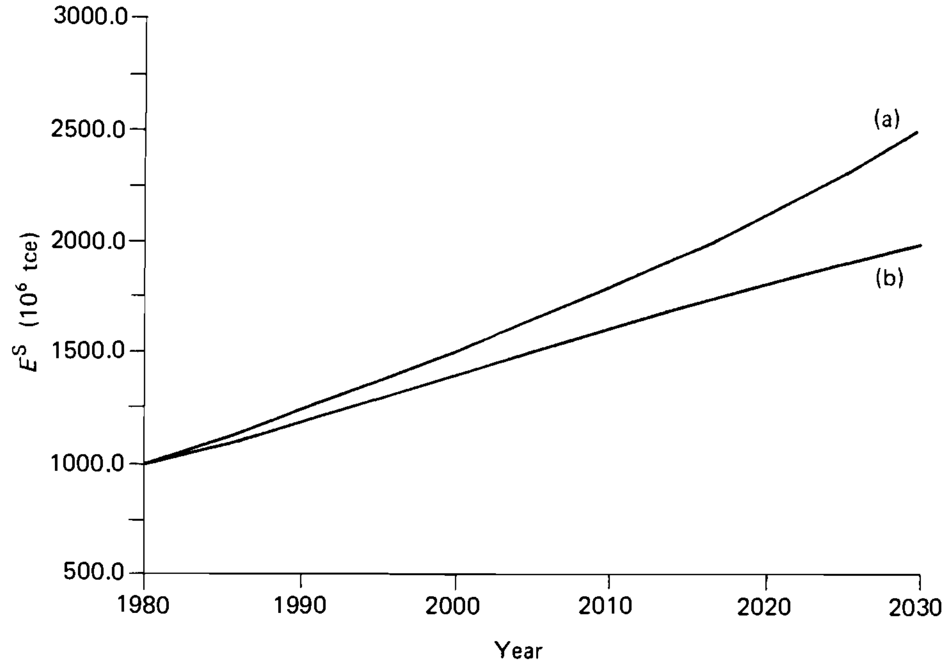

FIGURE 19 Comparison of the secondary energy supply E^S assumed in Scenario 2 (curve a) with that assumed in Scenario 3 (curve b), 1980–2030.

TABLE 5 Results of the MACRO run for Scenario 3: values of selected variables over time.

Variable	Year				
	1970	1985	2000	2015	2030
Gross regional product (10^9 EUA at 1970 prices and exchange rates)	618.2	1030.1	1692.5	2432.9	3109.7
Secondary energy (10^6 tce)	830.8	1081.6	1401.1	1715.3	1985.7
Investment rate (%)	22.8	21.6	20.2	18.3	16.3
Energy intensity (1970 = 100)	100.0	78.1	61.6	52.5	47.5
Price of energy [EUA/tce (deflated)]	30.4	64.8	128.4	214.5	301.8
Capital: output ratio	3.59	3.57	3.41	3.33	3.30

TABLE 6 Growth rates of selected variables, by time period, in Scenario 3 (% per year).

Variable	Time period			
	1960–1973	1985–2000	2000–2015	2015–2030
Gross regional product (at 1970 prices and exchange rates)	4.5	3.4	2.4	1.6
Secondary energy	4.6	1.7	1.4	1.0
Consumption per capita	3.7	3.2	2.5	1.6
Secondary energy per capita	3.8	1.5	1.2	0.7

price increases for imported and domestically produced energy amounted to 8% and 11%, respectively. These values range well above the price development assumed in the CEC's Case 2: there the price of imported energy was assumed to increase by 5% per year, while the price of domestic energy was assumed to increase by 6% per year.

A small test was carried out with MACRO to elucidate this price inconsistency between Scenario 3 and the CEC's Case 2. In this test the *price development* assumed in Case 2 was used as input to MACRO, instead of energy supply, and the corresponding equilibrium energy demand and its macroeconomic impacts were then calculated. Figure 20 contrasts the results of this test case with those of Scenario 3.

In the figure, the broken curves [(a) and (c)] represent real secondary energy prices and the solid curves [(b) and (d)] represent secondary energy demand. The CEC case is characterized by the lower energy demand and energy price curves [(c) and (d)].

In the test run (in which the assumed price evolution of the CEC's Case 2 was used as input to MACRO), the corresponding equilibrium secondary energy demand follows the high demand curve (b) in Figure 20. The availability of low-cost energy causes secondary energy demand to increase by a factor of 1.58 in this test case. Concurrently, equilibrium output and its major components shift upwards by 21.1%, as shown in Figure 21.

In contrast, in the MACRO run for Scenario 3 [in which the secondary energy availability shown in curve (d) is used as input], the corresponding equilibrium price follows the high price evolution shown by curve (a). *This suggests that if energy demand is to be*

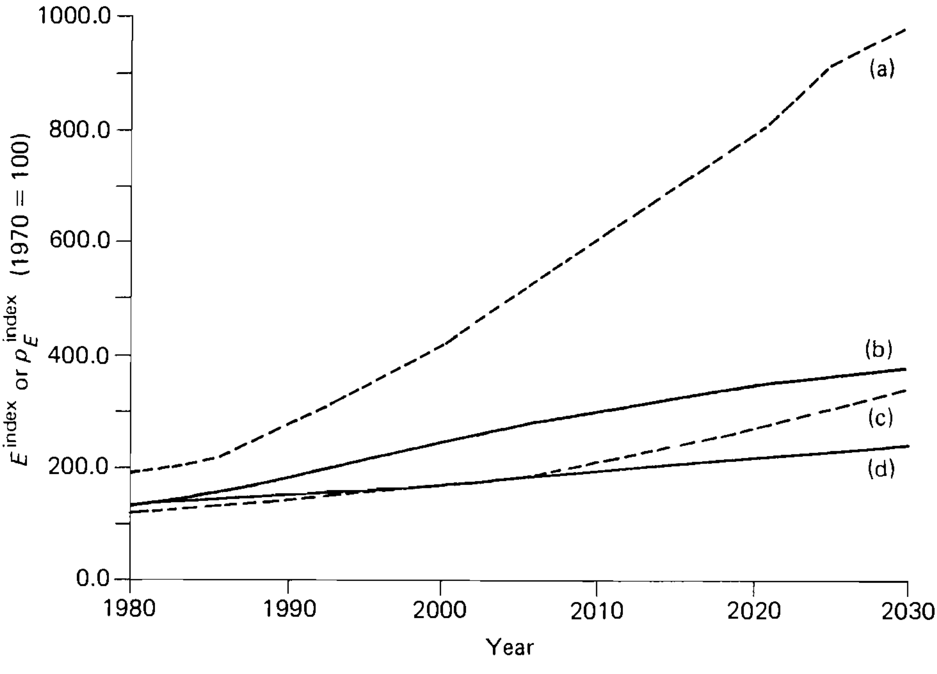

FIGURE 20 Secondary energy demand E^{index} (——) and the corresponding equilibrium energy price p_E^{index} (- - - -) in Scenario 3 (curves a and b) and in Case 2 (curves c and d) of the CEC study "Crucial Choices for the Energy Transition (CEC 1980), 1980–2030.

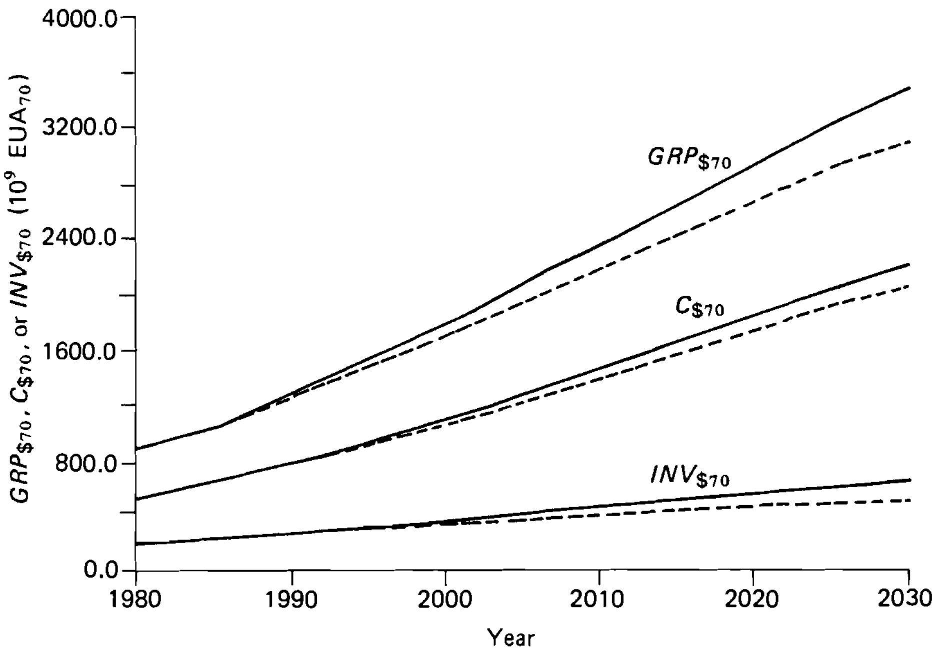

FIGURE 21 Evolution of gross regional product $GRP_{\$70}$, personal consumption expenditures $C_{\$70}$, and gross fixed capital formation $INV_{\$70}$ in Scenario 3 (——) and in Case 2 (- - - -) of the CEC study "Crucial Choices for the Energy Transition" (CEC 1980), 1980–2030.

kept at the low level of curve (d), the required price-induced conservation (and accompanying innovation) can only be achieved if energy prices accord with the high price development curve (a).

In conclusion, the results of the MACRO run for Scenario 3 indicate that the price-induced energy conservation assumptions used in MEDEE for Case 2 of the CEC study are very optimistic, if not infeasible. The adjustment processes built into MACRO allow for a strong reduction in secondary energy demand only in connection with significantly higher energy prices and a considerable loss in national income.

A Note on Lifestyle-Induced Conservation in the Context of MACRO

Scenario 3 shows clearly the problems of implementing strong energy conservation measures consistently in an aggregate macroeconomic model. MACRO determines the demand for the primary production factors (capital and labor) and for energy, under the assumption that these factors are rewarded their marginal products. Substitution between production factors is limited to relative changes in their prices and does not include efficiency improvements, unless the lower energy use resulting from such improvements is translated into additional labor or capital requirements.

Thus, probable long-run changes in consumer lifestyles, which underlie MEDEE's detailed demand analyses, cannot be represented satisfactorily in MACRO. Energy conservation measures considered in MEDEE (but not in MACRO) include potential energy savings in the household and service sector (for instance, through better insulation standards in housing and the introduction of heat pumps and soft solar technologies), advanced communication technologies, and improved mileage per unit of motor fuel in the transprotation sector.

It is possible, however, to deduce *indirectly* from MACRO improvements in energy efficiency associated with an economy subject to structural and lifestyle changes. To do so requires examination of *energy–income* and *energy–price elasticities.*[22] Over the period 1963–1973, the income elasticity λ in the EC region amounted to 0.875 and the corresponding price elasticity μ was -0.050. A 1% increase in GRP thus caused energy demand to grow by 0.875%, while a 1% increase in the price of energy reduced energy demand by 0.05%. If the period 1974–1978 is included in the historical analysis, the sharp rise in energy import prices associated with the oil crisis has a strong effect on the elasticities; a comparison of the first two columns in Table 7 shows this clearly. The income elasticity drops to 0.823, while the price elasticity climbs to -0.169, showing the strengthened consumer response to price changes.

As part of the long-term study of the EC region, various income elasticities were assumed for the 1979–2030 planning period, and the corresponding price elasticities were calculated on the basis of Scenario 3 results. As may be seen in Table 7, a high income elasticity of 0.9 is offset by a relatively strong price elasticity of -0.259, while a price elasticity of -0.114 is associated with a reduced income elasticity of 0.7. This interdependence of income and price elasticities suggests that prices should be used carefully as an energy management tool in the future.

If high income elasticities are maintained in the coming decades, any reduction in energy demand must come from consumers' reactions to energy price increases. At the same time, permanently increasing energy prices can have a negative effect on the consumption of energy-intensive commodities, and this in turn has a negative multiplier effect on commodities complementing energy-intensive goods and services. More expensive energy imports and transfer of national income abroad have unfavorable effects on the trade balance and intensify the burden on the economy. If energy demand is manipulated only through prices, without the initiation of structural changes, losses in aggregate demand will surely result.[23]

In contrast, low income elasticities represent a substantial structural change in industrial production, as well as in lifestyles. If the economy evolves smoothly toward an advanced economic structure characterized by low income elasticities, relatively high economic growth rates and full employment can be achieved. But such a smooth

TABLE 7 Energy–income (λ) versus energy–price elasticities: historical values and results for Scenario 3 under varying assumptions.

Elasticity	Historical values		Scenario 3 results		
	1963–1973	1963–1978	1979–2030	1979–2030	1979–2030
λ	0.875	0.823	0.900	0.800	0.700
μ	−0.050	−0.169	−0.259	−0.186	−0.114

transition takes much time – lead times are of the order of decades. Thus, any assessment of the effectiveness of energy conservation measures for the EC region must consider the high degree of inertia inherent in its social and economic system.

8.4 Scenario 4: The Effects of Capital Deepening in the Energy Sector

Scenario 4 focuses on the energy sector's future capital requirements and their impact on the capital available to other economic sectors. Because the composition of the EC region's future energy supply system serves as the point of departure for this analysis, it is appropriate to consider briefly the possible evolution of energy production and imports in the region, as well as associated capital needs. Overall, the regions' supply situation will be dominated by constraints – limited domestic energy resources, energy import curtailments, and time needed for capacity buildup and construction of new domestic power plants, conversion facilities, and domestic fuel extraction facilities.

Energy Availability in the EC Region

Compared with demand, the fossil fuel resources of the EC region are small. Even continuously rising world market prices will not turn present submarginal domestic energy resources into economically recoverable reserves. Offshore North Sea oil and coal located at great depths currently constitute Europe's most important resources; in the future, domestic fossil resources will become even more difficult to extract. At the same time, a desire to reduce dependence on energy imports will increase the pressure on the domestic energy production sector. If the EC's policy target of restricting imported energy to a maximum of 45% of total requirements by the year 2025 is met, domestic energy production capacity will have to increase by a factor of 1.33 – without even considering the actual expansion of total energy demand.

Limited domestic fossil fuel reserves combined with the need for increased output will compel the EC to consider all potential new energy sources, including "hard" and "soft" technologies – within the limits of their realizable potential and their compatibility with existing economic and social structures. Currently, decentralized renewable ("soft") resources, such as local solar, wind, biomass, and geothermal energy, seem difficult to introduce in Europe's large urban areas. Their energy supply density, about 0.5 watt/m^2, is extremely low compared with current energy consumption densities of about 5 watt/m^2 in urban areas (World Energy Conference 1978). Still, no energy option should be excluded *a priori*; structural changes and modifications in lifestyle, such as a reversal of the past trend of movement to urban areas, may favor "soft" technologies in the future.

Advanced centralized technologies, such as nuclear power and the solar tower concept, do seem suitable for the industrialized and urbanized infrastructure of the EC region. However, the widespread introduction of these technologies is also attended by difficulties. The application of nuclear power is currently hindered by the debate over societal compatibility and safeguards. Ultimately, it will be limited by the scarcity of economically recoverable world uranium resources, unless the breeder technology is introduced on a wide scale, and long lead times are associated with this technology. The competitiveness of the hard solar option is hampered by unsolved storage problems and the magnitude of its requirements for metals, concrete, and other materials. These constraints preclude the large-scale penetration of this technology into the energy sector before 2030.

These constraints and the long lead times connected with the large-scale introduction of newer energy technologies may be expected to produce continuing reliance on liquid fuels and electricity in the EC region during the next 50 years. However, restricted oil imports and environmental concerns are likely to put emphasis on synthetic liquid fuels and advanced electricity production technologies.

Future Capital Requirements of the Energy Sector

Rising capital costs for extracting coal and offshore oil will heavily influence the energy sector's future capital requirements. As domestic fossil resources become less accessible, the energy content per unit of extracted output will decrease and capital requirements per unit of installed capacity will increase. Concern for minimizing the environmental damage associated with extraction activities will also lead to higher capital costs at the beginning of the energy supply chain.

At the energy conversion stage, advanced technologies used to transform primary fuels into secondary and final energy forms will also be characterized by increasing capital intensity. Improvement of conventional conversion processes to meet environmental protection standards and parallel development of transmission and distribution systems will each augment the energy sector's capital requirements.

Replacement of the existing supply infrastructure with advanced and more capital-intensive energy production technologies, substitution of a certain share of previously imported energy through domestic production, and growth in primary energy demand will together lead to historically unprecedented capital needs in the energy sector during the next 50 years.

The Setting for Scenario 4

In Scenario 4, the EC region's future energy supply requirements and associated capital costs are described in quantitative terms through application of the whole IIASA model loop. MEDEE runs provide an estimate of future energy demand; MESSAGE calculates the corresponding primary energy requirements; IMPACT then determines the capital required to create the prerequisite energy supply infrastructure; finally, the issue central to Scenario 4 – the macroeconomic implications of concentrating capital in the energy sector – is examined in a series of MACRO runs.

The socioeconomic assumptions underlying Scenario 4 are the same as those used in Scenario 3. Thus, energy prices develop according to curve (a) in Figure 20, and corresponding lifestyle trends in the household and transportation sectors include continuing increases, in absolute terms, in the size of dwellings and quantitites of electrical appliances, as well as emphasis on private cars. Not surprisingly, electricity and liquid fuels are major components of the future energy demand calculated by MEDEE on the basis of these assumptions.

The corresponding energy supply requirements provided by MESSAGE are strongly affected by the EC energy import policy of restricting imports to no more than 45% of total energy needs by 2025. This constraint produces several notable fuel substitution trends, as illustrated in Figure 22. Although the relative share of liquid fuels remains fairly constant over the scenario time frame, the share of primary energy supplied by oil – mainly oil imports – declines from over 50% in 1975 to under 20% by 2030. This results from the substitution of coal-based synthetic fuels for oil and the accompanying replacement of coal by nuclear power for electricity generation. Hydropower and gas maintain their

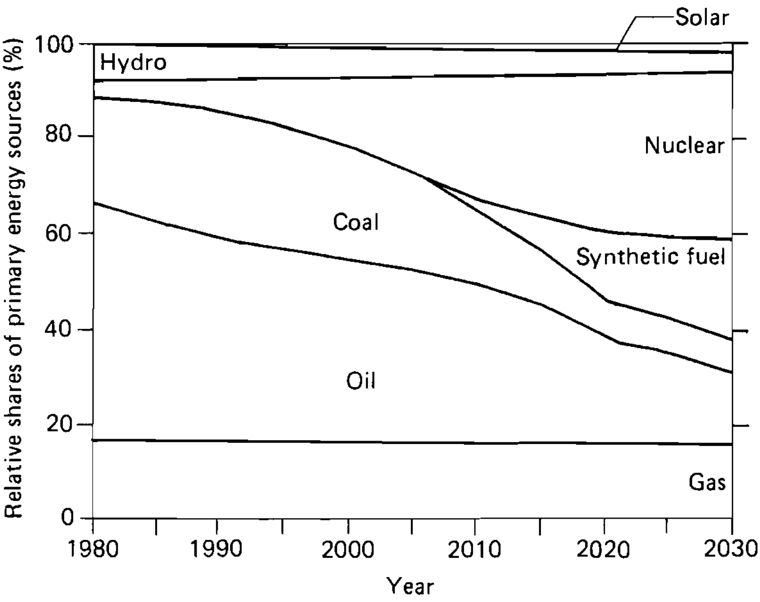

FIGURE 22 Primary energy shares by sources calculated for the EC region, Scenario 4, 1980–2030.

relative market shares, while, for reasons discussed above, renewable energy resources (represented by solar power in Figure 22) contribute little to overall energy supply.

IMPACT runs based on this energy supply configuration showed a 150% increase in the specific energy capital stock per watt of production capacity between 1970 and 2030. Expressed in constant 1970 monetary terms, capital stock increases from 0.27 EUA/watt in 1970 to 0.67 EUA/watt in 2030. The energy sector's capital stock as a share of total stock increases from 7% in 1970 to 16% in 2030.

In Figure 23 a continuation of the historical trend[24] of investments in the energy sector over the next 50 years is contrasted with the investment requirements calculated by IMPACT for Scenario 4. The accumulated difference between the two curves up to the year 2030 amounts to 720×10^9 EUA. Such a gap makes one ask whether the economy can raise enough additional capital to avoid a capital shortage in the energy sector, given the supply assumptions of Scenario 4.

This question is addressed in two successive MACRO runs. The first run investigates the impact of the energy sector's rapidly increasing capital : output ratio on interest rates and the profitability of its capital. The second run examines a government intervention strategy for boosting the profitability of the energy sector's capital to levels prevailing in other economic sectors.

Run 1: Assumptions and Results

In the first MACRO run for Scenario 4, the impact of capital deepening in the energy sector is analyzed without taking into consideration the traditionally assumed benefits of multiplier and acceleration effects. In other words, the rapid growth of the capital: output

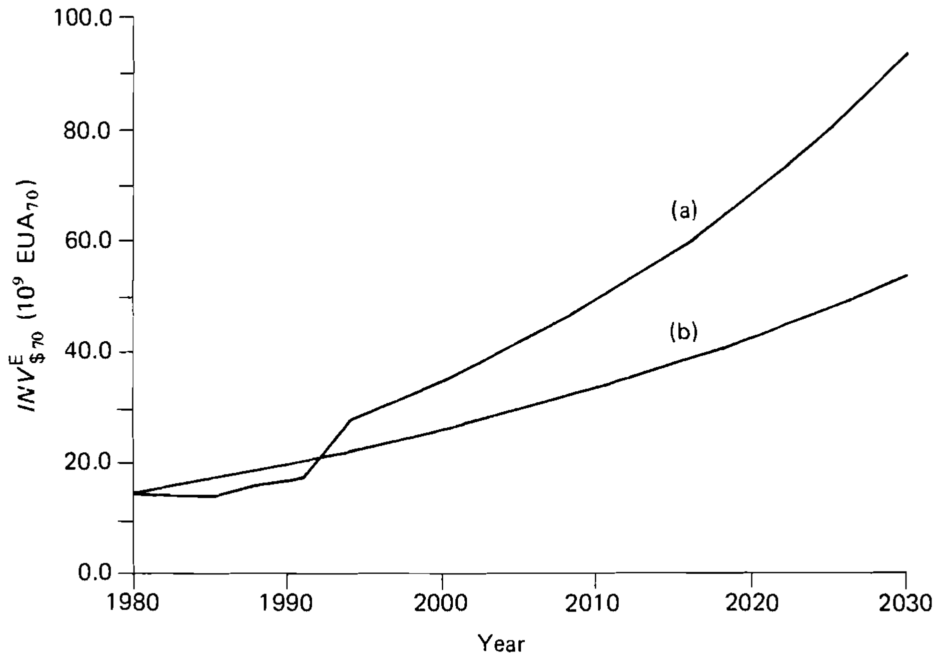

FIGURE 23 Comparison of projected requirements for gross fixed capital formation $INV^E_{\$70}$ in the energy sector of the EC region in Scenario 4 (curve a) with a continuation of the historical trend, 1980–2030 (curve b).

ratio in the energy sector is assumed to occur without corresponding increases in value added in this sector. Thus, the additional capital neeeded to fill the gap between the two curves in Figure 23 is taken to be unproductive in the traditional macroeconomic sense. Purchases of investment goods by the energy sector from other sectors may certainly induce multiplier and accelerator effects in those sectors. But an aggregate two-sector model is not designed to account for intersectoral growth effects.

The results of Run 1 show that the strong assumption about the growth of capital stock in the energy sector has a clear impact on the rest of the economy. In order to allocate sufficient capital to the energy sector and to balance total capital demand and supply, the model pushes the equilibrium real interest rate[25] for the economy as a whole about 2% above the historical 9–10% level by the end of the scenario time frame. The divergence between these results and an extrapolation of historical trends is shown in Figure 24.

Thus the higher level of overall capital demand and the requirement that the capital needs of the energy sector must be met result in higher overall capital prices. This in turn implies either that productivity and efficiency improvements occur to ensure an equivalent increase in capital profitability or that the rest of the economy reduces its propensity to invest – a direct consequence of the equilibrium condition in which the marginal product of capital must match the price of capital (i.e., the interest rate).

The response in Run 1 is a fall in the absolute quantity of investments in the rest of the economy. The level of investment is 7.5% lower than in Scenario 3 (in which it is

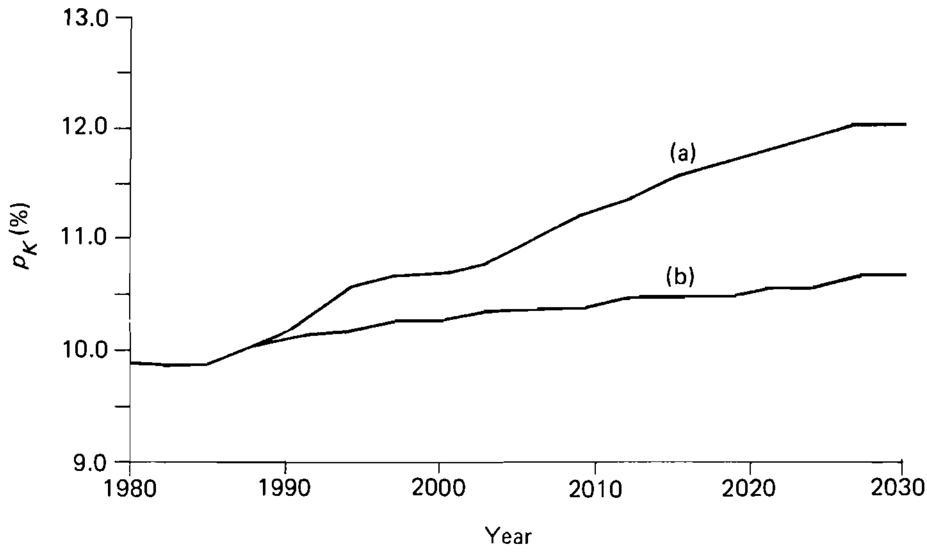

FIGURE 24 Comparison of the evolution of the cost of capital p_K (real interest rate) in Scenario 4 (curve a) with a continuation of the historical trend, 1980–2030 (curve b).

assumed that historical trends of investment in the energy sector continue). Thus, given a 2% increase in the rate of return of investments, 7.5% of the previously profitable investments in the rest of the economy fall below the level of economic feasibility. The reduction in the investment volume in the rest of the economy would correspond to about 90% of the additional capital requirements associated with the energy sector in Scenario 4.

However, as the equilibrium interest rate increases, the profitability of the energy sector's capital concurrently drops by 60%, to a low of 4.5%, to avoid violating the constant value-added constraint imposed on the sector in this run. In a market economy, the decline in the levels of capital profitability in the energy sector would certainly result in a capital drain from that sector to other sectors, since shareholders and capital lenders would not invest in submarginal objects whose interest is two-thirds lower than the prevailing market interest on capital. *This implies that the energy sector would not have access to the capital needed for Scenario 4's energy supply configuration, without some form of intervention on the capital market.* Accordingly, the second MACRO run for Scenario 4 simulated such intervention.

Run 2: Government Intervention on the Capital Market

MACRO is able to simulate one type of adjustment to capital deepening in the energy sector through manipulation of the *income tax scenario parameter* [see parameter η_2) in eqn. (5.19)]. MACRO calculates the amount of annual subsidies required to compensate capital owners in the energy sector with the appropriate market interest on capital. In an iterative procedure, the model then adjusts the income tax rate to maintain a balanced government budget, thereby reducing growth in disposable income and producing a lower level of private consumption. The decrease in private consumption is channeled, by means of the government budget, to subsidize the energy sector's returns on investment, i.e., to produce uniform interest rates and thus match the profitability of the energy sector's capital with that of the rest of the economy. The components of final demand in effect shift from personal consumption expenditures to gross fixed capital formation, without major impacts on overall economic activity.

In Run 2 the average income tax rate increases from 33.0% to 35.5% by the end of the planning horizon. The corresponding level of private consumption lies 4.5% below that which would have prevailed, given continuation of the historial energy investment and taxation trends assumed in Scenario 3. The overall impact of the stringent taxation policy assumed in Run 2, then, is a reduction in private consumption expenditures and increases in the investment rate sufficient to supply the capital needs of the energy sector.

The Trade Balance in Equilibrium

Even if government intervention on the capital market does make sufficient capital available to the energy sector, the EC economy would still be confronted with a serious trade imbalance. In 2030, 45% of total energy requirements in Scenario 4 stem from foreign sources, and steadily rising energy import prices have turned the trade balance into a permanent deficit. Because the trade balance acts as an explanatory variable in the determination of investment supply within MACRO, a deficit reduces the investment supply level and reflects the economic loss of paying a higher energy import bill.

A sensitivity study based on Scenario 4 focuses on ways of eliminating problems connected with the balance of payments and international exchange rates. Specifically, the run determines the expansion in imports required to equilibrate the trade balance and examines the macroeconomic impact of increased exports. The three main assumptions underlying the run are that a negative trade balance leads the EC to strive for a higher export volume on the international export market; that the international market absorbs any excess production from the EC economy; and that the export incentive of domestic business can be manipulated through institutional measures such as taxation, export subsidies, or special export credit facilities.

These policies are simulated in MACRO through manipulation of an *export parameter* [see parameter η_3 in eqn. (5.24)]. The parameter is adjusted exogenously in the model run to eliminate the trade balance deficit by 2030. Figure 25 contrasts the resulting evolution of the trade balance in the sensitivity study with that in the regular MACRO run for Scenario 4. Figure 26 shows the markedly higher export activities calculated in the sensitivity study, compared with the export development in Scenario 4; the evolution of the energy import bill over the scenario time frame is also plotted for reference.

Table 8 summarizes the long-term economic impacts of the additional export sales stimulated by manipulation of the export parameter. Besides favorably affecting the trade balance, the expanding export activities increase the incentive of private business to invest. Consequently, economic activity is stepped up and the growth rates of the gross regional product increase. (Part of this growth is absorbed by import expenditures, since increased economic activity implies a need for more energy and other imported products.)

At the same time, personal consumption expenditures are only marginally affected, because most of the added production of goods and services must be exported to raise revenue for energy imports or must be used in the capital formation process to accumu-

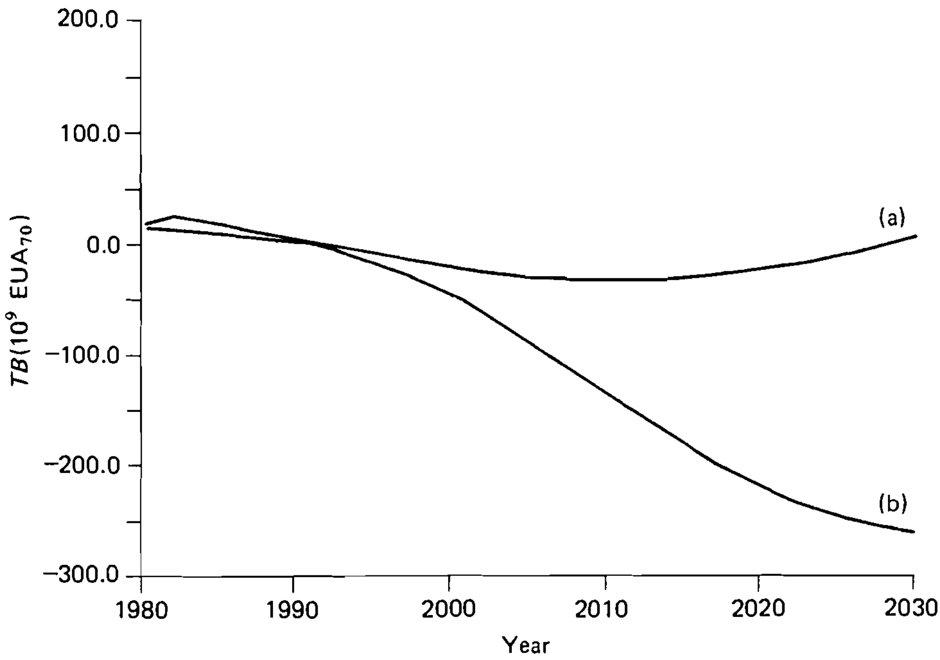

FIGURE 25 Comparison of the EC region's trade balance *TB* in Scenario 4 (curve b) with the results of a sensitivity study in which exports are adjusted to eliminate a trade balance deficit (curve a), 1980–2030.

late sufficient capital to increase overall economic activity. There is also only a relatively small increase in the required export share of gross regional product – 30.8%, compared to 29.5% in Scenario 3. This indicates the sensitivity of the EC economy to the future development of the world trade volume.

It must be stressed that equilibration of the trade balance rests on the assumption that the international trade market can in fact absorb the EC's excess exports, despite the already strong export dependence of the EC economy. Unfortunately, the present version of MACRO cannot be used to test the validity of this assumption.

In general, the results of the run indicate the pressure of the EC economy to maintain a high level of productivity and to become even more competitive on the international trade market. Effective political measures are in turn the prerequisite for stimulating productivity. A general conclusion, which may be drawn from all the MACRO runs for Scenario 4, is that *the investments necessary for diverting sufficient capital to the energy sector and for counteracting trade imbalances may not occur in the absence of effective policy*.

The world trade market is not the only wild card influencing the future growth prospects of the EC economy. It is necessary for political institutions to create the appropriate environment for businesses to invest, even in times when productivity tends to decline and economic resources are drained through unfavorable terms of trade. Without an adequate buildup of production capacities, the EC economy will not be able to react when an upswing in the world trade market does occur.

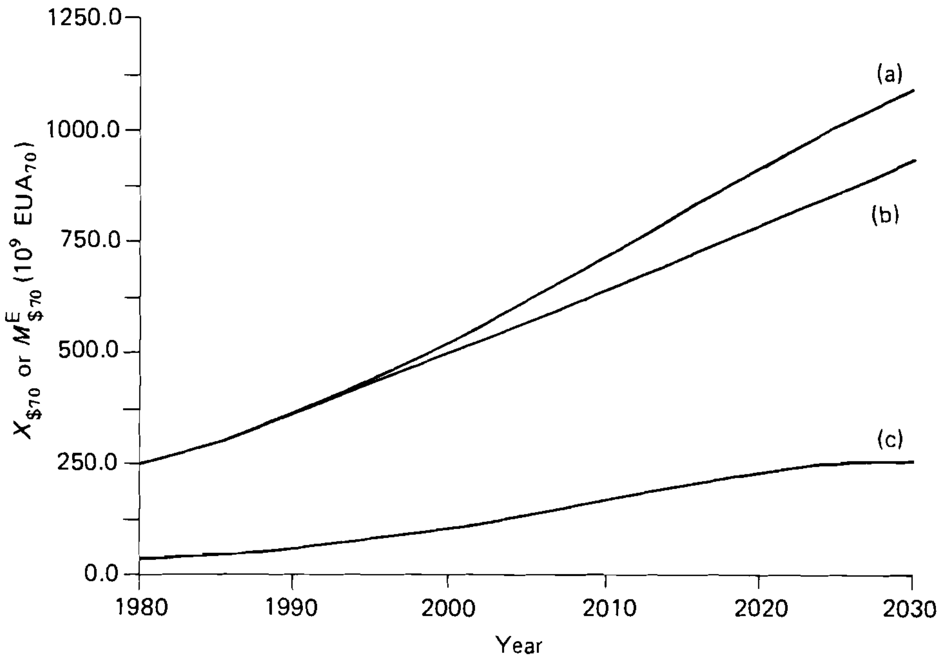

FIGURE 26 Comparison of the EC region's exports $X_{\$70}$ in Scenario 4 (curve b) with the results of a sensitivity study in which exports are adjusted to eliminate a trade balance deficit (curve a), 1980–2030. Curve c shows the development of expenditures for energy imports $M^{E}_{\$70}$ assumed in both cases.

A Comment on Productivity

The growth rates of productivity are assumed to gradually decrease over time in the scenarios presented in this report. This is not due to a predicted decline in technical innovation, for it does not seem reasonable to assume a slackening of the human urgency for investigation and exploration. Rather, the obstacles hindering future growth in productivity will probably arise from interactions between science, technology, and society, as suggested by the OECD (1980).

For example, the debate on future energy supply systems within the member countries of the European Community has made the future development of various economic sectors uncertain. In this situation, producers tend to concentrate on reducing production costs at present production levels, instead of developing new products and introducing new processes to improve productivity. An additional factor is that modest economic growth rates may reduce long-term R&D expenditures, thus limiting the financial resources required to make high-cost technological breakthroughs.

In recent years, societal resistance has blunted many technological breakthroughs. It has been especially difficult to obtain public acceptance for the introduction of large-scale, centralized technologies. But such technologies must be adopted, if the industrialized economy of the EC region is to achieve the gains in productivity necessary to cope with future challenges. Otherwise, the region's population must be willing to live with reduced economic growth rates and significant changes in lifestyles – a possibility not entertained in the scenarios described above.

TABLE 8 Results of the MACRO run for Scenario 4 and for a sensitivity study in which exports of goods and services are adjusted to produce an equilibrated trade balance.

Variable	Year			
	1985	2000	2015	2030
Exports of goods and services (10^9 EUA at 1970 prices and exchange rates)				
Scenario 4	294.8	491.8	707.7	915.1
"Adjusted Exports" Run	301.9	502.4	742.0	997.6
Gross regional product (10^9 EUA at 1970 prices and exchange rates)				
Scenario 4	1026.8	1683.4	2402.9	3097.9
"Adjusted Exports" Run	1049.9	1687.3	2434.3	3242.8
Personal consumption expenditures (10^9 EUA at 1970 prices and exchange rates)				
Scenario 4	635.7	1045.7	1516.1	1971.6
"Adjusted Exports" Run	647.8	1042.1	1507.3	1977.3
Gross fixed capital formation (10^9 EUA at 1970 prices and exchange rates)				
Scenario 4	224.3	345.5	463.8	562.4
"Adjusted Exports" Run	222.5	346.3	472.6	621.1
Investment rate (%)				
Scenario 4	21.8	20.5	19.3	18.2
"Adjusted Exports" Run	21.2	20.5	19.4	19.2
Personal consumption expenditures per capita (10^9 EUA at 1970 prices exchange rates)				
Scenario 4	2.178	3.849	5.415	6.799
"Adjusted Exports" Run	2.457	3.836	5.384	6.818
Capital stock in energy sector as share of total capital stock (%)				
Scenario 4	7.0	8.5	11.0	14.8
"Adjusted Exports" Run	7.0	8.6	10.6	13.2

9 MODEL WEAKNESSES AND STRENGTHS

Model Deficiencies

The development of a model that captures the essentials of the European Community's economy is hampered by problems of data availability. It was necessary to estimate the econometric relations within MACRO on the basis of data from the relatively short 1960–1978 (and sometimes only the 1966–1976) sample period. Because the statistical data available for the 1960–1978 period give more weight to the boom years of the 1960s than to the post–1973 economic slowdown, the attributes of short-term boom periods are inherently incorporated into MACRO's parameters.[26] The different, and even conflicting, systems of national accounts used by the nine countries that compose the aggregate EC region complicate the problem of constructing an adequate data base. Thus, much caution is required for long-term application of MACRO, due to the imperfection of the sample data and the shortness of the sample period.

A second problem is that the aggregate nature of MACRO precludes consideration of changes within and between various economic sectors. In particular, the model cannot reflect substitution effects between the factor inputs in a given economic subsector, the results of saturation of various social needs, or shifts in production from one sector to another. The difficulty of examining energy conservation measures with MACRO (as discussed in Section 8.3) provides an example of these shortcomings. An input–output model, which represents interactions between all economic sectors, would be needed to reflect such details.

A third deficiency is that MACRO's aggregate production function is based on the strong assumption that substitution between factors of production depends completely on relative prices. Of course, there are other incentives and motives for such substitution, including innovations and technical progress. Consideration of these factors would require the detailed description of sectoral production functions that account for all types of input factors, including materials. MACRO is in no position to respond to such a requirement.

The model's capabilities would also be improved if it contained an energy supply function in which higher energy prices could induce increased energy production. As the model now stands, energy supply is exogenously determined, thus limiting the model's flexibility. Finally, MACRO's equilibrium feature has to be viewed as an artificial attempt to balance demand for and supply of the primary input factors (capital, labor, and energy). In reality, an economy in equilibrium is more of an exception than a rule.

Model Achievements

Despite these deficiencies, the application of MACRO within the IIASA set of energy models may be considered successful. The model fulfills the CEC's original request for a consistency check of its member countries' long-term energy demand and supply strategies. As well, MACRO's compact structure permits easy examination of various scenarios and encourages the user to test the impact of imposed normative changes on the long-term behavior of the aggregate EC economy.

The scenarios presented in Section 8 demonstrate the types of questions that MACRO is designed to answer. Because MACRO contains a two-way linkage betwen the energy sector and the rest of the economy, it can be used to examine the effect of rising energy prices on the growth of gross regional product. As shown by the difference between the results of Scenario 1 and Scenario 2, large energy price increases accompanying constrained energy availability are likely to reduce gross regional product considerably.[27] As demonstrated in Scenario 3, MACRO is able to reveal inconsistencies in assumptions originating from the other models within the IIASA set of energy models. Scenario 4 illustrates the use of MACRO to analyze the long-term effects of higher energy prices and increased capital intensiveness in the energy sector on the structure of exports and the capital market.

Despite the uncertainties inherent in long-term scenario assumptions, MACRO runs revealed the need for intensified efforts to guarantee a high level of economic productivity during the next decades. Innovation and improvements in efficiency appear to be the best approaches for coping with future energy-related (and other) economic problems.

NOTES

1. The full-member countries of the EC ("EC of Nine") in 1979 were Belgium, Denmark, the Federal Republic of Germany, France, Ireland, Italy, Luxembourg, The Netherlands, and the United Kingdom.
2. The term "homomorphic picture" has been translated from the German concept "homomorphe Abbildung", coined by Professor Wolfgang Eichhorn.
3. MEDEE stands for "Modele de l'Evolution de la Demande d'Energie".
4. MESSAGE stands for "Model for Energy Supply Systems And Their General Environmental Impact."
5. IMPACT was developed at the Siberian Power Institute, Union of Soviet Socialist Republics. The model's name refers to the economic impacts of various energy strategies.
6. Indirect requirements are not considered in MACRO.
7. E^{I} and E^{D} are measured in physical units, i.e., in millions of tons of coal equivalent (10^6 tce).
8. As mentioned above, energy is treated totally as an intermediate good in MACRO. Therefore the value of energy demand as a final commodity (in monetary terms) that is already included in real *GRP* is counted twice. "Final" energy, however, accounts for a fairly small share of total value added, so the general usefulness of MACRO is not affected by this deficiency.
9. The notation used in this section should not be confused with that used in the other sections of the report. For instance, Q is used to denote output here, rather than y as in the other sections. This section constitutes a short survey of the theoretical foundation for the CES production function, and therefore somewhat different labels have been chosen to refer to given variables.
10. In this and the following equations the actual model will be presented. Therefore the labels may carry an additional term, such as $70, which indicates constant values measured in European Units of Accounts (EUA) at 1970 prices and exchange rates. Other variables are measured in current prices or physical units. Further information on variable units and the meaning of the mnemonics is given in Appendix A.
11. a and b do not necessarily add up to unity.
12. In the numerical specification of MACRO, the more exact variable total manhours worked *MH* was substituted for the more general variable labor.
13. One may also think of p_K as the equivalent of an interest rate.
14. The following scenario parameters were incorporated into MACRO: η_1 reflects changes in indirect business taxes *TAXES* and η_2 reflects changes in income taxes *TAXDIR*; η_3 and η_4 allow adjustments in the export and import shares of GRP and thus permit manipulation of the trade balance.
15. See Appendix B for a discussion of data sources used in the modeling effort.
16. Exogenous variables are marked with an "x" or an "I" in the variable list provided in Appendix A.
17. MACRO's numerical analysis of the impact of the energy shock did not correspond in every respect to Fried and Schultze's qualitative description. For instance, reinvestment of the oil producing countries' surplus is not an option considered in MACRO, so the model cannot reflect the "transition phase" described by these analysts. As a consequence, crisis-induced losses in sales by consumption-goods industries could not be offset by exports to oil-producing countries in the model. To some degree, the fact that exports to other oil-importing countries were assumed to remain unaffected (although these countries faced similar slowdowns in economic activity and would have had to reduce their volume of imports) compensated for this model deficiency. The level of exports in the test case was assumed to correspond to the historically observed share of exports within the gross national product.
18. This rate was also assumed in the study conducted by the Commission of the European Communities (CEC 1980).
19. There is a sharp distinction between scenario variables and the scenario parameters. The former belong to the group of scenario-defining variables used in scenario writing, while the latter are used to impose necessary or desired changes within a defined scenario.
20. It is possible to circumvent the equilibrium condition by exogenously determining maximum labor supply. In this case, the model adjusts labor demand freely in accordance with the relative price structure of the other factors of production.

21. The energy demand calculations in "Crucial Choices for the Energy Transition" were carried out by the CEC's Directorate-General for Scientific and Technical Information and Information Management, using the MEDEE model.
22. A popular relationship, which combines income and price elasticities with respect to energy, is defined as follows:

$$\ln(E/E_0) = \lambda \ln(GRP/GRP_0) + \mu \ln(P/p_0)$$

where λ is the energy–income elasticity, μ is the energy–price elasticity, and 0 is an index that determines the base year values for 1963 and 1979, respectively.
23. This is an extreme statement derived and interpreted from the simplistic concept of the interdependence of income and price elasticities. It is based on "back of an envelope" calculations.
24. In this context, historical trend denotes a continuation of the share of investments of the energy sector in total gross fixed capital formation observed between 1960 and 1976, i.e. 6.0–7.0%.
25. "Cost of capital" is the more exact term. It includes both interest and depreciation.
26. Some short-term diverging trends can be eliminated through the manipulation of certain scenario parameters (see Section 5.3).
27. Throughout the analysis presented in this report, the "elasticity of substitution" parameter was kept fixed at its estimated value of 0.38. Any value higher than 0.38 would decrease the energy–economy interdependence considerably, i.e., tighter energy availability would have less effect on economic growth rates. The uncertain validity of the constant elasticity assumption for the next 50 years – not to mention the uncertainty of its value in general – must be stressed.

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APPENDIX A: DEFINITION OF VARIABLES

All variables included in MACRO are listed below. Endogenous variables are indicated by an "e" in the second column, exogenous ones by an "x". Variables that are inputs originating from other models within the IIASA set of energy models (and that therefore are exogenous to MACRO, but exogenous to the loop) are marked with an "l". For completeness, parameters mentioned in the text and variables used in the general model specification are also included in the list, indicated by a "p" and a "g", respectively. EUA stands for "European Units of Accounts" and ROE stands for "rest of the economy."

VARIABLE	WHERE SPECIFIED	DEFINITION
$C_{\$70}$	e	Personal consumption expenditures (10^9 EUA at 1970 prices and exchange rates)
$c(E)$	g	Energy cost function for energy-exporting nations
DEP	g	Consumption of fixed capital
$DEP_{\$70}$	e	Consumption of fixed capital (10^9 EUA at 1970 prices and exchange rates)

E_{index}	l	Secondary energy demand (10^6 tce)
E	l	Secondary energy demand index (1970 = 100)
E^{D}	e	Domestic primary energy production (10^6 tce)
$E^{\mathrm{D,R}}$	e	Secondary energy demand in ROE (10^6 tce)
E^{E}	l	Energy requirements within the energy sector (10^6 tce)
E^{I}	e	Primary energy imports (10^6 tce)
E^{S}	l	Secondary energy supply (10^6 tce)
$G_{\$70}$	e	Government purchases of goods and services (10^9 EUA at 1970 prices and exchange rates)
$G(E^{\mathrm{D}})$	g	Domestic energy cost function
GRP	g	Gross regional product
$GRP_{\$70}$	e	Gross regional product (10^9 EUA at 1970 prices and exchange rates)
GT	e	Government transfer payments to persons (10^9 EUA at 1970 prices and exchange rates)
$HOURS$	x	Average total private nonagricultural hours of work per week
INV	g	Gross fixed capital formation
$INV_{\$70}$	e	Gross fixed capital formation (10^9 EUA at 1970 prices and exchange rates)
$INV^{\mathrm{E}}_{\$70}$	l	Supply of gross fixed capital formation in the energy sector (10^9 EUA at 1970 prices and exchange rates)
$INV^{\mathrm{R}}_{\$70}$	e	Supply of gross fixed capital formation in ROE (10^9 EUA at 1970 prices and exchange rates)
$INV^{\mathrm{S}}_{\$70}$	e	Total supply of gross fixed capital formation (10^9 EUA at 1970 prices and exchange rates)
K	g	Capital stock at end of period
$K_{\$70}$	e	Estimated capital stock at end of period (10^9 EUA at 1970 prices and exchange rates)
K^{D}	g	Total demand for capital
$K^{\mathrm{D,R}}_{\$70}$	e	Capital stock required at end of period in ROE (10^9 EUA at 1970 prices and exchange rates)
$K^{\mathrm{E}}_{\$70}$	l	Capital stock at end of period in energy sector (10^9 EUA at 1970 prices and exchange rates)
$K^{\mathrm{R}}_{\$70}$	e	Supply of capital stock at end of period in ROE (10^9 EUA at 1970 prices and exchange rates)
K^{S}	g	Total supply of capital
L	g	Labor input
L^{S}	e	Total labor force (10^6 persons)
M	g	Imports of goods and services
$M_{\$70}$	e	Imports of goods and services (10^9 EUA at 1970 prices and exchange rates)
$M^{\mathrm{E}}_{\$70}$	e	Energy imports (10^9 EUA at 1970 prices and exchange rates)
$M^{\mathrm{N}}_{\$70}$	e	Nonenergy imports (10^9 EUA at 1970 prices and exchange rates)

MH	e	Total manhours (10^9 hours)
MH^{E}	l	Annual demand for manhours in the energy sector (10^9 hours)
MH^{R}	e	Manhours worked in ROE
$MH^{\mathrm{R,D}}$	e	Annual demand for manhours in ROE (10^9 hours)
$NI_{\$70}$	e	National income (10^9 EUA at 1970 prices and exchange rates)
p	e	Implicit price deflators for *GRP* (1970 = 100)
p_E	l	Secondary energy price (EUA/tce)
p_E^{index}	l	Secondary energy price index (1970 = 100)
p_I	l	Energy import price (EUA/tce)
p_I^{index}	l	Energy import price index (1970 = 100)
p_{NEI}	x	Nonenergy import price index (1970 = 100)
p_K	e	Real interest rate (cost of capital) (%)
p_L	e	Wage rate (EUA at 1970 prices and exchange rates)
p_M	e	Import price index (1970 = 100)
p_V	x	Implicit price deflator of value added in ROE (1970 = 100)
p_X	x	Export price index (1970 = 100)
POP	x	Population
$POPOCC$	e	Occupied population (10^6 persons)
$POP > 65$	x	Population over 65 (10^6 persons)
Q	g	Output (value added)
R	g	Marginal rate of substitution
RES	x	Residual from *GRP* identity (10^9 EUA at 1970 prices and exchange rates)
$SUR_{\$70}$	e	Government budget, surplus or deficit (10^9 EUA at 1970 prices and exchange rates)
$TAXDIR$	e	Personal taxes, corporation taxes, and social insurance (10^9 EUA at 1970 prices and exchange rates)
$TAXES$	e	Indirect taxes and government surplus (10^9 EUA at 1970 prices and exchange rates)
TB	e	Trade balance (10^9 EUA at 1970 prices and exchange rates)
$TIME$	x	Time trend (1960 = 1)
V	g	Value added in ROE
V^{E}	g	Value added in energy sector
$V_{\$70}$	e	Value added in ROE (10^9 EUA at 1970 prices and exchange rates)
$V_{\$70}^{\mathrm{E}}$	e	Value added in energy sector (10^9 EUA at 1970 prices and exchange rates)
$UNEMP$	e	Unemployed persons (10^9 persons)
w	g	Hourly wage rate
X	g	Exports of goods and services
$X_{\$70}$	e	Exports of goods and services (10^9 EUA at 1970 prices and exchange rates)

Y	g	Gross output of ROE
$Y_{\$70}$	e	Gross output of ROE (10^9 EUA at 1970 prices and exchange rates)
$YD_{\$70}$	e	Spendable income (10^9 EUA at 1970 prices and exchange rates)
a	p	Distribution parameter for energy in the CES production function
b	p	Distribution parameter for value added in the CES production fucntion
c	p	Parameter
r	p	Parameter
cf	p	Conversion factor (primary to secondary energy)
α	p	Factor share of *GRP* to labor in Cobb–Douglas production function
β	p	Substitution parameter in CES production function
γ	p	Neutral productivity parameter in CES production function
ϵ_1	p	Energy price elasticity
δ	p	Distribution parameter in CES production function
δ^E	p	Consumption of capital in the energy sector
δ^R	p	Consumption of capital in ROE
η_1	p	Scenario parameter for indirect taxes (*TAXES*)
η_2	p	Scenario parameter for income taxes (*TAXDIR*)
η_3	p	Scenario parameter for exports
η_4	p	Scenario parameter for nonenergy imports
π	p	Aggregate profit function of the ROE sector
π_O	p	Energy-exporting countries' profit function for oil sales
σ	p	Elasticity of substitution parameter in CES production function
θ	p	Productivity parameter in Cobb–Douglas production function

APPENDIX B: DATA SOURCES

The data for the 1960–1978 sample period originate mainly from publications of the Statistical Office of the European Communities (EUROSTAT 1972, 1976, 1977, 1978, 1979). Publications of individual national statistical offices of the EC member countries were also consulted when necessary. To maintain comparability and consistency, the aggregate, though sometimes incomplete[a] data series for the EC region as a whole were preferred to more precise data from national sources.

The European Community's "National Accounts ESA" publication (EUROSTAT 1977) provides primary macroeconomic accounts in aggregate form for the Community as a whole. The data contained in this publication include the components of aggregate demand and aggregate demographic information (population, labor force, employment, compensation of employed persons, for example). This source also contains aggregate time series on consumption of fixed capital, taxes linked to production (indirect taxes), national income, and price indices for gross regional product and its components. The post-1976 aggregates were derived from the indices provided by EUROSTAT (1979).

Data on direct taxes, social insurance contributions, government transfer payments to persons, as well as data on value added and capital formation related to the energy sector, were available only on a country-by-country basis in detailed tables within the EUROSTAT National Accounts series (EUROSTAT 1972, 1978). The necessary conversion of national data into real (constant) European Units of Accounts was based on 1970 exchange rates and prices. The aggregation of the national data would have been straightforward if compatible and complete time series for all nine EC member countries had been on hand. However, this was nearly never the case, except for the aggregated data provided in the national accounts statistics prepared by the European Communities (EUROSTAT 1977). The weighted-average method (still meeting minimum consistency requirements) was therefore used to make the aggregation in cases where the internal characteristics of an individual economy had to be taken into account, or when data were simply missing. Relevant relationships or postulated dependence on other existing aggregate variables were used to choose the weights. For example, the national income share of an individual country was used in determining missing data on direct taxes.

Data on energy consumption and energy imports were taken from the *Quarterly Bulletin of Energy Statistics* (EUROSTAT 1976), while energy prices were based both on the data for the Federal Republic of Germany, France, and the United Kingdom compiled by Doblin (1979) and on the data for Belgium, Italy, the Netherlands, and Luxembourg supplied by Cleutinx (1979). A unique energy price could be calculated from these data, using the weighted-average method.

The ILO *Bulletin of Labour Statistics* (1979) contains time series for the average hours worked per week in individual countries and data on the number of persons employed in the energy sector. In both cases, however the ILO statistics do not supply complete information. This made it necessary to consult national statistical publications and then to apply the weighted-average method, using the share of total occupied population as the identifier in the calculation of the employed persons in the energy sector.

One aggregate variable that proved difficult to construct was capital stock. Gross capital stock can be calculated using the following recursive permanent inventory equation:

$$K_t = K_{t-1} + INV_t - DEP_t$$

where K_t is capital stock at the end of the present period, K_{t-1} is capital stock at the end of the previous period, INV_t is gross fixed capital formation at the end of the present period, and DEP_t is consumption of fixed capital at the end of the present period. Data on investment and consumption of fixed capital stock were provided in the EUROSTAT statistics, but the use of this equation also required a value for the initial capital stock K_0 or an initial capital:output ratio. Unfortunately, data on capital stock were not provided at all in the EUROSTAT statistics and were available from national statistical publications on national accounts only for the Federal Republic of Germany, France, and the United Kingdom. It was therefore necessary to use in addition the aggregate capital-stock time series and capital: output ratios for Western Europe constructed by Ströbele (1975).

Applying the weighted-average method to the capital-stock information supplied by these sources, an initial (1970) capital:output ratio of 3.59 was calculated for the EC region. This value lies above Ströbele's aggregate value of 3.19 for Western Europe as a whole: but because the more industrialized countries of western Europe are concentrated in the EC region, the higher value of 3.59 seems reasonable.

APPENDIX C: COMPUTERIZATION OF MACRO

The development of a macroeconomic model requires a computer system to handle various computation problems. As an unavoidable initial step, the modeler is confronted with the issue of data management. Appropriate time series, cross-sectional data and other information have to be collected and stored in a data bank. This data bank must be easily accessible at various points during the model's development process. The capability to manipulate and transform data, to add and easily retrieve information, and to provide adequate documentation is an essential requirement.

Once a data bank is established, it serves as a central tool in the succeeding steps of model development. These steps include estimation of econometric parameters and relationships, statistical analyses, and performance of significance tests for the estimated parameters. The data bank is accessed continuously, as data series are retrieved for the estimation procedure and the resulting information is stored.

The final step in the development of a macroeconomic model is the simultaneous solution of all estimated relationships. It is necessary to generate input files for the actual simulation, i.e., to provide the estimated coefficients and exogenously specified variables, before linear or nonlinear econometric models can be solved. Output files, graphs, and tables providing comparisons with reference cases complete model software requirements.

MACRO was designed and developed with the aid of the *Software Package for Economic Modeling*, created by Norman (1977). Although the software package was developed for the PDP 11/70 interactive mode of operation, it is almost computer-independent. Only slight modifications are needed to run the package on a CDC or IBM computer.

APPENDIX D: FORTRAN SUBROUTINES

The subroutines *const.f, solve.f, and post.f* contain the necessary FORTRAN code for MACRO. These subroutines are compatible with SIM – the simulation component of the *Software Package for Economic Modeling* (Norman 1977). Each equation in MACRO is normalized for a different endogenous variable and is split into a constant component and a simulation component:

$$y(i) = f_i(y,z) + c(i)$$

where $y(i)$ is the i^{th} endogenous variable, f_i is the simulation component of the equation, y is the vector of endogenous variables, z is the vector of predetermined variables, and $c(i)$ is the constant component of the equation.

All predetermined (exogenous and lagged endogenous) variables should be coded in *const.f.* The development of productivity $y(26)$ is representative of the variables calculated in this subroutine. The actual nonlinear simulation part of the model is coded in *solve.f,* using the $c(i)$s calculated in *const.f*; an example is the determination of value added in the energy sector $y(49)$. In subroutine *solve.f*, the iterative process of a Gauss–Seidel algorithm is performed, and the subroutines *const.f* and *post.f* are called only once for each time step. After a converging solution has been obtained, SIM calls up subroutine *post.f.* Post-recursive equations are contained in this subroutine, i.e., equations that do not influence the solution of other endogenous equations, but depend on solution values from *solve.f* [e.g., the investment rate $y(13)$].

The subroutines *const.f, solve.f,* and *post.f* are presented below.

```
        SUBROUTINE CONST(y,ex,el)
       common i4,i5,i6,d(150),ia,a(100),i1,i2,pa,z(120),c(60),xnor(60)
     1     ,ibx(60),ca(60),inl(60),b(60),nv1,iy1,ip1,ib1,lab(61),ngr
     2     ,ik(60),test(60),logic(50),xl(65),sim,nvc,ned,nex,nxs,nl
     3     ,max,nt,ned1,nr,date1,date2,lis,title(12),ncol,nit,nvc1
     4     ,maxr,it(60),kset(60),nrr
      real*8 lab,ld,label
      integer date1,date2,error,sim,pa
      logical*1 logic,ltu,lfa
      dimension y(100),ex(100),el(100),tr(2)
c     exp(zzx)=zzx
      data ics/0/
      do 2 i=1,ned1
      xl(i)=-1.0e30
      if(inl(i).gt.0) xl(i)=x(1,i)
2     xnor(i)=1.0
      if(nxs.eq.1) go to 4
      do 3 i=1,nex
      el(i)=-1.0e30
      if(inl(i+ned).gt.0) el(i)=e(1,i)
3     ex(i)=z(i+ned)
4     continue
c
c     change of productivity over planning horizon
      if(z(38).gt.29.and.z(38).le.41.) a(4)=a(4)-.00113
      if(z(38).gt.41.) a(4)=a(4)-.0005
c
      y(26)=(exp(a(4)*z(38)+a(5)))*1.0103                          prod
      if(z(38).gt.29.) y(26)=exp(a(4)*3.)*xl(26)                   prod
      if(z(38).eq.11.) y(59)=29.                                   pr.dom
      if(z(38).gt.11.) y(59)=xl(59)*exp(a(55)*3.)                  pr.dom
c
      if(z(38).le.17.) goto 44
      y(31)=xl(31)*exp(a(38)*3.)                                   p-m.en
      if(z(38).gt.30.) a(38)=a(38)+a(39)                           p-m.en
c
44    c(21)=a(10)*(z(19)-z(20))+a(12)                              labor
      if(z(38).gt.17.) a(11)=a(11)+a(41)                           labor
      b(25)=z(24)*52./1000.                                        mh.tot
c
      if(z(38).gt.23.) a(28)=a(28)+a(44)                           m$.ne
      if(a(28).gt.a(40)) a(28)=a(40)                               m$.ne
      y(41)=a(17)*xl(45)+a(18)                                     dep.re
      c(40)=a(37)*xl(40)                                           k$.en
      if(z(38).gt.17.) y(48)=a(36)                                 p-k
      y(47)=xl(47)                                                 p-l
c
      y(36)=z(33)*14.29*.001                                       e.imp$
      y(57)=z(59)*z(54)*.001                                       do.$df
      y(55)=z(36)*z(31)/z(28)                                      m.e$df
      y(56)=z(55)/z(33)*1000.                                      p-me$d
      y(60)=(z(55)+z(57))/z(12)*1000.                              dummy
      y(51)=z(60)*z(28)/100.                                       p-en$
```

```
c
      a(21)=a(60)                                                       taxdir
c
      logic(2)=.true.
      logic(3)=.true.
      logic(4)=.true.
      logic(5)=.true.
c
      return
      end

      SUBROUTINE SOLVE(y,ex,el)
      common i4,i5,i6,d(150),ia,a(100),i1,i2,pa,z(120),c(60),xnor(60)
     1      ,ibx(60),ca(60),inl(60),b(60),nv1,iy1,ip1,ib1,lab(61),ngr
     2      ,ik(60),test(60),logic(50),xl(65),sim,nvc,ned,nex,nxs,nl
     3      ,max,nt,ned1,nr,date1,date2,lis,title(12),ncol,nit,nvc1
      real*8 lab,ld,label
      integer date1,date2,error,sim,pa
      logical*1 logic,ltu,lfa
      dimension y(100),ex(100),el(100)
c
1     nt=nt+1
c
      y(52)=((z(28)*.01*(z(1)-z(49))+z(34)*z(51)*.001)/(z(1)-z(49)+     gdp-df
     1z(34)*30.4*.001))*100.                                            gdp-df
c
      if(z(38).le.17.) goto 30
      dta=1.+(z(52)-xl(52))/xl(52)
      y(29)=xl(29)*dta                                                  p-x
      y(32)=xl(32)*dta                                                  p-m.ne
30    continue
c
c                          SUPPLY  SIDE
c
      y(21)=a(11)*z(47)+c(21)                                           labor
      y(25)=b(25)*z(21)                                                 mh.tot
      y(11)=z(25)-z(43)                                                 mhre.s
c
c       ITERATIONS' SECTION
c
      if(z(46).gt.z(11).or.z(11).gt.1.05*z(46)) logic(2)=.false.        mh.it
      if(z(46).gt.z(11)) y(47)=1.02*z(47)                               mh.it
      if(z(11).gt.1.07*z(46)) y(47)=.99*z(47)                           mh.it
c
      if(z(34).gt.z(12)) y(51)=1.01*z(51)                               ene.it
      if(z(12).gt.1.01*z(34)) y(51)=.99*z(51)                           ene.it
c
      y(58)=z(51)/z(52)*100.                                            p-e.s$
      b(60)=z(60)-z(58)                                                 diff
c
      if(z(45).gt.z(10)) y(48)=1.01*z(48)                               k.it
      if(z(10).gt.1.01*z(45)) y(48)=.99*z(48)                           k.it
c
c
      y(3)=a(13)*z(1)+a(14)*z(39)+a(15)*z(48)+a(16)                     Inv$
      y(44)=z(3)-z(37)                                                  I$.re
      y(10)=xl(10)+3.*(z(44)-z(41))                                     K$re.s
c
c       CES-function
c
      y(42)=(a(2)*z(12)**(-a(1))+a(3)*(z(26)*z(10)**(1.-a(6))           Y$
     1*z(46)**a(6))**(-a(1)))**(-1./a(1))                               Y$
c
c
c                                  DEMAND  SIDE
c
      r0=z(48)*.01*z(42)**(-a(1)-1.)*z(26)**a(1)/(a(3)*                 gk$.d
     1(1.-a(6)))*z(46)**(a(1)*a(6))                                     gk$.d
      y(45)=r0**(1./(a(1)*a(6)-a(1)-1.))                                gK$.d
c
      t0=z(47)*z(42)**(-a(1)-1.)*z(26)**a(1)/(a(3)*a(6))                mhre.d
     1*z(45)**(a(1)-a(1)*a(6))                                          mhre.d
      y(46)=t0**(-1./(a(1)*a(6)+1.))                                    mhre.d
```

```
c
      ye=.001*z(51)/(z(52)*.01)/a(2)                                    sec.de
      y(34)=ye**(1./(-a(1)-1.))*z(42)                                   sec.de
c
c             TAXES, etc.
c
      y(16)=a(19)*z(52)*z(1)*.01+a(20)                                  taxin
      y(17)=a(21)*z(52)*z(8)*.01+a(22)                                  taxdir
      y(15)=z(2)/z(19)                                                  c/pop
      y(18)=a(23)*(z(20)+z(23))+a(24)*z(15)*z(52)*.01+a(25)             gtr
c
c       IDENTITIES
c
      y(1)=z(42)-z(58)*z(12)*.001+z(49)                                 grp$
      y(7)=z(45)+z(40)                                                  gk$
      y(8)=z(1)-z(41)-c(40)-z(16)/z(52)*100.                            ni$
      y(9)=z(8)-(z(17)-z(18))/z(52)*100.                                yd$
      y(2)=a(42)*z(9)+a(43)                                             c$
      if(z(38).gt.23.) y(2)=z(9)-z(3)+z(41)+c(40)                       c$
c
c       TRADE
c
      y(5)=(a(26)*z(1)*z(52)*.01+a(27))/(z(29)*.01)                     x$
      y(35)=(a(28)*z(1)*z(52)*.01+a(29))/(z(32)*.01)                    m.ne$
      y(6)=z(35)+z(36)                                                  m$
      y(39)=z(5)-z(30)/z(29)*z(6)                                       tb
c
c             Miscellaneous
c
      c(7)=a(54)*z(7)                                                   K$.en
      y(40)=3.*z(37)+xl(40)-3.*c(40)                                    K$.en
      if(c(7).gt.z(40)) logic(3)=.false.                                K$.en
      if(.not.logic(3)) y(37)=(c(7)-a(54)*xl(7))/3.+c(40)               inv.en
      if(.not.logic(3)) y(40)=3.*z(37)+xl(40)-3.*c(40)                  K$.en
      y(49)=z(47)*z(43)+c(7)*z(48)*.01                                  va$.en
      y(50)=z(40)-c(7)                                                  adj.Ke
c
      y(22)=z(21)-z(23)                                                 ocpop
      y(23)=(z(11)-z(46))*1000./(52.*z(24))                             unempl
      y(4)=z(1)-z(2)-z(3)-z(5)+z(6)-b(37)                               g$
      if(logic(2)) y(47)=z(1)*(1.-a(6))/(z(46)+z(43))                   w*
      y(30)=(z(35)*z(32)+z(36)*z(31))/(z(35)+z(36))                     p-m
      if(.not.logic(5)) goto 31                                         d-in.e
      b(37)=z(37)-.08*z(3)                                              d-in.e
      if(b(37).gt.0.) logic(4)=.false.                                  d-in.e
      if(.not.logic(4)) a(58)=a(21)+a(59)                               d-in.e
      if(.not.logic(4)) tt1=b(37)*z(52)/100.                            d-in.e
      if(.not.logic(4)) tt2=tt1-(a(58)-a(60))*z(52)*z(8)*.01+a(22)      d-in.e
      if(.not.logic(4)) a(21)=a(58)                                     taxdir
      if(tt2.le.0.) logic(5)=.false.
31    logic(4)=.true.
c
      if (nt.lt.nit) go to 1
      return
      end

      SUBROUTINE POST(y,ex,el)
      common i4,i5,i6,d(150),ia,a(100),i1,i2,pa,z(120),c(60),xnor(60)
     1      ,ibx(60),ca(60),inl(60),b(60),nv1,iy1,ip1,ib1,lab(61),ngr
     2      ,ik(60),test(60),logic(50),xl(65),sim,nvc,ned,nex,nxs,nl
     3      ,max,nt,ned1,nr,date1,date2,lis,title(12),ncol,nit,nvc1
      real*8 lab,ld,label
       integer date1,date2,error,sim,pa
      logical*1 logic,ltu,lfa
      dimension y(100),ex(100),el(100)
c
      y(27)=((z(16)+z(17)-z(4)*.01*z(52)-z(18)))/(z(52)*.01)            surplus
      y(3)=z(3)+b(37)                                                   inv$.a
      y(13)=z(3)/z(1)                                                   i/gnp
      y(14)=z(2)/z(1)                                                   c/gnp
c
      if(sim.ne.2) goto 1
1     return
      end
```

The Fortran routines contain coefficients and numbered variables. The corresponding variable names and the coefficients' values are given below.

a vector

1	1.5754	2	0.0671	3	0.8970	4	0.0295	5	−0.1542
6	0.6606	7	0.0000	8	0.6724	9	31.9003	10	−0.3016
11	7.7450	12	159.7051	13	0.1763	14	0.7058	15	13.7946
16	−106.1501	17	0.0424	18	−28.6982	19	0.1062	20	16.9305
21	0.3311	22	−14.0093	23	2.6369	24	82.1011	25	−87.3376
26	0.2950	27	−0.2471	28	0.2394	29	−25.8946	30	0.9092
31	0.0470	32	0.8107	33	0.1456	34	0.6577	35	0.0232
36	9.4000	37	0.0300	38	0.1000	39	−0.0050	40	0.2750
41	−0.3000	42	0.8357	43	−1.1792	44	0.0016	45	0.6000
46	−0.0083	47	0.0210	48	0.0125	49	−0.0008	50	0.0244
51	0.0010	52	−0.0050	53	0.1000	54	0.0703	55	0.0300
56	−0.0011	57	−0.0005	58	0.0000	59	0.0010	60	0.3311
61	0.0000	62	0.0020	63	0.2950				

num	name	test	kset	lag	ibx	no	iy	ip	ib
1 e	grp$70	0.010	1	1	1	6	0	1	1
2 e	c$70	0.010	2	0	3	6	0	1	1
3 e	inv$70	0.010	3	0	4	6	0	1	1
4 e	g$70	0.010	4	0	5	6	0	1	1
5 e	x$70	0.010	5	0	6	6	0	1	1
6 e	m$70g	0.010	6	0	7	6	0	1	1
7 e	gk$70	0.010	7	1	8	6	0	1	1
8 e	ni$70	0.010	8	0	10	6	0	1	1
9 e	yd$70	0.010	9	0	11	6	0	1	1
10 e	gk$re.s	0.010	10	1	12	1	2	1	1
11 e	mhre.s	0.010	11	0	14	1	0	1	1
12 x	sec.sup	0.010	12	1	15	6	0	1	1
13 e	i/grp	0.010	13	0	17	6	0	1	1
14 e	c/grp	0.010	14	0	18	6	0	1	1
15 e	c/pop	0.010	15	0	19	6	0	1	1
16 e	taxin	0.010	16	0	20	6	0	1	1
17 e	taxdir	0.010	17	0	21	6	0	1	1
18 e	gtr	0.010	18	0	22	6	0	1	1
19 x	pop	0.010	19	0	23	24	0	1	1
20 x	pop>65	0.010	20	0	24	24	0	1	1
21 x	labor	0.010	21	0	25	6	0	1	1
22 e	ocpop	0.010	22	0	26	6	0	1	1
23 e	unempl	0.010	23	0	27	6	0	1	1
24 x	hours/w	0.010	24	0	28	22	2	1	1
25 e	mh.tot	0.010	25	1	29	4	2	1	1
26 e	prod	0.010	26	1	31	1	0	1	1

27 e	surpl	0.010	27	0	33	1	0	1	1
28 x	p-va	0.010	28	1	34	24	0	1	1
29 x	p-x	0.010	29	1	36	6	0	1	1
30 e	p-m	0.010	30	0	38	6	0	1	1
31 x	p-m.en	0.010	31	1	39	6	0	1	1
32 x	p-m.ne	0.010	32	1	41	6	0	1	1
33 x	m-en	0.010	33	1	43	24	0	1	1
34 e	sec.dem	0.010	34	1	45	6	0	1	1
35 e	m$70-ne	0.010	35	0	47	6	0	1	1
36 e	m$70-en	0.010	36	0	48	1	0	1	1
37 x	inv$.en	0.010	37	1	49	6	0	1	1
38 x	time	0.010	38	0	51	24	0	1	1
39 e	eb	0.010	39	0	52	6	0	1	1
40 e	k$.en	0.010	40	1	53	6	0	1	1
41 e	dep$.re	0.010	41	0	55	6	0	1	1
42 e	y$70	0.010	42	0	56	5	1	1	1
43 e	mh.en	0.010	43	1	57	4	2	1	1
44 e	inv$.re	0.010	44	0	59	6	0	1	1
45 e	gk$.re	0.010	45	1	60	6	0	1	1
46 e	mhre.d	0.010	46	0	62	4	2	1	1
47 e	w-rate/p	0.010	47	1	63	4	2	1	1
48 e	r/p	0.010	48	1	65	22	2	1	1
49 e	va$.en	0.010	49	1	67	6	0	1	1
50 x	adj.ke	0.010	50	1	69	1	0	1	1
51 x	p-en$	0.010	51	1	71	23	1	1	1
52 e	grp-def	0.010	52	1	73	7	0	1	1
53 x	prim.en	0.010	53	1	75	24	0	1	1
54 x	dom.en	0.010	54	1	77	6	0	1	1
55 x	m$-e.df	0.010	55	1	79	6	0	1	1
56 x	p-e.m$df	0.010	56	1	81	1	0	1	1
57 x	do.e$df	0.010	57	1	83	1	0	1	1
58 x	p-e.s$df	0.010	58	1	85	1	0	1	1
59 x	p-e.do$d	0.010	59	1	87	1	0	1	1
60 x	dummy	0.010	60	1	89	1	0	1	1

NOTE TO THE APPENDIXES

a Denmark, Ireland, and the United Kingdom joined the EC after 1960.

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