E N E R G Y   A N D   E C O N O M I C   G R O W T H   I N   S W E D E N

An Analysis of Historical Trends and Present Choices

by

Lars Bergman

Foreword

Late in 1973 the (Swedish) Energy Forecasting Commission initiated development of an econometric model at the Economic Research Institute (EFI) at the Stockholm School of Economics to be used in forecasting energy consumption. It became my privilege to carry out the project, in cooperation with Clas Bergström and Anders Björklund. Professor Karl-Göran Mäler, at that time a member of the Commission, was to be responsible for the project and to serve as adviser. A first version of the Energy Forecasting Model (EFM) was completed in the spring of 1976. The present study, which is an outgrowth of the work with EFM and wider in scope, uses EFM as a tool in analyzing energy policy issues.

When work on EFM was started in 1973 energy policy was not the controversial subject it is today. The present-day debate has largely focused on the pros and cons of nuclear power. The very considerable public interest in this particular issue has led me to put a number of nuclear power policy alternatives and the choice between them at the center of analysis in this study. However, this does not necessarily mean that I regard choice of technology in the power generating sector as the only or most important energy policy issue in Sweden at the present time.

I have expected that potential readers of this book have a wide variety of professional backgrounds and are willing to allocate quite different amounts of time on it. This poses a problem of presentation which has been solved in two ways. First, in order to make the study self-contained some material has been included, especially in Chapter 3, which is quite well-known to economists, but presumably not to others. Second, presentation of EFM is kept entirely within Part II. Also, the model's data base is presented in Part II, while the specific assumptions made in this study are presented in Part III. Chapter 11 contains a summary of the main results and conclusions arrived at in the study.

My work with this study has benefitted greatly from good advice and critical comments by professors Karl G. Jungenfelt and Karl-Göran Mäler. I am very grateful for their support and encouragement. I also wish to thank Tomas Restad and Olle Djerf as well as several other participants at seminars at the Stockholm School of Economics where a preliminary version of this book was discussed. Needless to say I am solely responsible for all remaining errors.

Clas Bergström made extraordinary efforts when the simulations using EFM were carried out. To him I am very grateful, as well as to Georg Saros for research assistance during various phases of the project. In the preparation of Chapter 2 I benefitted from my work at the Secretariat for future studies and cooperation there with Bo Diczfalusy and Harry Flam.

I also want to express my gratitude to Margareta Blomberg and to Siv Jonsson, Kerstin Niklasson and Monica Peijne who have typed the many versions of this book. Julie Sundqvist has been faced with the arduous task of correcting and simplifying my English. Language errors in the final version of the text are results of my own last-minute changes. Rune Castenäs and the staff of EFI and of the Stockholm School of Economics provided support in many practical matters.

Financial support for this study has been given by Riksbankens Jubileumsfond, which is gratefully acknowledged.

Finally, my debt to my wife Lena and daughter Malin is substantial. They provided me with an optimum mix of encouragement and disturbance during the years when EFM practically was a member of our family.

Stockholm, February 1977

Lars Bergman

CONTENTS

PART I

THE BACKGROUND

1. INTRODUCTION

1.1 Goals and Constraints in Swedish Energy policy

Since the turn of the century Swedish energy policy has been governed by two basic ideas. One is that cheap energy is an important factor in promoting economic growth. The other is that there are risks connected with high dependence on foreign suppliers of energy.

These ideas have sometimes been in conflict with each other, sometimes not. For instance, the utilization of Sweden's large water power resources provided industries and households with cheap electricity. At the same time dependence on imported fuels was reduced. On the other hand, the transition from solid fuels to oil meant a transition from relatively expensive to relatively cheap fuels, and also a transition from domestic to imported fuels.

However, the concept of a coordinated "energy policy" is fairly recent in the Swedish political sphere. The term was not used in official statements until 1969.[1/] At that time the Minister of Industry formulated the goals of Swedish energy policy in the following way:[2/]

> "That sufficient amounts of energy, in forms which are adapted to the demand for energy, are put at the disposal of the consumers with a minimum of social cost and due consideration to the side-effects on preparedness, security, environment and health."

The implication of this statement is that the most economically competitive energy resources and energy transformation technologies should be used as long as their side-effects were not too severe.

1/ Before that, issues related to the supply and demand of energy were a matter of either "water power policy" or "fuel policy". The purpose of the former was the rapid and efficient utilization of the country's water power resources, while the latter aimed at reducing Sweden's dependence on imported energy by replacing imported coal with domestic fuels. See Lundgren (36).

2/ Wickman (52).

The term "due consideration", however, was never explicitly defined. The same applies to trade-offs between the various side-effects. The preferences of the politicians were nevertheless clearly revealed by the actual post-war development of Swedish energy production and consumption.

The Swedish economy experienced a fairly high rate of GNP growth during the first three post-war decades. The growth of Sweden's energy consumption was even faster. This led to rapid expansion of the energy supply system which, however, was by no means uniform. Coal and domestic solid fuels were replaced by imported oil and the output of electricity grew faster than the total output of energy. Electricity generation capacity was increased through investments in hydro power plants. Some figures indicating how the Swedish energy supply system was restructured are shown in Table 1.1. It should be noted that Table 1.1 only gives a very brief survey of the development of the Swedish energy balance. Chapter 2 is devoted to a more detailed description and analysis of this development.

As can be seen in Table 1.1 the share of oil, entirely imported, in the Swedish energy balance increased dramatically during the 1950s and the 1960s. Moreover, the share of electricity in the total consumption of secondary energy increased markedly. On the basis of Table 1.1 it seems as if Swedish energy policy was to a large extent directed towards ensuring the supply of low-cost energy without quantitative restrictions. The benefits from cheap oil seems to have been considered more important than the risks associated with a continued and increased dependence on imported energy.[1/] Further, the vast exploitation of water power resources can be regarded as a revealed preference for cheap electricity at the expense of environmental aspects.

1/ In fact, the original plans for investments in nuclear energy were based on concern for Sweden's dependence on other countries with respect to energy supply. However, the main point was that construction of heavy water nuclear power plants would convert Swedish uranium deposits into usable domestic energy resources without intermediate enrichment abroad. When this technology turned out to be considerably more expensive than expected, the plans were reformulated and directed towards light water reactors fueled with imported enriched uranium. This, again, indicates a significant preference for cheap energy at the expense of other considerations.

Table 1.1 The Swedish energy supply system, selected figures, 1950 and 1972.

	1950	1972
Total consumption of energy, TWh	146	448
Share of (imported) oil in Sweden's energy balance, %	29	75
Share of electricity in the consumption of secondary energy	12	18
Share of domestic hydro power production in domestic electricity generation, %	95	75
Exploited water power resources in relation to economically available water power resources, % 1/	21	78

Sources: Ds Fi 1967:8. Rapport rörande Sveriges energiförsörjning 1955-1985.

SOU 1974:64. Energi 1985-2000.

As exploitation of available water power increased planning for the next era of Sweden's electricity production began. As in many other countries nuclear power was expected to become an efficient technology for producing cheap electricity. Accordingly vast nuclear power investment plans were formulated.2/ Moreover the existing laws were changed so as to permit electric heating and thereby increase the use of electricity.3/

1/ In SOU (62) the maximum amount of exploitable water power resources in Sweden is estimated to be 200 TWh per annum. Of these, 85 TWh were considered economical in 1972, but 15 TWh were reserved for environmental reasons. In 1974, after the oil price increase, the figures were revised and 95 TWh water power were considered economical.

2/ See CDL (55).

3/ See Lundgren (36).

In the beginning of the 1970s the energy scene changed dramatically. The founding of OPEC changed the structure of the international oil market which culminated in the "oil crisis" of 1973-74. Doubts about the safety and profitability of nuclear power became increasingly widespread. With such a large share of imported oil in her energy balance and vast nuclear power investment plans, the preconditions for Sweden's energy policy were changed and the energy policy became a matter of prime political importance.

The problem now facing the energy policy makers can be split into three sub-problems, namely:

i) a supply problem;
ii) a problem of national independence;
iii) an environmental problem.

That is, the "energy problem" still has the elements quoted above, but the relative importance of the latter two sub-problems is much higher now than it was one or several decades ago.

In the spring of 1975 the former Swedish government presented the general principles for a new energy policy.[1/] One of the basic ideas in the government's proposal is that the energy field is beset by a number of important uncertainties. This refers not only to nuclear power technology in particular, but also to other supply options. In addition it applies to the markets for oil and nuclear fuel both in terms of prices and supply reliability.

Due to these circumstances it was not considered possible, or desirable, to formulate a detailed long-term plan for the development of Sweden's energy supply system. Instead, the energy policy is formulated on the explicit assumption that it will be revised as soon as the results from a number of studies about energy supply option and energy conservation possibilities, initiated in 1975, become available. The first revision is expected to take place in 1978.

1/ Regeringens proposition 1975:30, Energihushålling m m.

As a consequence of this approach, the energy policy decisions made today should put as few constraints as possible on the future set of feasible energy policy strategies. This can be called the principle of "freedom of action".

In order to attain a high degree of "freedom of action", energy policy is aimed at reducing the rate of growth of energy consumption. Thus, the official goal is that total consumption should grow by no more than 2% per annum between 1973 and 1985 and that no growth at all should occur after 1990.[1/] But the market share of electricity, is expected to grow. Thus consumption of electricity is expected to increase by approximately 6% per annum between 1973 and 1985.[2/] The realization of these goals implies that the growth of oil consumption has to be very limited.

However, according to the former government's proposal, both the attempts to attain a high degree of freedom of action in the choice between energy policy strategies, and the long term energy policy finally chosen are subject to an important constraint: neither of the policies should conflict with the realization of important social goals.

Examples of such goals, explicitly mentioned, include not only a safe environment, national security and indepedence, but also high employment and continued economic development. The concept of "continued economic development" refers to increased welfare and security for less-privileged groups.[3/] Since there is no mention of reductions in the material standard of other groups, this constraint can be interpreted as a requirement that energy policy should not be in marked conflict with continued GNP growth. This requirement, in turn, can be transformed into a constraint on supplied quantities and supply prices of energy.

1/ The post-war average has been about 5% per annum.

2/ The post-war average has been about 7% per annum.

3/ Energihushållning op.cit. p. 12.

Neither of the constraints on energy policy is quantified in the governments proposal, nor are there any indications about the trade-offs between the different constraints. However, the growth constraint is fairly easy to quantify. Further, there are well established expectations about the rate of economic growth.[1/] Thus, at least for the next decade, an energy policy which is likely to lead to a negative rate of economic growth is not feasible. In other words the economic growth constraint is likely to rule out many more energy supply options than the environmental or national independence constraints.

To sum up, the purpose of the "new" energy policy is to maximize the freedom to choose among different energy policy strategies subject to environmental (including health and safety), national independence and economic growth constraints.

To the extent that this interpretation of the "new" Swedish energy policy is valid, it points to an important problem inherent in this policy: What is the relation between a given economic growth constraint and the degree of freedom to choose among presently existing energy supply technologies? Will there be any degree of freedom in this choice at a given positive rate of economic growth? Or can we choose any of the known energy supply technologies and still maintain a positive rate of economic growth?

The answers to these questions will to a large extent determine the possibilities of carrying out a "new" energy policy, that is, an energy policy which is not primarily directed towards energy cost minimization.

The relation between economic growth and the choice of energy policy strategy depends primarily upon the following two sets of factors:

---

1) For instance, in the medium term projection by the Ministry of Finance (SOU, (64)), various social reforms which have already been decided are transformed into economic growth requirements.

i) the differences between various energy supply options in terms of the cost of the energy that is produced;

ii) the substitutability of different kinds of energy, of energy and other factors of production and of energy intensive and less energy intensive products.

Consider as an illustration a closed economy where, in the choice between two energy production technologies, the more expensive (in terms of private costs) is chosen. This means that as compared to a case where the other technology had been chosen, energy prices will be higher. As a result, for all products where energy is a direct or an indirect factor of production, the supply prices will increase, The prices of energy intensive products will increase most. This will tend to reduce the demand for energy intensive products, which in turn will stimulate the producers of energy intensive products to change their methods of production in a less energy intensive direction.

The final result of the adjustment process is that both final consumption patterns and the production methods have become less energy consuming. Further the general level of prices will be somewhat higher than would have been the case if a cheaper energy production technology had been used. In other words, since more resources are used for energy production, less resources can be used for consumption. Finally, the higher energy prices result in a lower level of energy consumption.

This illustration shows the strategic role of the above mentioned factors in the relation between the choice of energy production technology and the rate of economic growth. If the different supply options yield approximately the same supply prices of energy, the choice of energy production technology can be made without taking economic growth objectives into consideration. The same applies if energy can easily (cheaply) be replaced by other factors of production and energy intensive products by less energy intensive products. However, if the differences between the alternatives, in terms of energy supply prices, are substantial and/or energy can be replaced by other factors of production only with great difficulty, the choice of energy supply technology is strategic from an economic growth point of view.

1.2 The Purpose and Scope of the Study.

This study can be seen as a first step towards an analysis of different energy policy strategies from an economic growth point of view and thereby a first attempt to analyze of the possibilities of implementing a "new" energy policy in Sweden. The purpose of the study is to evaluate the flexibility of present energy supply and demand patterns in Sweden. Thus, we concentrate on an analysis of the substitutability of different kinds of energy and of energy and other factors of production. Another important aspect is the relation between specific energy policy strategies and energy supply and demand patterns.

The time horizon of the study is the "medium term". This means that the analysis is confined to a time period which is short enough to exclude the possibility that important new energy supply options will become available. On the other hand, the time period is long enough to permit a complete adjustment to changes in energy prices and various energy policy measures. All kinds of structural problems connected with unexpected changes in energy prices or energy policy are disregarded. Further, by concentrating on presently existing energy supply options, the long term relations between energy supply and economic growth are more or less neglected. However, in Chapter 3 a brief survey of the long term perspectives is made.

We noted above that the Swedish "energy problem" has three aspects: the supply aspect, the national independence aspect and the environmental aspect. Even if none of these should be treated separately without due regard to the others, this study is almost entirely confined to the supply aspect. The rationale for this lies in our interpretation of the prospects of the "new" Swedish energy policy; the economic growth constraint is likely to be efficient in more cases than the other constraints.

In the previous section it was proposed that the relation between the choice among different energy policy strategies and the rate of economic growth is to a large extent determined by two sets of factors:

i) the cost differences between various energy supply options;
ii) the substitutability of different kinds of energy, of energy and other factors of production and of energy-intensive and less energy-intensive products.

All aspects of these issues obviously cannot be dealt with in a single study. We therefore confine ourselves to the following three issues:

i) the cost differences between a number of alternative organizations, in terms of plant structure, in the electricity and heat production sector;

ii) the substitutability of different kinds of energy and of energy and capital in the residential heating sector;

iii) the sensitivity of the composition of the final demand for goods and services to energy price variations, and the resulting changes in the demand for energy.

These specific problem areas were not chosen arbitrarily. Considering the role of nuclear power in the Swedish energy policy controversy, the first point cannot be avoided. Moreover, an analysis of the heating sector requires a simultaneous analysis of the entire energy production system.

Since space heating can be achieved with low temperature heat, all kinds of energy can be utilized for heating purposes. The energy requirements of a given building at given indoor and outdoor climatic conditions are determined to a large extent by the degree of insulation. In other words, energy and capital are substitutes in this sector. Accordingly, the organization of the residential heating sector has a significant impact on both the size and the structure of the energy supply sector as a whole.

The rationale behind the third point is explained in detail in Chapter 2, where it is shown that changes in the composition of the final demand for goods and services have had an important impact on the growth of energy consumption in Sweden.

1.3 The Plan of the Study

The plan of the study is as follows. The post-war development of Sweden's energy consumption is described and analyzed in Chapter 2. The discussion is focused on the relation between Sweden's GNP and her consumption of energy, that is, the energy intensity of Sweden's GNP. The factors underlying the observed development of the energy intensity of Sweden's GNP are identified and explanatory hypotheses are proposed.

The present study primarily deals with the development of energy consumption patterns at given assumptions about the growth of the economy and the prices of energy resources. In a more elaborate study the growth of the economy, energy supply conditions and energy consumption patterns should be regarded as interdependent phenomena. Thus, a discussion about these interdependencies is needed as a background for the present study. Chapter 3 is devoted to a brief discussion about the factors behind the long-run development of the prices of energy resources, and how changing energy prices affect the growth of the economy.

This study is carried out primarily on the basis of a numerically formulated model of the Swedish economy. The choice of model is motivated in Chapter 4. That chapter also contains a discussion of some theoretical aspects of the model. The empirical version of the household consumption demand model used in this study is discussed as well.

The model presented in Chapter 4 is constructed as a set of interrelated submodels. In Chapter 5, 6, and 7 the three submodels of particular interest for this study are discussed in greater detail. Thus, Chapter 5 deals with a model of all sectors which produce non-energy commodities (steel, paper, etc.) Chapter 6 treats a model of the Swedish electricity and heat supply sector, while a model of the Swedish residential heating sector is dealt with in Chapter 7.

Results from simulations with the model system are presented and discussed in Chapters 8, 9 and 10. In Chapter 8 four alternative strategies for the future nuclear power policy in Sweden are formulated. Under the assumption of given demands for electricity and heat the impact of each of these policy alternatives on the power and heat production sector is analyzed. The attention is focused on the choice of technology and the development of electricity and heat prices.

Chapter 9 deals with the results obtained from simulations using the residential heating system model. It is shown how the profitability of different residential heating options, and thus the total energy demand for residential heating purposes, is affected by price variations for energy and energy conservation equipment. The allocation of energy conservation investments between different kinds of residences is also discussed. Moreover Chapter 9 deals with the impact on the residential heating sector of the above mentioned alternatives for the future nuclear power policy in Sweden.

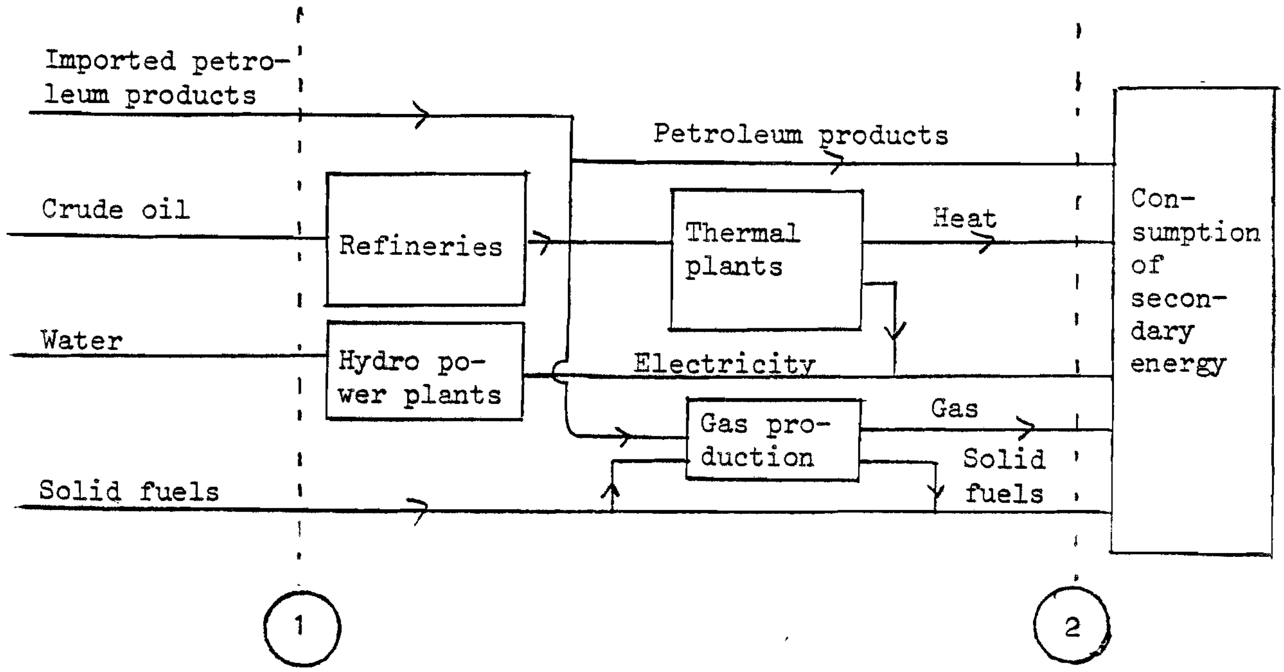
In Chapter 10 the attention is focused on the relation between the composition of final consumer demand and the demand for energy. Thus, in a first step the changes of commodity prices in response to assumed changes of energy prices are estimated. By means of the model of the household sector's demand for commodities, the estimated price-changes are transformed into changes of the quantities demanded. Then, by means of the model of the production sectors, the changes in final demand for commodities are transformed into changes in the demand of energy.

Chapter 11 contains a summary of the main results of the study. In addition some conclusions about the flexibility of the energy consumption patterns are drawn. It is also discussed how the approach adopted in this study can be used in studies of other problems related to Sweden's energy policy than those analyzed in this study.

2. ENERGY IN POST-WAR SWEDEN: HISTORICAL DEVELOPMENT

The purpose of this chapter is to present and analyse the development of Sweden's consumption of energy during the first two and a half post-war decades. Section 2.1 deals with large aggregates such as GNP and total energy consumption. In section 2.2 a brief comparison of Sweden and some other industrialized countries with respect to the consumption of energy is carried out. In section 2.3 the consumption of energy is assigned to different components of GNP and in section 2.4 input-output analysis is used for a decomposition of the observed changes of energy consumption in Sweden. The chapter ends with a discussion about some explanatory hypotheses about the observed growth of the consumption of energy in Sweden.

Throughout the consumption of energy is expressed in physical terms. Thus it is necessary to mention a few words about the problems of measurement in energy analysis.[1/] The discussion is confined to the difference between the concepts "primary energy" and "secondary energy" and the problems connected with the aggregations of different kinds of energy sources



1/ See for instance Johansson - Lönnroth, (31).

By means of the simple flow diagram above, the meaning of the concepts "primary" and "secondary" energy used in this study can be clarified.

If the flow of energy is measured at point 1 we talk about "primary energy", while we use the concept "secondary energy" when the measurement is carried out at point 2. For a single country imported petroleum products can be regarded as primary energy, but from a global point of view petroleum products are always a kind of secondary energy.

The difference between primary and secondary energy is the conversion losses in the energy sector. The problem is, however, that electricity can be produced by means of different kinds of primary energy, and the conversion losses in the electricity sector depends on the kind of primary energy used in the production process. Thus, at a given level and composition of secondary energy consumption, the consumption of primary energy can attain many different levels.

One way to circumvent this problem is to set the energy value of water power and uranium equal to the thermal content of the amount of oil that had been needed in order to produce the amount of electricity actually produced in hydro and nuclear power plants. In this way the consumption of secondary energy will always be a constant fraction of the consumption of primary energy, but the consumption of primary energy will be overestimated. This approach, however, has not been utilized in this study. Thus, in the statistics presented in section 2.1 the changing share of conversion losses reflects the changing composition of Swedens' primary energy consumption.

All kinds of secondary (and primary) energy can be measured in a common unit such as kWh. Thus, different kinds of secondary energy can, seemingly, be aggregated. However, different kinds of energy very often represents different qualities of energy. One kWh of electricity has many potential uses such as for lighting, mechanical work and heating, while one kWh 20°C water has very few uses. Moreover, when one kWh of electricity is used in a process, such as lighting, that process yields both light and one kWh heat as output; energy can never be destroyed, only degraded.

Thus, the laws of thermodynamics limit the substitutability of different kinds of energy. This means that the analysis should be carried out in terms of "free energy" which is a concept that take the quality of the energy into account. Nevertheless, in this study the discussion is carried out in terms of "energy" and the quality problem is disregarded.

2.1 The Increased Energy Intensity of Sweden's GNP

In 1950 the total consumption of primary energy in Sweden was 146 TWh.[1/] Twenty-two years later, in 1972, the corresponding figure was 448 TWh. This means that the average annual growth of primary energy consumption was 5.1% during this period. However, there were substantial yearly variations in the growth rate of energy consumption. Most of these yearly variations can be explained by climatic conditions; that is, the average winter temperature and the amount of rainfall.

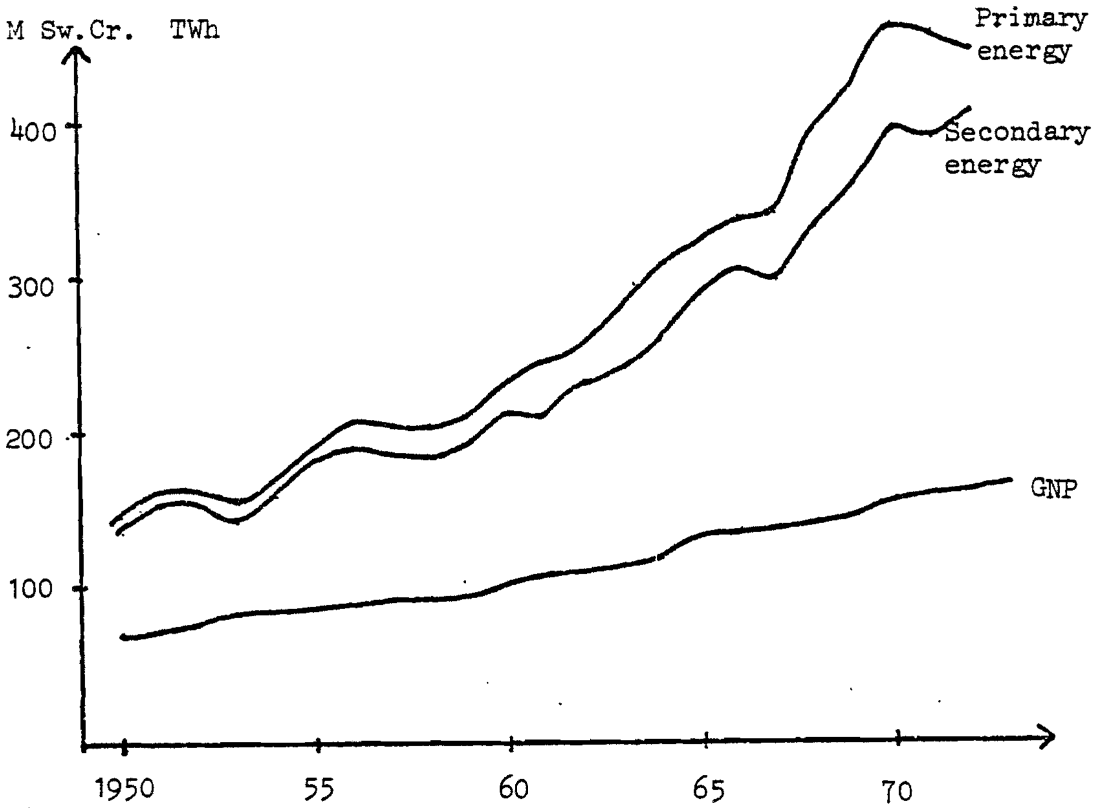
The increase in primary energy consumption is, of course, to a large extent a result of the growth of Sweden's GNP. However, the average annual rate of GNP growth was only 3.6% during this period. It follows that the average content of primary energy per unit of GNP grew between 1950 and 1972; see in Diagram 2.1.

Diagram 2.1 also reveals that the consumption of secondary energy grew somewhat more slowly than the consumption of primary energy, although still faster than the GNP. Thus, the increased energy intensity of Sweden's GNP is only to some extent the result of greater losses in the energy transformation sector. The small increase in energy transformation losses that actually occurred can be explained by the enlarged share of thermal power plants in total electricity generation. Another explanation is the increased share of domestically refined products in the total domestic supply of petroleum products.[2/]

1/ 1 TWh = 10^3 GWh = 10^6 MWh = 10^9 kWh

2/ Between 1965 and 1970 the share of domestically refined products in the total supply of petroleum products rose from 21.2% to 39.2%.

Diagram 2.1 GNP and the consumption of primary and secondary energy in Sweden, 1950-1970. Millions (1968) of Sw Cr and TWh.



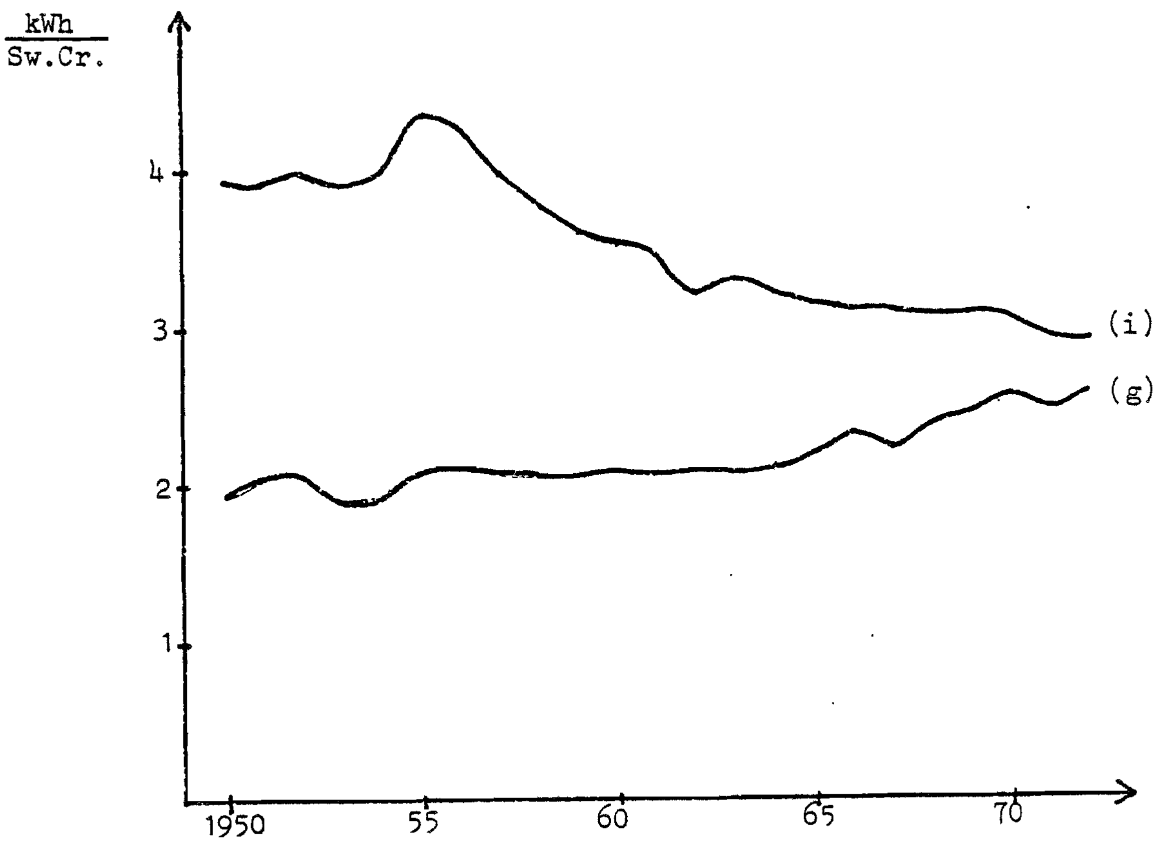
Sources: En bok om olja, Svenska Petroleum Institutet, Stockholm 19 .
SOS, Industri 1950-73.
Statistisk Årsbok 1950-74.

In contrast to the increased energy intensity of Sweden's GNP, the corresponding figure for industrial output has been declining during the post-war period. This is shown in Diagram 2.2. The decline in the energy intensity of Swedish industrial output has been accompained by an increase in the share of industrial output in the GNP. As a result, the share of industrial energy consumption in Sweden's energy balance has been almost constant over a long period.[1/] Consequently, changes in

1/ The industrial share of total secondary energy consumption is slightly more than 40%.

industrial consumption of energy have not affected the energy intensity of Sweden's GNP upwards or downwards.[1/] That is, the increased energy intensity of Sweden's GNP is due to greater energy consumption in non-industrial sectors.

Diagram 2.2 Energy intensity of Sweden's GNP (g) and industrial output (i), 1950-1970. kWh/(1968) Sw.Cr.

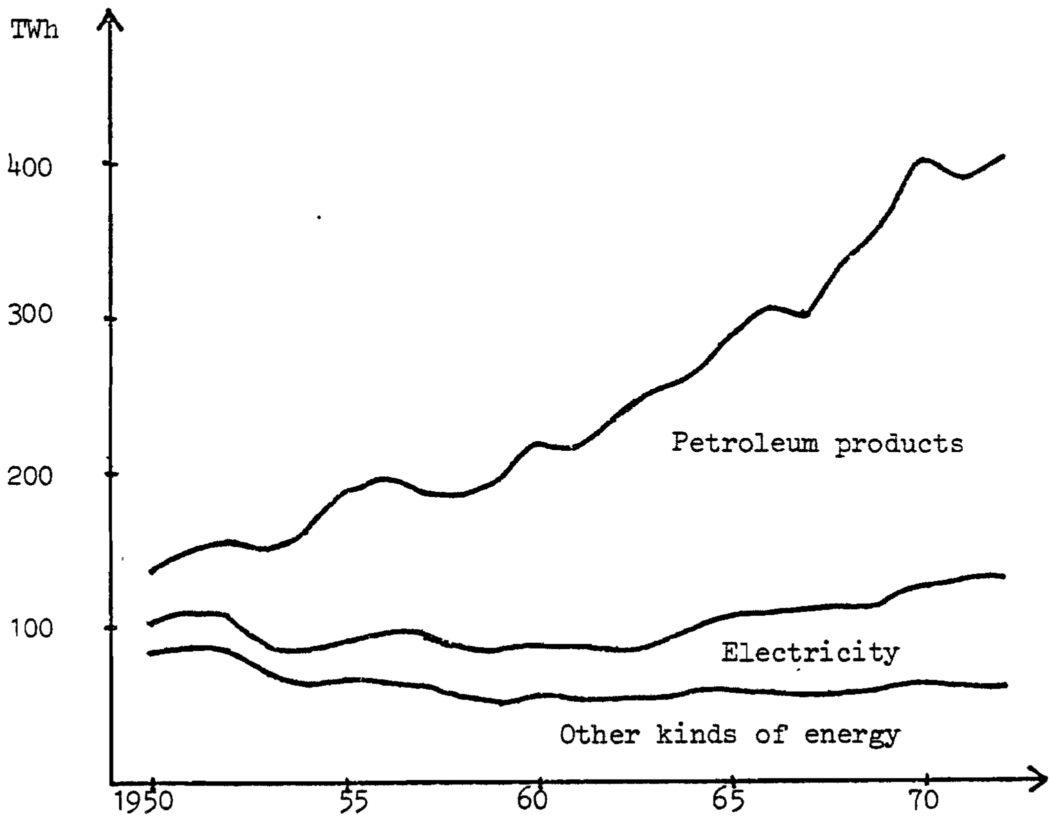


Sources: See Diagram 2.1.

1/ As can be seen in Diagram 2.2, industrial output is in general more energy intensive than the GNP as a whole.

The rapid growth of energy consumption has been accompanied by dramatic changes of the market shares of various kinds of energy. The total consumption of primary energy grew on an average of 5.1% annually, but the corresponding figure for petroleum (crude oil and refined products) was 9.5%. Further, between 1950 and 1972 the growth of the total consumption of secondary energy averaged 4.8% per annum, while the corresponding figures were 8.7%[1/] for petroleum products and 6.7% for electricity. The market shares of different kinds of secondary energy are shown in Diagram 2.3.

Diagram 2.3 Shares of different kinds of secondary energy in the Swedish energy market, 1950-1970. TWh



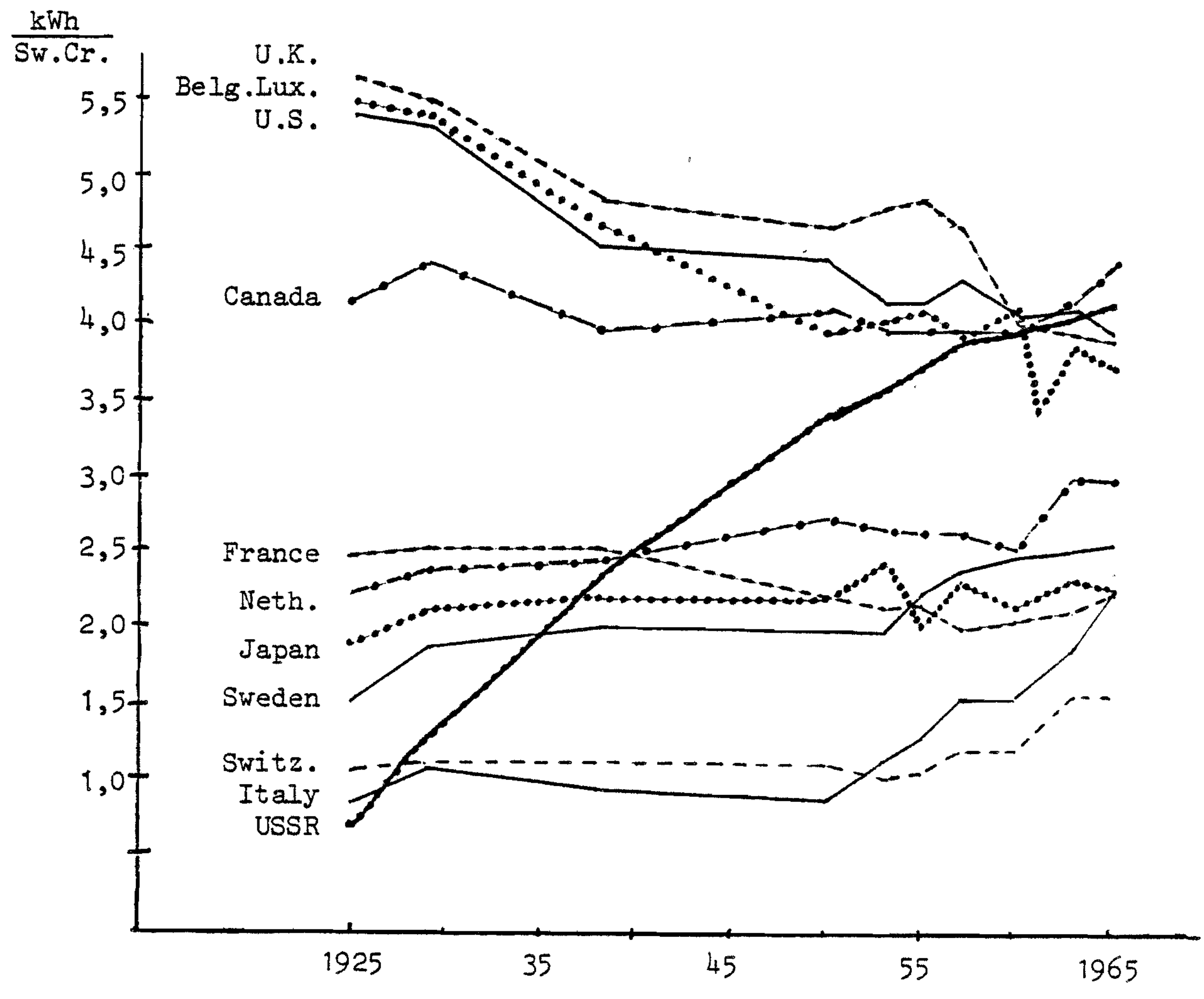
Sources: See Diagram 2.1.

1/ The difference between 9.5% and 8.7% per annum reflects the increased share of losses in the energy transformation sector.

2.2 A Comparison between the Development in Sweden and Other Industrialized Nations

A comparison with other industrialized nations will provide the necessary international context for continuing our discussion of the development of the Swedish energy consumption; see Diagram 2.4.

Diagram 2.4 Trends in the ratio of energy consumption to GNP, 11 selected countries, 1925-1965. KWh and 1965 Sw.Cr.



Source: Darmstadter, J.: Energy in the World Economy, RfF, Baltimore and London, 1971, p. 72. The diagram is plotted on the following benchmarks: 1925, 29, 38, 50, 53, 55, 60, 63, 65. The figures are converted from kg. coal equivalents and U.S. $.

The diagram shows that the energy intensity of Sweden's GNP increased sharply during the late 1920s, remained approximately stable between 1930 and 1950, and then started to increase again. It is also clear from the diagram that, in terms of energy intensity of GNP, many industrialized countries have followed approximately the same path as Sweden. However, there are also countries that have developed quite differently in this respect. Thus, there does not seem to be any universal "law" of increasing energy intensity of GNP.

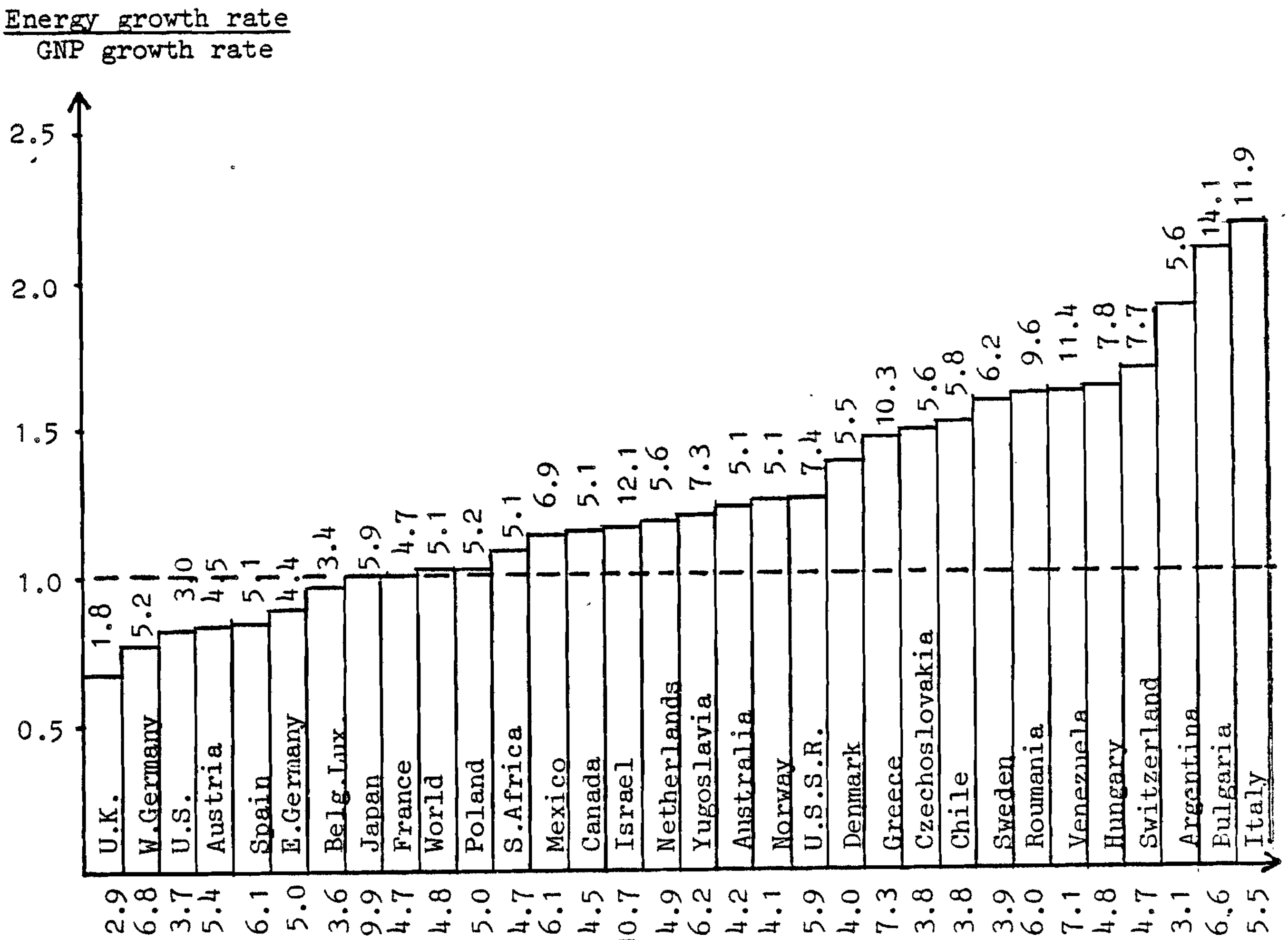
Diagram 2.4 also reveals substantial differences between countries in terms of the level of GNP energy intensity. These differences would have been even more pronounced if some less developed countries had been included in the comparison. However, the differences in terms of energy intensity levels between the countries to a large extent depend on the exchange rates which are used for the conversion of the national currencies to U.S. dollars. For instance, in a study by Parent[1/] where the exchange rates prevailing in 1972 were used, Sweden and the U.S. had almost equal energy intensity of GNP.

It can be seen in Diagram 2.4 that for the industrialized countries covered by the diagram there is a tendency towards convergence in GNP energy intensity. This tendency towards international convergence of the energy intensity of the GNP is not surprising. It is likely that a number of decades ago the comparative advantages of different countries were to a large extent determined by differences in natural resource endowments. The energy intensity of a country's GNP used to be determined largely by the amounts of energy needed to exploit the resources traded by the country in question. As time passed the comparative advantages of the various countries became more differentiated. Moreover, energy consumption for space heating and passenger traffic grew rapidly in all industrialized countries. During this process the production systems of these countries became increasingly similar in terms of energy intensity.

We now turn to Diagram 2.5 which contains information about the income elasticity of energy in some selected countries.

1/ See Parent, (43).

Diagram 2.5 <u>Energy - GNP elasticity coefficients, selected countries and regions, 1950-1965</u>



<u>Source</u>: See Diagram 2.4

Upper figure = average annual % growth rate of energy consumption

Lower figure = average annual % growth rate of GNP

The broken line in Diagram 2.5 indicates unity energy income elasticity. Countries below the broken line have experienced a decrease in the energy intensity of GNP during the post-war growth process, while the opposite applies to the countries above the line.

Diagram 2.5 reveals substantial differences between countries in the GNP elasticity of energy consumption. There is no obvious pattern in these figures. For instance, both slow-growing and fast-growing as well as rich and relatively poor countries can be found over and under the broken line. This implies that there is no simple relationship between the level or the rate of growth of a country's GNP and the energy intensity of its GNP. So, in order to understand and explain the post-war development of energy consumption in Sweden, we cannot rely on any more or less universal law. Further, international comparisons indicate that the observed relationship between energy consumption and GNP cannot be considered stable enough to serve as a basis for long-term energy demand predictions.

2.3 The Energy Intensity or Different GNP Components

The preceding surveys revealed that the energy intensity of Sweden's GNP has increased since 1950. Further, although not unusual, such a development path has not been followed by all industrialized countries. In this section we again concentrate on Swedish developments and investigate whether the pattern, observed for GNP as a whole, holds for different components of the GNP as well.

Table 2.1 shows the total (direct plus indirect[1/]) consumption of primary energy incurred by the domestic production of goods and services demanded for various purposes. The figures refer to the amounts of energy allocated to domestic production of goods and services for private consumption, investment, etc.[2/] The table is based on input-output statistics. Since such statistics are not available for years prior to 1959, the whole period, 1950-72, could not be covered in this way.

1/ If the production of an arbitrary commodity, ceteris paribus, is increased by one unit, there will be a direct increase in the demand for energy and a number of other inputs. In order to produce these other, non-energy inputs some additional energy consumption is required. This is the indirect demand for energy incurred by the increased production of the arbitrary commodity in question.

2/ The calculations are based on the assumption that the import content of each particular group of commodities is the same for all kinds of final uses.

Table 2.1 Use of primary energy for the production of goods and services demanded by different aggregate demand categories, selected years. TWh and percentage shares

	Commodities produced for	1960		1965		1970	
		TWh	%	TWh	%	TWh	%
1	Private consumption	99.1	47.9	146.3	50.0	191.4	43.6
2	Central government consumption	9.1	4.4	12.5	4.3	18.5	4.1
3	Local government consumption	10.1	4.9	15.2	5.2	22.5	5.1
4	Total investments	32.9	15.9	42.9	14.6	57.6	13.1
5	Exports	49.3	23.9	68.7	23.5	135.0	30.8
6	Inventory changes	6.3	3.0	7.3	2.5	14.3	3.2
7	GNP	206.7	100.0	292.6	100.0	438.5	100.0

Sources: The National Accounts, Industry and Trade statistics and input-output statistics compiled for the Ministry of Finance.

Table 2.1 indicates that the allocation of Sweden's total energy consumption to GNP components has been relatively stable over time. The only exceptions are the marked changes in the relative shares allocated to private consumption and exports between 1965 and 1970. These divergencies are the result of variations in the energy intensity of the different GNP components and the relative share of BNP of these components.

Table 2.1 and the National Accounts can be used to calculate the average "primary energy intensity" of different parts of the Swedish production system. The results of these calculations are presented in Table 2.2. Note that the figures refer to the total (direct and indirect) energy content of domestically produced commodity groups, each worth one Sw.Cr. in 1968 prices and composed so as to be typical of the demand category in question.

Table 2.2 Average primary energy content of domestically produced commodities for various purposes, selected years. KWh/1968 Sw.Cr.

Commodities produced for	1960	1965	1970	Average annual rate of change. %
Private consumption	2.13	2.62	3.06	3.6
Central governm. cons.	1.17	1.21	1.70	3.7
Local government cons.	1.07	1.27	1.24	1.5
Total investments	1.94	1.85	2.16	1.1
Exports	3.58	3.53	4.70	2.7
GNP	2.20	2.35	2.88	2.7

Sources: See Table 2.1.

Table 2.2 reveals that the energy intensity of all GNP components has been increasing over time, although the rates of growth and levels of energy intensity differ substantially. Thus, assuming a given commodity composition for each of the GNP components, a reallocation of the domestic use of resources from sectors producing goods and services for public consumption and investment purposes to sectors producing for private consumption and export would increase the energy intensity of the GNP.

The allocation of the GNP to various uses for some selected years is shown in Table 2.3.

Table 2.3 Allocation of Sweden's GNP to various uses in 1960, 1965 and 1970. GNP measured in 1968 market prices. Percentage shares*

	1960	1965	1970
Private consumption	49	47	44
Central government consumption	7	7	6
Local government consumption	7	8	10
Total investments (incl. inventory changes)	18	21	20
Exports	19	17	20

Source: The National Accounts, 1950-1970, SM N 1971:99.

* The import content is assumed to be the same in all kinds of final uses.

The high energy intensity of Swedish exports reflects the predominance of natural resource products, with a high consumption of energy per produced unit, in the country's total exports.[1/] Another factor is that there is some Swedish export of energy. Domestic production of certain petroleum products is greater than domestic consumption, so that some refined petroleum products are exported. The substantial increase in the energy intensity of Swedish exports between 1965 and 1970 is partly a result of the growth of the Swedish petroleum refinery sector.

The low energy intensity of investment goods is probably a reflection of Sweden's high level of industrialization. In a well-developed industrial economy there is a relatively low share of infrastructural investments in total capital formation. Since the manufacturing of capital goods generally does not require very much energy per produced unit, capital formation on the average is not very energy intensive in such an economy.

1/ The high energy intensity of Swedish exports indicates that the energy intensity of Swedish production is higher than the corresponding figure for Swedish consumption. In other words, it is likely that Sweden is a net exporter of energy contained in commodities. This hypothesis is confirmed by a recent study, SOU (63) pp. 51-128.

As can be seen in Table 2.2, there are substantial differences in the level of energy intensity between private and public consumption. These figures should be interpreted with care. What they in fact indicate is that tax-financed consumption in Sweden to a large extent consists of basic services such as education, medical care, etc. Even if the consumption of these services were not tax-financed, they would still be consumed in large amounts. In such a case the average energy intensity of household expenditures would be lower. Thus, the rapid increase in the energy intensity of a typical private consumer commodity basket can probably be explained to some extent by the increase in the share of local government consumption in the GNP. This hypothesis is consistent with the slow growth of the energy intensity of local government consumption.[1/]

However, still it seems reasonable to project that the consumption of energy in Sweden would be greater if the public sector were smaller. This is so if additional disposable household incomes to a large extent were to be spent on cars, one-family houses, and electrical appliances, while the public sector would spend additional resources on the production of various services. The way additional real disposable incomes in the household sector are allocated, to some extent depends on the way the additional incomes are distributed among different socio-economic groups in the society. The relation between energy consumption and the distribution of disposable incomes between different income groups has been studied by B. Diczfalusy[2/]. The study was carried out on a fairly high level of aggregation. This fact can be the explanation to the somewhat surprising result that the average energy intensity of the expenditures on goods and services was approximately the same for middle and high income groups.

1/ See Table 2.3.

2/ See Diczfalusy, (16).

2.4 A Decomposition of Observed Changes in Swedish Energy Consumption

So far, energy consumption in Sweden has been analyzed along two dimensions:

i) the consumption of energy for different kinds (industrial and non-industrial) of production;

ii) the consumption of energy in the production of goods and services for various purposes (private consumption, etc.).

It appears that the increased energy intensity of Sweden's GNP is essentially the result of changes in the non-industrial part of the economy. However, these changes have probably been checked somewhat by the growth of the public sector and the concomitant reduction in the share of private consumption in the GNP.

We now proceed to an analysis on a somewhat disaggregated level. This will constitute an attempt to isolate the effects on total energy consumption in Sweden of changes in production technology and in the composition of final demand.

2.4.1 A Methodological Note

The empirical basis of the analysis carried out in the following subsection is a series of 23 × 23 input-output tables[1)] where the intersectoral flows are measured in 1968 purchasers' prices. Unfortunately, this input-output material is not very well-suited to our present purpose, mainly because imports are treated in a very crude way. There is no distinction between the consumption of imported and domestically produced goods of the same type. That is, there is no indication as to where imports are used in the domestic production system. Consequently, we have to assume that all importation of a given type of commodities is carried out by the domestic production sector producing those commodities, and that all domestic deliveries of commodities of a given type contain imported and domestically produced units in fixed proportions.

1) The tables were compiled for the Ministry of Finance by the National Central Bureau of Statistics.

The usual input-output assumptions are also made. That is, production processes are characterized by constant returns to scale and perfect divisibility; each commodity is produced by one process only and each process has a single output. Thus, we can identify commodities with supply processes.

The following notations are used:

X_j = domestic gross production of commodity j, $j = 1, 2, \ldots, n$

M_j = total imports of commodity j

S_j = total domestic supply of commodity j (thus $S_j = X_j + M_j$)

F_k = total use of resource k, $k = 1, 2, \ldots, m$

μ_j = share of imports in the supply of commodity j

α_{ij} = input of commodity i per supplied unit of commodity j

ε_{kj} = input of resource k per supplied unit of commodity j

Y_j = final demand for commodity j.

With obvious matrix notations we can write the following equilibrium conditions:

$$\begin{cases} S = \alpha \cdot S + Y \\ M = \mu \cdot S \\ F = \varepsilon \cdot S \end{cases} \qquad (1)$$

where α and μ is $n \times n$, ε is $m \times n$, S M and Y are $n \times 1$ and F is $m \times 1$.

Provided α is nonnegative and indecomposable with at least some positive element and

$$\sum_{i=1}^{n} \alpha_{ij} < 1$$

for all j,[1] then $(I-\alpha)$ is a positive matrix and (1) can be written

1) If α is a semipositive indecomposable square matrix it has among its characteristic roots a dominant root, λ^*, real and nonnegative, such that for all $\mu > \lambda^*$, $\mu I-A$ is nonsingular and $(\mu I-\alpha)^{-1}$ is a positive square matrix. Moreover, if s is the smallest and S the largest column sum (that is $s = \min_j \sum_i \alpha_{ij}$ and $S = \max_j \sum_i \alpha_{ij}$) then $s < \lambda^* < S$. Thus, if $S < 1$ then $1 = \mu > \lambda^*$ and $(I-\alpha)^{-1}$ is positive. See Lancaster, (33). The input-out tables used in this study satisfy these conditions.

$$
\begin{aligned}
S &= (I-\alpha)^{-1}Y \equiv AY \\
M &= \mu(I-\alpha)^{-1}Y \equiv hY \qquad (2) \\
F &= \varepsilon(I-\alpha)^{-1}Y \equiv eY
\end{aligned}
$$

where, consequently, A and h is n × n and e is m × n.

It follows that h_{ij} is a measure of the total (direct and indirect[1]) import of commodity i incurred by a domestically supplied unit of commodity j Further, e_{kj} is a measure of the total use of resource k incurred by a domestically supplied unit of commodity j.

Next we introduce a time superscript into the variables and use the last equation of (2) to express the difference in the aggregate use of resources ΔF_k, k = 1, 2, ..., m, between period t and period t+1. We then get:[2]

$$
\begin{aligned}
\Delta F &= F^1 - F^0 \\
&= e^1Y^1 - e^0Y^0 \\
&= e^1Y^1 - e^0Y^1 + e^0Y^1 - e^0Y^0 \qquad (3) \\
&= (e^1-e^0)Y^1 + e^0(Y^1-Y^0).
\end{aligned}
$$

The volume, i.e. the market value at base year prices, of a given final demand vector, Y, is

$$y = \sum_{j=1}^{n} Y_j.$$

By means of this new variable, we define a hypothetical final demand vector $\hat{Y}$ such that

i) $\hat{y} = y^1$

ii) $\dfrac{\hat{Y}_j}{\hat{y}} = \dfrac{Y_j^0}{y^0}$; $\forall j$

which means that $\hat{Y}$ has the same volume as Y^1 and the same composition as Y^0.

1) From the model formulation, it follows that h_{ij} is equal to the indirect use of imported commodities of type i whenever $i \neq j$.

2) Expression (3) is the same as the one derived by Reardon (46). Reardon did not carry the decomposition any further, however.

Now, the decomposition of ΔF, initiated in (3), can continue in the following way:

$$F = (e^1-e^0)Y^1 + e^0(Y^1-\hat{Y}+\hat{Y}-Y^0)$$

$$= (e^1-e^0)Y^1 + e^0(Y^1-\hat{Y}) + e^0(\hat{Y}-Y^0) \qquad (4)$$

SUP COMP VOL

where

SUP = the share of ΔF that can be attributed to changes in e (that is ε and α)

COMP = the share of ΔF that can be attributed to changes in the composition of final demand

VOL = the share of ΔF that can be attributed to changes in the volume of final demand.

Next we want to decompose SUP, the term $(e^1-e^0)Y^1$, the size of which is determined by variations in ε and α. The coefficients ε_{kj} and α_{ij} reflect the economy's technology. In addition both sets of coefficients depend on the import share in the supply of various commodities. For our purposes it would be interesting to distinguish the effect of changes in domestic technology from changes in the share of imports in the supply of various commodities.

On the basis of (2) the total import content of a comestically supplied unit of commodity j can be determined by the sum of h_{ij} over i, i.e. $\sum_{i=1}^{n} h_{ij}$.

We neglect the resource content of imports and define the n × n diagonal matrix $\hat{\eta}$ by $\hat{\eta} = (\hat{\eta}_{ij})$ where

$$\hat{\eta}_{ij} = \begin{cases} \dfrac{1}{1 - \sum_{s=1}^{n} h_{sj}} & \text{when } s = j \\ 0 & \text{when } s \neq j. \end{cases}$$

Then the m x n - matrix $\pi = (\pi_{kj})$ is defined by

$$\pi = e \cdot \hat{n}$$

where the typical element π_{kj} can be written $\pi_{kj} = e_{kj} \cdot \hat{n}_{jj}$

It follows that π_{kj} can be interpreted as the amount of resource k which is used when one unit of commodity j is supplied by means of domestic production. Alternatively π_{kj} can be interpreted as the global amount of resource k which is used when one unit of commodity j is produced and the same technology is used in all countries.

The decomposition of ΔF in (4) can now be completed. It then becomes:

$$\Delta F = (\pi^1-\pi^0)Y^1 + [(e^1-e^0) - (\pi^1-\pi^0)]Y^1 + e^0(Y^1-\hat{Y}) + e^0(\hat{Y}-\hat{Y}^0) \qquad (5)$$

TOT I/O IMP COMP VOL

where

I/O = the share of ΔF that can be attributed to changes in domestic technology

IMP = the share of ΔF that can be attributed to changes in the share of imports in the domestic supply of different commodities.

The interpretation of the components I/O and IMP is not quite straightforward, but can be clarified by a few simple examples.

Assume that an economy has only one sector producing one type of output by means of a single domestic resource, labor. The output commodity is also imported. Assume further that the total supply of the single commodity is 100 units in both of two periods. This means that the numerical value of the components COMP and VOL becomes zero. Using the same symbols as above, we can construct the following four examples:

Example	A		B		C		D	
Period	1	0	1	0	1	0	1	0
e^t	2	5	1,6	5	2	5	2	4
h^t	0.5	0.5	0.6	0.5	0.6	0.5	0.6	0.6
$\pi^t = \frac{e^t}{1-h^t}$	4	10	4	10	5	10	5	10
Y^t	100	100	100	100	100	100	100	100
$(e^1-e^o)Y^1$	-300		-340		-300		-200	
$(\pi^1-\pi^o)Y^1$	-600		-600		-500		-500	
$[(e^1-e^o) - (\pi^1-\pi^o)]Y^1$	300		260		200		300	

where

e^t = total content of resources (labor) in one supplied unit of the output commodity

h^t = share of imports in one supplied unit of the output commodity

π^t = total content of domestic resources (labor) in one domestically produced unit of the output commodity

t = time index.

If we disregard the crucial fact that, in the long run, imports have to be paid for by exports, the importation affects the domestic use of resources (labor in the examples) in two ways.

First, by assumption, the domestic resource input coefficient of imports is zero. This means that an increase in the import share of total supply tends to reduce the average use of domestic resources per unit supplied. Second, and still by assumption, efficiency variations in the utilization of a particular resource always stem from the domestic production system. This, of course, is because the domestic resource input coefficient of imports does not change; it is always zero. Thus, if domestic producers become more efficient, a positive import share in total supply implies that actual resource savings become smaller than would have been the case if the total supply had been produced domestically. In the opposite case, when domestic producers become less efficient, a positive import share has a resource saving effect.

Examples A-D demonstrate how the model works. In A the import share is 50% in both periods and domestic producers reduce the labor-input coefficient from 10 to 4. Thus, if total supply had been produced domestically, 600 units of labor would have been saved. Since half of the supply is imported, the actual savings become 300 and the "loss" due to the impossibility of increasing the resource efficiency of imports is, accordingly, 300 units.

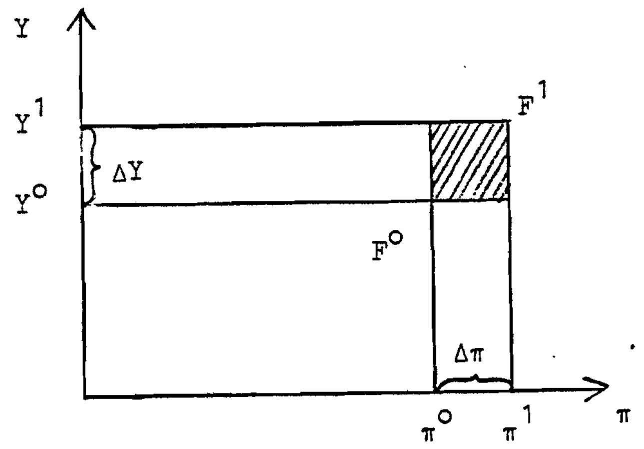
In example B the increase in domestic efficiency is the same as in A, but in this case the share of imports increases from 50% to 60% between period 0 and period 1. Again there is a "loss" since importation, in contrast to domestic production, has not become more resource efficient. This loss is reduced, however, by the fact that a larger share of domestic supply has a zero input coefficient for domestic labor. Accordingly, the actual savings of labor are greater in B than in A.

In C the domestic productivity increase is smaller than in A and B. Accordingly, it "costs" less to have an increasing import share. In D, finally, the domestic productivity increase is the same as in C, but as the import share is greater in D than in C, the "cost" of non-realized efficiency gains is larger in D than in C.

To conclude this part of the analysis, the first component in (5), I/O, is a measure of the change in the use of domestic resources that would have occurred if the total supply had been produced domestically and thus subject to domestic efficiency changes. The second term, IMP, is a mirror of domestic efficiency changes. If domestic efficiency increases, there is a "cost" for positive import shares, while imports are "profitable" if domestic efficiency is reduced. The partial effect of an increase in import shares is always a reduction in the domestic use of resources.

The results of an empirical ΔF-decomposition are presented in the following subsection. The presentation is based on expression (5). It is important to note that the results should not be given a causal interpretation. This is because the different components identified by the method presented above are not exogenously determined variables underlying the process of economic growth. Instead they are endogenously determined by the interplay of supply and demand on a great number of markets. Thus, the results presented in the following subsection should only be given a descriptive interpretation.

Further, the decomposition is not unique. This can be seen by considering the following figure:



The total difference between F^o and F^1 can be written as either

$$\Delta F = \underbrace{\Delta Y \cdot \pi^1}_{VOL} + \underbrace{Y^o \cdot \Delta\pi}_{I/O}$$

or

$$\Delta F = \underbrace{\Delta Y \cdot \pi^o}_{VOL} + \underbrace{Y^1 \cdot \Delta\pi}_{I/O}$$

In the first case the shaded area in the figure is allocated to the VOL component, while in the second case it is allocated to I/O.

As can be seen in (5), the chosen decomposition tends to overestimate the numerical values of I/O and IMP, while COMP and VOL are underestimated.

It is also important to note that the relative importance of the different components depends to a large extent on the level of aggregation. For instance, changes that on one level of aggregation are assigned to changes in the input-output coefficients, might, after some disaggregation, be assigned to changes in the composition of final demand.[1/]

2.4.2 Some Results

The empirical application of the method described above is based on three 23 x 23 input-output tables (1960, 1965, 1970) where the flows are measured in 1968 purchaser's prices. The tables were compiled by the Central Bureau of Statistics at the request of the Ministry of Finance. A distinction is made between five kinds of primary[2/] energy: crude oil, refined petroleum products, coal, coke and water power. In addition to the decomposition of changes in energy consumption, changes in the number of hours worked are assigned to different components.

As a consequence of the way imports are treated in available input-output statistics, only a few sectors engage in direct consumption of primary energy. Thus, crude oil and coal are direct inputs only in the "Mining and quarrying" sector. Refined petroleum products and coke are direct inputs in "Petroleum refineries, manufacture of products made from petroleum and coal" while water power is a direct input in the "Electricity, gas and water" sector. It follows that the input of crude oil in the refinery sector becomes an indirect input; it is contained in deliveries from the "Mining and quarrying" sector.

The results of the decompositions are presented in Table 2.4. The total changes in the use of the different resources are assigned to the following components:

1/ See Höglund (29) for a detailed analysis of the effects of aggregation in input-output models.

2/ The concept of "primary energy" is defined on p. 14.

TOT = total change in the use of the resource in question during the period

SUP = share of TOT that can be assigned to the combined effect of changes in domestic input-output coefficients and import shares

I/O = hypothetical change in the use of the resource in question that would have materialized if the total supply had been produced domestically; see page 31

IMP = share of TOT that can be attributed to changes in the share of imports in the domestic supply of different commodities

COMP = share of TOT that can be assigned to changes in the composition of final demand

VOL = share of TOT that can be assigned to changes in the volume of final demand at a given composition.

Observe that TOT = SUP + COMP + VOL, that is, I/O + IMP = SUP.

The demand for goods and services by the public sector is included as part of final demand in the input-output statistics. Thus, employment in the I/O-sectors is not equal to employment in the economy as a whole. In Table 4 the changes in the number of hours worked in the public sector have been recorded in the column COMP.

Domestic refining increased rapidly between 1965 and 1970. Since such changes in the energy supply structure tend to disturb the results of the decomposition, the period 1960 to 1970 is divided into two parts. This partitioning of the 1960s is also appropriate from another point of view; 1970 was a very dry year and consequently the supply of water power was lower than usual.

Table 2.4 A decomposition of observed changes in the consumption of primary energy and the number of hours worked, 1960-65 and 1965-70.

	(1)	(2)	(3)	(4)	(5)	(3)+(4)+(5)
1960 - 1965	I/O	IMP	SUP	COMP	VOL	TOT
Imported crude oil (TWh)	3.3	-0.2	3.1	1.2	9.2	13.5
Imported petroleum products (TWh)	-0.8	5.9	5.1	13.0	35.4	53.5
Imported coal (TWh)	-4.4	2.3	-2.1	0.4	3.4	1.7
Imported coke (TWh)	-23.2	15.2	-8.0	1.4	3.7	-2.9
Water power (TWh)	10.5	-1.3	9.2	0.7	10.1	20.0
Total primary energy (TWh)	-14.6	21.9	7.3	16.7	61.9	85.9
Hours worked (1.000 hours)	-2378	645	-1733	99	1667	33

1965 - 1970	I/O	IMP	SUP	COMP	VOL	TOT
Imported crude oil (TWh)	150.6	-74.0	76.6	4.0	11.0	91.6
Imported petroleum products (TWh)	-187.5	175.2	-12.3	30.7	43.0	61.4
Imported coal (TWh)	-6.8	2.0	-4.8	1.2	3.3	-0.3
Imported coke (TWh)	-21.3	15.8	-5.5	1.7	2.4	-1.4
Water power (TWh)	-29.4	4.4	-25.0	6.1	13.4	-5.5
Total primary energy (TWh)	-94.5	123.6	29.1	43.7	73.1	145.9
Hours worked (1.000 hours)	-2116	426	-1690	163	1364	-163

The results in column I/O in the 1965-70 part of Table 2.4 should be interpreted with some care. The restructuring of the oil supply in combination with the scarcity of water power might have disturbed the results. However, these disturbances are probably not severe enough to completely distort the figures in column (1) of Table 2.4. Thus we can conclude that during the 1960s the Swedish production system as a whole became more efficient both in terms of energy and labor. On the other hand, the positive figure for Water power in the first part of Table 2.4 indicates that there was a significant transition from fuels to electricity in the production system.

Column (4), COMP, in both halves of Table 2.4 indicates that the composition of final demand has changed in an energy-intensive direction. The table also indicates that final demand in particular, has become more oil and electricity intensive. This, as such, is not surprising, but the impact of this change is indeed significant, especially during the latter subperiod.

Although energy is a typical intermediate good, some energy deliveries are recorded as final purchases of energy. The direct energy purchases recorded as final demand are household purchases of fuels for residential heating and private cars, household lighting expenditures and all public energy purchases. Of these uses, energy consumption for space heating purposes predominates in quantitative terms.

Accordingly, there are two kinds of changes in the composition of final demand that can lead to an increase in the consumption of energy. The first involves and increase in the relative share of energy intensive products in total final demand. The second is an increase in the relative share of direct purchases of energy in total final demand. The latter kind of change seems to have prevailed in the Swedish post-war growth process. This is consistent with our previous observation that the share of industrial energy consumption in total energy consumption has been fairly stable. Thus the share of expenditures on direct purchases of energy grew from 2.7% in 1960 to 4.5% in 1970. This means that the share of total energy consumption recorded as final energy purchases rose from 50% in 1960 to 62% in 1970.

Column (5) in Table 2.4 indicates that the increased volume of final demand has contributed positively to the growth of energy consumption and employment. This, of course, is an obvious result. It shows that the increased efficiency (in terms of production per hour worked) in the utilization of human labor has only to a relatively minor extent been used to shorten working hours (see columns I/O and TOT in Table 2.4). As a result, the production and consumption of material goods and services have expanded, leading to an increase in the consumption of energy.

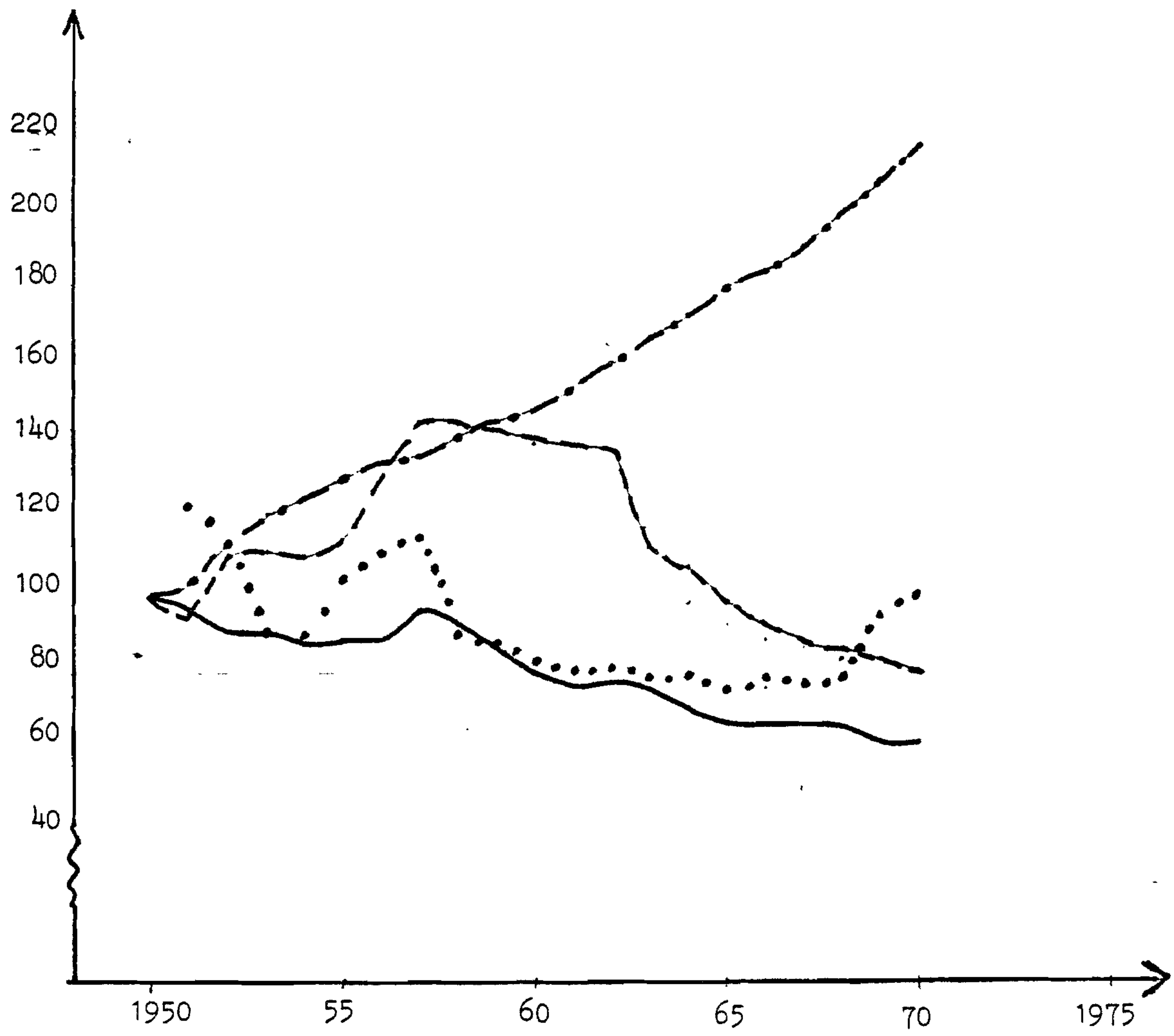
2.5 Some Tentative Conclusions about Underlying Factors

We are now left with two observations about the Swedish post-war growth process. Changes in production methods have tended to reduce the energy intensity of the GNP, while changes in the composition of the GNP have worked in the opposite direction.

However, this is only the descriptive part of the story; so far no explanation has been given as to why the developments observed actually came about. Why did consumption patterns change as they did? Why did the energy intensity of industrial output decline as slowly as it did? These questions cannot be answered within the framework of this study, but a few hypotheses can be presented.

A natural point of departure is the relative price trends which can be seen in Diagram 2.6. It should also be noted that prior to 1973, Swedish electricity tariffs were characterized by quantity discounts. Thus, the marginal price of electricity was lower than the average price of electricity. The tariffs applied after 1973 to some extent have this feature as well, since there are certain fixed items in the tariff, but quantity discounts are much less significant in the new tariffs.

Diagram 2.6 Energy prices and industrial wages in relation to the GNP-deflator, 1950-74 (1950 = 100)



__________ = Petroleum products including taxes

.... = Coal (polish coal, 62.5% big pieces and 37.5% small pieces)

---------- = Electricity (industrial tariff, taxes excluded; 20 kV, 0.5 MW and 1.5 GWh/year)

—·—·—·—· = Industrial workers' wage rate.

Sources: Svenska Petroleum Institutet, The National Accounts.

An important price not shown in Diagram 2.6 is the user cost of capital. However, on the basis of an attempt by Bergström[1/] to measure the user cost of capital in the Swedish economy, the development of electricity prices and the user cost of capital was fairly parallel between 1950 and 1970.[2/]

As can be seen in the diagram, real energy prices fell in relation to real wages almost throughout the post-war period. This would be expected to induce a substitution of energy for other factors of production and consumer goods. Thus, on the basis of relative price trends, both production methods and the composition of final demand should be expected to change towards higher energy intensity. As noted above, this has not been the case. However, this is not an anomaly but simply the result of technical change.

The development of factor proportions in the Swedish mining and manufacturing industry is shown in Table 2.5.

Table 2.5 Production and factor inputs in the Swedish mining and manufacturing industry, 1955-1970. Yearly rates of growth.

	Production	Capital stock	Hours worked	Energy
1955 - 1960	5.2	4.8	0.2	3.1
1960 - 1965	7.4	5.5	0.6	4.3
1965 - 1970	4.9	4.2	-1.5	4.1
1955 - 1970	5.9	4.8	-0.2	3.8/4.5 *

* Including waste products from the pulp industry.
Source: SOU 1974:65, Energy 1985-2000, Bilaga 3, table 17.

1/ See Bergström (9).

2/ The following figures were obtained (1950 = 100)

	1955	1960	1965	1970
Petroleum products including taxes	114	124	127	147
Electricity (defined as in Diagram 2.6)	155	224	192	195
User cost of capital	160	125	180	260 (1968)

This table is an indication of factor-saving technical progress in the Swedish manufacturing industry; the rate of output growth has been faster than the rate of input use growth. However, technology has become relatively more capital and energy intensive and relatively less labor intensive. That is, capital and energy have been substituted for labor and thus reduced the impact of technical change on the average energy input coefficient of the industrial sector. This implies that the observed changes in factor proportions are consistent with the development of relative factor prices.

However, this observation does not tell us anything about the impact of falling energy prices on factor proportions. In other words, would higher energy prices, ceteris paribus, have led to less energy intensive production methods? This question can be discussed in conjunction with some results from a study by Björklund.[1/]

Among other things, Björklund studied the determination of electricity and fuel intensities of value added in three industries: the paper and pulp, stone and clay, and iron and steel industries. Some statistical problems were encountered owing to the poor quality of energy price data. Further, the "price of capital" was not included at all. The results indicated a statistically significant impact of technical change on the energy intensities studied. However, the prices of energy were not significant throughout and in a few cases had the wrong signs. The latter phenomenon, which also applied to the wage rate in a few cases, could have been the result of the omitted "price of capital" variable.

Although Björklund's results are uncertain, they indicate that falling real energy prices did not significantly affect the choice of factor proportions in the industries studied. This is, after all, not surprising. In fact, falling energy prices should not be expected to have a significant effect on the choice of factor proportions in the production system or on the composition of final demand.

1/ See Björklund (12).

This point becomes clear if we consider the ways in which energy is used. Energy is always an input in a production process. In some cases energy is an input in an industrial production process e.g. producing material goods. In other cases energy is an input in a household production process e.g. producing heat, cold, light or mechanical work. This menas that the demand for energy is always derived from the demand for the output of these production processes and thus the price of energy is not an independent variable in people's or industry's demand functions. Consequently, energy price variations are likely to affect the demand for energy only if the share of energy cost in the price of the goods and services demanded is significant. At the post-war level of energy prices this has not been the case.[1/]

In accordance with this line of reasoning, it is likely that the choice of technology in the industrial, trade,agriculture and public sectors has been determined essentially by the cost of labor in relation to the cost of capital equipment. Further, the increased energy intensity of household consumption is probably the combined effect of disposable income increases and high income elasticities for energy-consuming goods and services such as housing, cars and electrical appliances[2/]. Considering the low level of energy prices in the early 1950s, a slight increase in real energy prices is not likely to have brought about markedly different developments in the demand for energy in Sweden.[3/]

This leads to the conclusion that during the first three post-war decades energy prices were important only by being unimportant. At the low level of energy prices, the demand for energy was determined essentially by the relative prices of non-energy factors of production and by the growth of incomes. The continuation of this pattern is highly dependent on the long-run effect of the 1973-74 oil price increase and the long-run development of energy prices. The next chapter is addressed to the latter issue.

1/ See Bergman (6) and Bergman-Bergström (7) and chapter 10.

2/ This conclusion is confirmed by a number of household demand studies; see e.g. Lybeck (37).

3/ Cf. the relation between the development of the industrial workers' wage rate and the consumer price index in Diagram 2.6, p. 40.

3. LONG RUN ENERGY PRICES AND ECONOMIC GROWTH

One feature of the present study is that prices of energy resources like oil, coal and uranium are regarded as exogenous variables. As such this is a reasonable approach; even though per capita consumption of energy is relatively high in Sweden as compared to most other countries[1/] Sweden is a small buyer on the markets for energy resources. For instance, oil accounts for more than 70% of Swedish energy consumption, but still annual consumption of oil in Sweden is only about 1% of annual global consumption.

However, since prices of energy resources are not determined within our model, we have to make assumptions about their future development. This is, indeed, not an easy task; most assumptions made in the study can be based on information obtained from official predictions and other kinds of published reports, but in the case of energy resource prices no such material is available. There are several reasons for this situation: the political role of oil, uncertainty about politicies towards nuclear power in important energy consuming countries, uncertainty in terms of time and cost for the development of alternative energy sources, etc. Thus our assumptions about energy resource prices have the nature of informed guesses.

Nevertheless it is possible to identify some critical factors behind the long term development of energy resource prices. Such an analysis can be based on the "economic theory of exhaustible resources" originally developed by Hotelling.[2/] The main purpose of this chapter is to briefly discuss the economics of long term energy prices. In Section 3.1 the concept of "energy transformation technology" is introduced. Section 3.2 deals with the choices between such technologies and the resulting development of energy prices under a number of simplifying assumptions. The validity of the conclusions derived from this analysis is also discussed.

1/ See Bergman-Flam (10) p. 45-48

2/ See Hotelling (26).

Another feature of the present study is that the analysis of energy price changes is confined to their impact on energy consumption patterns. Thus, relations between energy prices and growth of GNP, consumption of goods and services and other macroeconomic variables are more or less neglected. However, in Section 4.4 these issues are briefly touched upon.

3.1 Energy Resources and Energy Transformation Technologies.

Useful energy forms such as electricity, heat, mechanical work etc. can be obtained from several energy sources. Direct solar energy, stored solar energy, geothermal energy and energy released from nuclear fission and nuclear fusion are all examples of basic energy sources. To each basic energy source a set of energy resources can be associated. For instance, direct solar energy appears as water power, wind power and direct solar radiation; stored solar energy as various fossil fuels, wood, etc. Further, by means of uranium useful energy can be released through nuclear fission. Thus, utilization of energy sources always involves utilization of energy resources.

Energy resources can be transformed into useful energy by means of capital and labor. We can define an "energy transformation technology" as a method, or way of using capital and labor, for transforming a certain kind of energy resource into one unit of useful energy. Obviously, the supply of energy resources is related to the existence of energy transformation technologies. Prior to the development of nuclear reactors uranium was not an energy resource, and if fusion reactors can be developed sea-water will become an energy resource. Thus, the global supply of energy resources is related to the availability of energy transformation technologies.

According to our definition each energy transformation technology is based on a particular energy resource. Later on in this chapter we will associate an energy transformation technology with energy resource deposits of a specified quality. The physical characteristics of the energy resource deposits constrains potential utilization of the energy transformation technology in question. In the case of fossil fuels the resource deposits are exhaustible, and in the case of water power and other so called continous energy resource there is a maximum annual supply.

However, the amount of energy resources that can be utilized by means of existing energy transformation technologies is very large. In fact, since energy sources such as direct solar energy and fusion energy can be regarded as infinitely large, access to new energy transformation technologies may make the supply of energy resources infinitely large. Thus, within a reasonable time horizon (say 50-100 years) the "energy problem" does not seem to be a problem of physical supply. To the extent that there is a real "energy problem" for the world as a whole, it is an environmental problem and perhaps a cost problem; the more capital and labor allocated to transforming energy resources into useful energy the less can, ceteris paribus, be allocated to production of consumer or capital goods.

The development of the global energy supply system can be regarded as a sequence of transitions between energy transformation technologies. The order of utilization of energy transformation technologies in this sequence is determined in a complex process where economic, political and environmental factors interact. In the next section we will analyze the outcome of this process within a very simplified framework. By means of that analysis some strategic factors behind the development of energy prices and energy resource prices can be identified.

3.2 The Determination of Long Run Energy Prices.

In the following discussion useful energy is regarded as a homogenous commodity with specified quality. Alternatively we may say that quality differences between a number of useful energy forms are disreagrded. This is a reasonable simplification on this level of abstraction.

1/ This holds in particular for coal. See for instance Industridepartementet (57), p. 106.

Assume that there is one single market for energy. To be precise this means that all energy consuming activities have the same geographical location, and that the unit cost of utilizing each energy transformation technology includes all relevant transportation and distribution costs. Competitive conditions are assumed to prevail on the energy market; there is a large number of potential profit maximizing suppliers and a large number of buyers of energy. Each potential supplier of energy has one specific energy transformation technology at his command but several producers may have access to the same type of technology. The demand shedule for energy is constant over time and perfectly known by all potential suppliers. The demand shedule is such that at a specific positive price the quantity demanded is zero. Since the consumption of energy can never be zero when there is some economic activity, the maximum price can be thought of as the price at which high quality energy is entirely replaced by low quality energy. There is a perfect capital market where funds can be borrowed and lended at a constant rate of interest. The prices of non-energy commodities and factors of production are assumed to be (almost) independent of energy prices.

We assume that each energy transformation technology is based on energy resource deposits of a certain quality, for instance coal on a ceratin depth etc. All energy transformation technologies are assumed to be based on an exhaustible resource deposit. The unit cost of utilizing an energy transformation technology is assumed to be constant and thus independent of the accumulated production of energy with that technology. We disregard the situation of the individual firm, and focus on the group of producers utilizing a specific energy transformation technology.

Given these assumptions we will analyze the equilibrium prices of energy resources over a finite time period. [1/] The terminal point in time can be thought of as a date when a new energy transformation technology based on an energy resource in practically unlimited supply, and with lower utilization cost than each existing technology, becomes available.

1/ To a large extent the discussion is based on Herfindahl (23) and Solow (49).

The following symbols are used:

$P(t)$ = price of energy in period t;

C_j = cost per unit of output produced by means of energy transformation technology j;

r = rate of interest;

T = terminal point in time.

The difference $P(t) - C_j$ is the royalty in period t on the type of energy resource utilized by energy transformation technology j. Obviously the royalty can be regarded as the price of the resource before extraction.

3.2.1 One Energy Transformation Technology.

To begin with, consider a situation where there is only one single energy transformation technology, denoted "a". Utilization of this energy transformation technology implies exploitation of the energy resource deposits on which it is based. If each year during the period of exploitation is to have some production, no year can be more attractive to an owner of a deposit than another. If some years were more attractive the profit maximizing producers would shift production from less attractive to more attractive years. Thus, in equilibrium the present value of the royalty at different points in time must be the same. That is:

$$\{P(t^*) - C_a\}e^{-r\cdot t^*} = \{P(t^{**}) - C_a\}e^{-rt^{**}} ; \qquad (1)$$

must hold for all pairs of t* and t**.

This equilibrium condition implies that the royalty of the energy resource must rise at a relative rate equal to the rate of interest. Energy resources can be regarded as capital assets, which, in equilibrium, must increase in value at the same relative rate as other assets.

From (1) the development over time of P(t) can be determined. To see this, let t* and t** in (1) be zero and t respectively. We then get

$$P(0) - C_a = \{P(t) - C_a\}^{-r\ t}$$

which can be written

$$P(t) = \{P(0) - C_0\}e^{rt} + C_a \quad (2)$$

Thus, in equilibrium the price of energy also rises over time, but at a lower rate than r. The rate of incrase of P(t), however, does approach r as a limit as P(t) becomes large in relation to C_a.

Above we assumed that there is a positive price at which the quantity demanded is zero. Let that price be $\bar{P}$. In equilibrium the level of P(0) is such that $\bar{P}$ is reached at the terminal point in time, and at that date the last units of the energy resource are used up. If the initial price is lower the resource would be exhausted before the terminal point in time. Then prices, and thus profits, could be incrased without leaving some part of the resource unexploited. If, on the other hand, the initial price is too high, the maximum price would be reached before the terminal point in time, and part of the resource would remain unexploited. This situation is not consistent with profit maximization; some producers could increase their profits by selling at lower prices.

Thus for the equilibrium price path it holds that

$$\bar{P} = P(T) = \{P(0) - C_a\}\ e^{rT} + C_a \quad (2')$$

and that the energy resource deposits are exhausted exactly at the terminal point in time. That is, the equilibrium energy price path is determined by the shape of the demand function, the available amount of the energy resource, the length of the exploitation period and the cost of utilizing the energy transformation technology.

In (2') it can easily be seen that the longer the exploitation period, ceteris paribus, the lower is the initial price. As T goes to infinity, P(0) approaches C_a. That is, an energy resource has a positive royalty only if it is exhaustible. This means that if energy is supplied by means of energy transformation technologies based on energy resources in abundant supply, the equilibrium energy price is close to the marginal cost of utilizing the energy transformation technology in question. In the limiting case where energy supply is based on contínous energy sources like direct solar energy, the equilibrium energy price is constant over time and equal to the marginal cost of production (provided the yearly capacity of the continous energy sources is large enough).

3.2.2 Several Energy Transformation Technologies

Next we consider a situation where several energy transformation technologies are available. To begin with we retain the assumption that all energy transformation technologies are based on exhaustible energy resources, and focus on the order in which the technologies are utilized under certainty and competitive conditions.

In accordance with the discussion above, the equilibrium royalties on exhaustible energy resources rise at the rate of interest. Further, the price of energy must be the same no matter what source is used. Suppose energy transformation technologies a and b both are being utilized at the initial point in time. At t=t* it would then be necessary that

$$P(t^*) = \{P(0) - C_a\}e^{rt^*} + C_a = \{P(0) - C_b\}e^{rt^*} + C_b \qquad (3)$$

But (3) implies that $(C_b - C_a)e^{rt^*} = C_b - C_a$, which is true only if $C_b = C_a$ when r is positive. Thus, if the operating costs of two energy transformation technologies differ, both will not be simultaneously utilized in equilibrium. This means that the transition between energy transformation technologies occurs at specific points in time.

Suppose that energy transformation b is utilized between the initial point in time until t=t', and that technology a is utilized from t=t' until t=t". Further, assume that $C_a < C_b$. The present value at the initial point in time of the royalty in t=t' on the energy resource on which technology a is based is $\{P(t') - C_a\}e^{-rt'}$. But if technology a is utilized at the initial point in time the royalty would be $P(0) - C_a = [\{P(t') - C_b\}e^{-rt'} + C_b] - C_a$. Since, by assumption, $C_b - C_a > (C_b - C_a)e^{-rt'}$ when r is positive it holds that $[\{P(t') - C_b\}e^{-rt'} + C_b] - C_a > \{P(t') - C_a\}e^{-rt'}$. This means that in equilibrium the more efficient technology a is utilized before the less efficient technology b. In fact, this is intuitively obvious; any price high enough to keep technology b in business would tempt those possessing technology a to enter and invest the proceeds in any asset paying the market rate of interest.

We conclude that under conditions assumed here the most efficient energy transformation technology will be used first. Within the utilization period of each technology the royalty of the energy resource on which the technology is based rises at the rate of interest. The price of energy rises at a lower rate which gradually increases toward the rate of interest but never reaches it. At each point of transition between energy transformation technologies the rate of price increase shifts to a lower level and then starts increasing toward the rate of interest again.

The situation is only slightly changed by the existence of energy transformation technologies like hydro power, wind power etc., that is technologies where the accumulated production over time is unlimited, but where there is a maximum yearly production of energy. We can call this a continous energy transformation technology. Once a technology of this kind is installed, the marginal cost of utilizing it is practically zero. Thus, from the other producers' point of view, the installation of, for instance, a hydro power plant, can be regarded as an inward parallell shift of the demand for energy. <u>Ceteris paribus</u>, the price of energy at each point in time will be lower when a continous technology is installed.[1/]

1/ In terms of (2') a reduction of $\overline{P}$ must be accompained by a reduction of P(0).

At the date of the exploitation decision the capital value of a continous energy resource is equal to the present value of all future revenues less the initial investment outlay.[1/] The capital value can be regarded as a royalty on the energy resource. If the roaylty is positive at the given interest rate and the equilibirum energy price path, the continous energy transformation technology is installed at the initial point in time. Otherwise it is not installed at all before the terminal point in time.

3.2.3 Some Remarks on Long Run Energy Prices

The theory presented in this section is extremely simplified.[2/] Yet, it points to a number of important factors behind the long run development of energy prices. Under conditions of certainty and competition the basic factors seem to be:

i) the available quantities of exhaustible energy resources at different extraction cost levels;

ii) the availability and cost of using various energy transformation technologies;

iii) the price-elasticity of energy demand;

iv) the expectations about the date for a major technological breakthrough in the field of energy production.[3/]

First we will discuss the development of energy prices in a case where all the assumptions made in the analysis above hold. Then we will briefly discuss the validity of the conclusions arrived at.

At the present time low-cost oil is the major energy resource in the global energy system.[4/] It seems to be a common view that the supplies

---

1/ Provided there are no operating costs.

2/ A thorough treatment of the economic theory of exhaustible resources can be found in Herfindahl-Kneese (24).

3/ In our analysis these expectations were replaced by perfect knowledge about the data at which a new energy transformation technology with lower costs than existing technologies becomes available.

4/ About 47% of global energy consumption 1971. The figures for coal and natural gas are 33% and 17,5% respectively. See Energihushållning (61), Bilaga 1, p. 11.

of low-cost oil will be exhausted before any major technological breakthrough occurs in the field of energy production. Of course, such a prediction is subject to great uncertainty; new oil fields may be found, demand may grow at a slower rate than expected, etc. However, to the extent that the prediction is correct, we should expect a transition from low-cost oil to costlier energy resources.

Accepting the results from the analysis in the preceeding sections as a valid description of the real world, data about the availability of various energy resources and the cost of utilizing known energy transformation technologies would enable us to estimate the long run development of energy prices. Such an analysis has been carried out by W.D. Nordhaus[1/], who used a linear optimization model to simulate a cost-minimizing sequence of transitions between known energy transformation technologies. The statistical basis for the study consisted of estimates about remaining reserves of different kinds of energy resources, and the cost of using various energy transformation technologies.

In Nordhaus' study the demand for energy was divided into five different categories[2/] which were assumed to be growing over time and completely price inelastic. On the other hand, there existed a wide range of substitution possibilities between various kinds of energy. The breeder reactor was designated as "backstop technology", that is, a technology based on an energy resource in practically unlimited supply.

According to Nordhaus' results an efficient plan for the future U.S. energy supply system implies that breeder reactors (the backstop technology) would be used for electricity generation from the year 2020[3/] and onwards. After 2120 all kinds of energy demand would be satisfied by means of production in breeder reactors. Between 1970 and 2120 there was an increase in the calculated price of energy delivered to all five demand categories. The rate of price increase was generally higher during the subperiod 1970 to 2010 than during the subperiod 2010 to 2120.

1/ See Nordhaus (40)

2/ Electricity generation, industrial heat, residential heat, substitutable transportation, and non-substitutable transportation.

3/ It is interesting to note that in Nordhaus' optimal path light water reactors (conventional nuclear plants) are not introduced until the year 2000.

However, the rates of calculated energy price increases were not substantial. The price of electricity was calculated to grow by 1.1% per annum between 1970 and 2010, while the corresponding figure for energy for transportation purposes was 3.5%. Since the rate of interest was set equal to 10% the royalty would grow at that rate also. For semi-processed energy resources such as crude oil and gasoline, transported to Europe, the calculated rate of price increase was 4.6% and 3.5% respectively.

These figures should, of course, be interpreted with great care. For instance, if breeder reactors are not allowed for security reasons some other, and presumably costlier, backstop technology must be included in Nordhaus' model. In such a case the entire price path for each kind of energy would be affected. The same applies to the case where new energy transformation technologies such as the fusion reactor or technologies based on direct solar energy are developed within the time horizon of Nordhaus' study. Moreover, it cannot be ruled out that gradual improvements of energy transformation technologies serve to reduce, partly or fully, the increase in the relative price of energy resources.

Thus, even within the extremely simplified framework of Nordhaus' study, the results are very uncertain. The main uncertainty, however, is related to a basic assumption underlying Nordhaus' study as well as the analysis presented in the preceding sections, namely the assumption that the future is perfectly anticipated by all economic agents. The approach implies that at the initial point in time there is a set of markets where energy can be bought for delivery at any future point in time. Obviously such a set of markets does not exist in the real world.

When the assumption about the existence of a complete set of future markets is dropped, the markets for current deliveries of energy resources may become unstable. Suppose, for instance, that the royalty on a certain kind of energy resource rises faster than the market value of other assets. The owners of energy resources of this kind then have incentives to reduce the rate of exploitation. Thus, current supply is reduced and the current royalty is futher increased. In the opposite case, where the royalty rises more slowly than the value of other assets, the owners of energy resources have incentives to deplete their deposits as rapidly as possible in order to avoid future capital losses. As a consequence, however, the current royalty is further decreased. However, if there is a group of speculators with correct expectations about the future their activities may stabilize energy resource markets.

This discussion suggests that actual energy resource prices are likely to substantially differ from the prices consistent with equilibrium on a complete set of future markets. Moreover, according to the theory discussed in the preceding sections, such equilibrium prices rise smoothly over time. That may not be the case when there are no future markets. In fact, it cannot be ruled out that energy resource prices decrease, at least for some time, in the future in spite of the transition to high-cost deposits.

However, in the empirical part of this study the assumption is that real energy resource prices will increase in the future. The rates of increase are assumed to be 3% per annum. After the discussion in this chapter it should be obvious that the realism of that assumption is very difficult to evaluate.

3.3 Economic Growth with Rising Energy Resource Prices.

In this study we focus on the impact of changing energy prices on energy consumption patterns. However, there are also other effects. For instance, if the cost of imported energy resources rise, more capital and labor must, *ceteris paribus*, be employed in producing export and import competing goods. Consequently,relatively less production factors can be employed producing consumer goods and services or investment goods.

The purpose of this section is to briefly indicate the relative importance of this aspect of higher energy cost. Since imported oil is the dominating energy resource used in Sweden the discussion can be confined to the impact of rising costs for imported oil on the growth of material (non-oil) consumption in Sweden. Thus we will simply analyze to what extent rising prices of imported oil affect Sweden's terms of trade, and to what extent a given terms of trade deterioration affects the growth of material (non-oil) consumption in the country.

To begin with we derive a simple formula, using the following symbols:

$P \cdot M$ = value of total imports;

$P_e \cdot E$ = value of imported energy resources;

$P_y \cdot M_y$ = value of non-oil imports.

The import volumes M, E and M_y are all expressed in constant, base-year prices. The price variables P, P_e and P_y represent the price of total imports, oil imports, and non-oil imports respectively, in relation to an index of export prices. The variable P is the inverse of the country's terms of trade.

Definitionally it holds that

$$P \cdot M = P_e \cdot E + P_y \cdot M_y$$

or

$$P = \frac{P_e \cdot E}{M} + \frac{P_y \cdot M_y}{M} \qquad (1)$$

On the assumption that changes in the world market prices of oil affect imported and exported non-energy commodities to the same extent, differentiation of (1) with respect to P_e yields

$$\frac{\partial P}{\partial P_e} = \frac{1}{M} \{E(P_e) + P_e \frac{dE}{dP_e}\}$$

which means that the change in relative import prices becomes

$$dP = \frac{1}{M} \{E(P_e) + P_e \frac{dE}{dP_e}\} dP_e \tag{2}$$

Multiplication of (2) with $\frac{1}{P}$ and rearrangement of terms yields

$$\frac{dP}{P} = \frac{P_e \cdot E}{P \cdot M} \{1 + \frac{dE}{dP_e} \frac{P_e}{E}\} \frac{dP_e}{P_e} \tag{3}$$

where the second term within the brackets simply is the price elasticity of the demand for imported oil.

As can be seen in (3) a change in oil prices in relation to export prices does not affect the country's terms of trade if the demand for oil has a price eleaticity of unity. If demand is inelastic an oil price increase tends to deteriorate the terms of trade, while the opposite holds when demand is elastic.

The price elasticity of the demand for oil reflects the total effect of a number of substitution mechanisms in the economy; higher oil prices induce producers in the energy sector as well as other sectors to change their methods of production, and higher prices of oil intensive products induce consumers to change their patterns of consumption. In general a reduction in oil consumption can, ceteris paribus, be attained only by increasing the use of some other factors of production. Thus, even in a case where an oil price increase does not affect the country's terms of trade, less capital and labor may be available for production of consumer goods and services.

For illustrative puposes we can make a few calculations by means of (3). The term $(P_e \cdot E) : (P \cdot M)$ in (3) represents the value of oil imports in relation to the value of total imports. In 1975 the numerical value of this fraction was about 0.15. Thus, if the price elasticity of oil demand is zero, a 7% increase of oil prices leads to a 1% deterioration in the terms of trade.

In a study by T. Restad[1/] the impact on the growth of the consumption of goods and services of a 2% annual deterioration in Sweden's terms of trade between 1980 and 2000 was estimated. The result was that the annual growth of consumption of goods and sercices was reduced from 3% to 2%. The growth of exports increased from 3.0 - 3.3% to 4.6 - 4.7% per annum. According to our calculation above a 2% annual terms of trade deterioration roughly corresponds to a 14% annual increase in real oil prices, provided the price elasticity of oil demand is zero. These results indicate that the growth of the economy mainly is determined by other factors than oil (or energy) prices. With this background it seems reasonable to confine the analysis of the effects of changing energy prices to their impact on energy consumption patterns.

With this discussion we leave the macroeconomic growth issues as well as the determination of energy resource prices. The rest of this study is devoted to an analysis of the relation between the size and structure of the Swedish consumption of energy and a couple of strategies for the nuclear power policy in Sweden. The emphasis is on the substitutability of energy and other factors of production. We will identify different substitution mechanisms and try to estimate the contribution of these substitution mechanisms to the total flexibility of Sweden's demand for energy.

1/ See Restad (47)

P A R T I I

T H E M O D E L

4. SOME THEORETICAL AND EMPIRICAL ASPECTS OF THE COMPLETE MODEL SYSTEM

The model of the Swedish economy used in this study was originally developed at the request of the Energy Forecasting Commission.[1] It is intended as a tool for predicting energy demand. In this study the model is referred to as the "Energy Forecasting Model" (EFM).[2] However, this terminology is somewhat misleading; the EFM is not a single model, but rather a system of models.

The purpose of this chapter is to descibe the general structure of the EFM and to discuss some theoretical and empirical aspects of the model system. We also indicate how the model is used in this particular study. The next three chapters each deal with a particular submodel of the EFM. The so-called "Final Commodity Supply Submodel" is described in Chapter 5. Then the electricity and heat supply submodel is developed in Chapter 6 and the residential heating services supply model in Chapter 7.

The first section of this chapter contains a very brief description of the modelling approach represented by the EFM. The supply model is discussed in some detail in Section 4.2 and the demand model is dealt with in Section 4.3. The problems associated with solution of the complete model are dealt with in Section 4.4. The use of the EFM in this particular study is indicated in Section 4.5.

4.1 The Complete Model

4.1.1. The General Structure of the Energy Forecasting Model

The EFM represents a general equilibrium approach to energy modelling in the sense that there is interaction between a number of markets in the model-economy. One important aspect of the EFM is that energy is

---

1) In the middle of 1974 the Energy Forecasting Commission became part of the Energy Department at the National Industrial Board.

2) The EFM is described in detail in Bergman et al. (8).

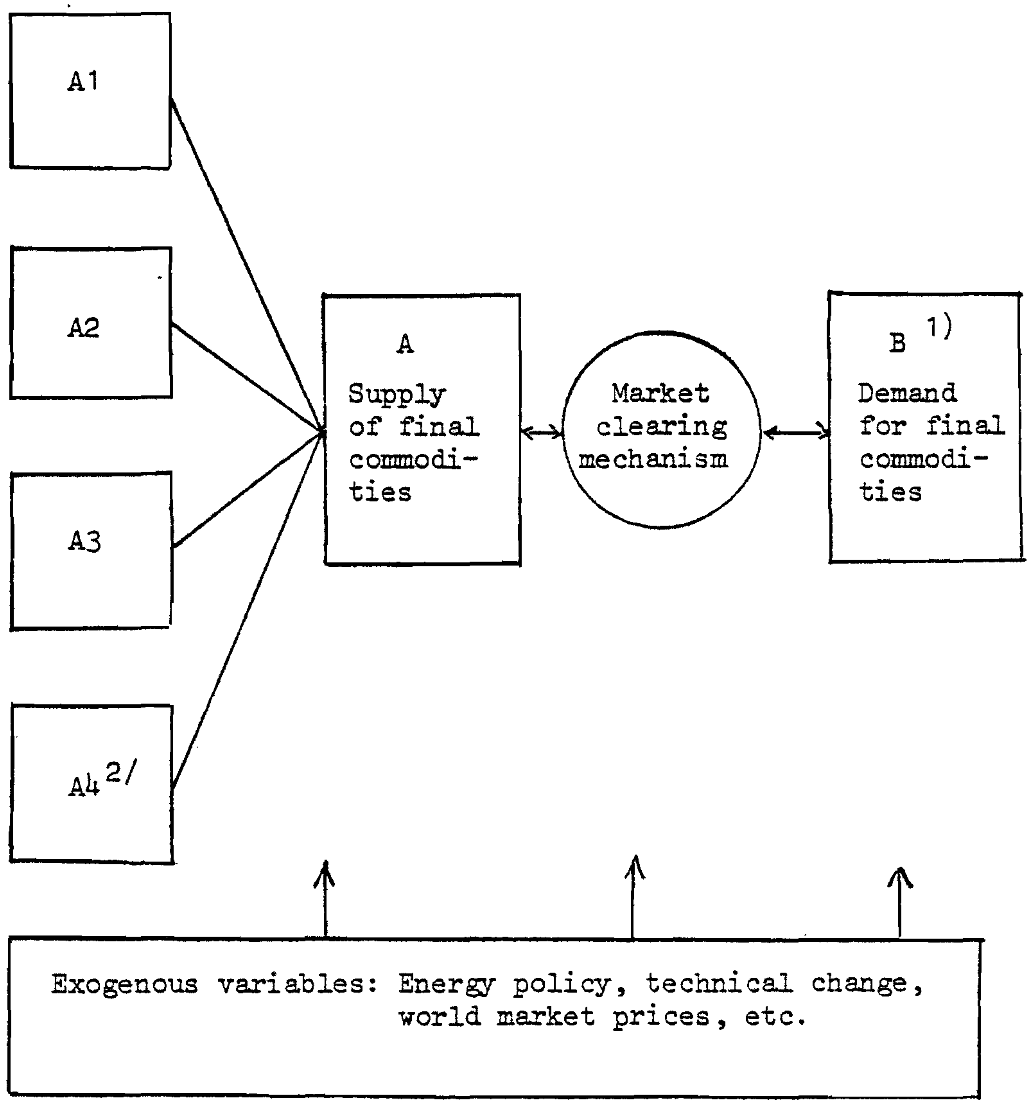
treated as an intermediate good, the demand for which is derived from the demand for final goods and services. Another important aspect of the EFM is that the mathematical structure of the supply model differs radically from that of the demand model.

The supply model consists of a set of linear activity models which can be linked to each other. The various submodels cover different sectors in the private production system of the Swedish economy. Three of the submodels are based on engineering data and one on input-output data. Mathematically the supply submodels are formulated as cost minimization linear programming models. This means that for each set of exogenously determined final demand for the outputs of the production sectors, the supply model determines a set of cost minimizing production and investment activities. A set of supply (shadow) prices for the different commodities is associated with each optimal solution to the supply model.

The demand model comprises a private and a public demand model. Public demand is determined by a simple transformation of development in the public sector into demand for the outputs of the private production sector. This means that in the EFM, public demand is exogenously determined and thus inelastic with respect to price variations.

The private demand model consists of a set of simultaneously estimated non-linear demand functions where commodity prices and the level of real expenditures appear as explanatory variables. The parameters of the private demand model are estimated on the basis of time series data on prices, expenditures and demanded quantities.

The complete system of models can be visualized as follows:



A1 = The non-energy commodity supply submodel

A2 = The residential heating services supply submodel

A3 = The electricity and hot water supply submodel

A4 = The refined petroleum products supply submodel[2)]

1/ Developed by Björklund.

2/ Developed by Bergström.

Each submodel in the set which comprises the supply model can either be used alone or be linked to one or all of the other supply submodels. The supply model can be regarded as a multi-period input-output model where some sectors have been given extensive treatment. Submodels A2 - A4 are the elaborated parts of the model, while A1 is what remains of the input-output model. An obvious development of the model would be to replace additional input-output vectors in A1 by submodels.

The supply submodels can easily be linked to each other simply because they all have the same mathematical structure; when two supply submodels are linked together the size of the linear programming problem increases, but is still a linear programming problem. Thus, the existence of solutions to the supply model can easily be proved. However, since the mathematical structure of the supply and demand models are quite different, the existence, uniqueness and stability of solutions to the complete model are not self-evident. As indicated in the above diagram, some sort of market clearing mechanism is required to bring about equality between supply and demand on all markets of the model economy. The treatment of this problem in the present study is discussed in Section 4.4.

There are three kinds of energy policy parameters in the model:

i. the set of available energy transformation technologies can be changed;

ii. taxes can be levied on different kinds of energy;

iii. the maximum supply of different kinds of energy can be constrained.

The demand for energy, as determined by the model, is influenced by assumptions about the world market prices of energy and other commodities as well as assumptions about the input-output relations in the production system.

4.1.2 Motivation for the Choice of Model Structure

The general idea underlying the EFM is that it should be a model of the entire Swedish economy based on an input-output framework. Both of these features facilitate the coordination of energy predictions with medium and long-term predictions as to the general development of the Swedish economy made by the Ministry of Finance.[1)]

Another important point of departure was that in order for energy demand predictions to aid in the formulation of energy policy strategies, these predictions should be based on explicit energy policy assumptions and important exogenous variables such as the world market price of oil.

Given these very general goals, the model can be constructed in many different ways. The final model choice involves two steps. The first is to determine which parts of the economy should be treated extensively. The second is to choose a type of model which is appropriate in terms of the issues to be studied. The actual choices regarding these two steps in the development of the EFM were briefly described in the preceding section. These choices will now be motivated.

The power and heat and the refinery sectors were given elaborate treatment in the model simply because the choice of a strategy for future energy policy is likely to have a direct impact on the development in these sectors. Access to these two submodels enables us to study the substitutability of different kinds of primary energy, including different kinds of crude oil, at a given level and composition of secondary energy demand. This makes it possible to evaluate the impact of different energy policy measures on the prices of secondary energy.

---

1) At the Ministry of Finance, two qualitatively different macroeconomic multisectoral growth models are used for medium (5 years) and long-term predictions about the development of the Swedish economy. Both of these models can be regarded as elaborated input-output models. See SOU (66), SOU (67) and Restad (47).

In general capital and/or labor can be substituted for secondary energy in the production of goods and services. From an energy policy point of view, the substitutability of different factors of production is particularly important in sectors where a large share of the energy supply is consumed. This means that in studying the Swedish energy situation, the most important sectors are residential heating, paper and pulp transportation and iron and steel.[1] Due to the resource constraint, however, residential heating was the only sector given elaborate treatment in the EFM.

The decision to deal extensively with the household demand for final non-energy goods and services in EFM was based on the observation that there are substantial variations in the total energy used to produce different goods and services.[2] Consequently, the composition of the final demand for goods and services is an important determinant of the demand for energy. This conclusion is supported by the results of our analysis in Chapter 2.

However, the findings in Chapter 2 indicated that the postwar development of energy prices did not have any significant effect on the composition of final demand. Thus, it could be argued that an extensive household demand model is not necessary in a model such as the EFM; the development of final demand is important from an energy point of view, but the choice of a strategy for energy policy is not likely to significantly affect the composition of final demand. On the other hand, it was pointed out that if the relative prices of energy rise, the price elasticity of energy demand is also likely to increase.

Thus, we cannot rule out the possibility that rising energy prices will have an impact on the composition of the final demand for goods and services. Moreover, the choice of a strategy for energy policy will

---

1) Approximately 30 % of the total consumption of secondary energy in Sweden can be assigned to the residential heating sector, about 17 % to the paper and pulp industry and about 8 % to the basic metal industry.

2) This was clearly indicated in Bergman & Bergström (7).

certainly have an effect on the development of energy prices. Accordingly it became obvious that at least part of the final demand for goods and services should be an endogenous part of the EFM.

The process of choosing the mathematical structure of the different parts of the EFM was based on the following considerations. In the case of the demand for final goods and services, the model was intended to incorporate the past behavior of households in response to price and real income variations. This consideration calls for an econometric approach. Moreover, since the demand for a particular commodity is not independent of the consumption of other commodities, it is desirable that the demand model consists of one demand equation for each of the commodities demanded by the households, and that all demand equations should be estimated simultaneously. A number of demand models have these features and the choice between them is discussed briefly in Section 4.3.

In the case of the supply model, three main approaches were contemplated:

i. A model where all input-output coefficients are endogenously determined. The model developed by Hudson and Jorgenson [1] for the Energy Policy Project of the Ford Foundation represents an example of this approach.

ii. An elaborated input-output model where the labor and capital input coefficients are determined by means of sectoral production functions and neoclassical profit maximization assumptions. The multisectoral growth model developed by Johansen[2] represents an example of this approach.

iii. An input-output model which is extended by means of additional processes (input-output vectors) in some or all sectors, and

---

1) See Hudson & Jorgenson (28).

2) See Johansen (30). A quite similar approach was adopted by Restad in his work for the Ministry of Finance. See Restad (47).

thus transformed into a linear activity model. The model developed by Thoss[1)] represents an example of this approach.

It has already been indicated that we chose the third approach. The main reasons for this choice are as follows.

The first approach, exemplified by the Hudson & Jorgenson model, is indeed quite elegant from a theoretical point of view. A change in relative factor prices leads to changes in factor proportions, and the predicted changes in factor proportions are consistent with past behavior. From the point of view of the EFM project, however there are several drawbacks connected with the Hudson & Jorgenson approach.

Since the estimation problems increase markedly as the size of the model increases, the number of sectors and commodities in a model of this type has to be kept small. Only eleven different kinds of commodities, nine production sectors and four kinds of production factors were incorporated in the Hudson & Jorgenson model. Four of the commodities were energy commodities. For the same reason, some separability assumptions had to be imposed. Thus, the input-output coefficients in the Hudson & Jorgenson model are determined in two steps. First the relative input proportions of capital, labor, an aggregated input denoted "materials" and an aggregated energy commodity are determined. Then the composition of the aggregated materials and energy inputs is determined in separate submodels. This procedure represents a simplification that is difficult to evaluate. In any case all of the sectors included in the projections carried out by the Swedish Ministry of Finance cannot be dealt with separately using the approach represented by the Hudson & Jorgenson model.[2)]

---

1) See Thoss, (51).

2) There are 24 sectors in the medium-term model and 15 in the long-term model.

Another problem inherent in the Hudson & Jorgenson approach is that the input-output coefficients are determined as the partial derivatives of the price-possibility frontier. In order to estimate the parameters of the price-possibility frontier access to accurate price data is needed. Since such data for Sweden are not readily available no attempt was made to apply the Hudson & Jorgenson approach.

The second model approach, represented by the Johansen model, does not require any sophisticated estimation techniques. The number of sectors to which it is applied can be increased with very few complications. However, the Johansen approach is not well suited when different sectors are to be treated on different levels of aggregation. For this reason the Johansen approach was not chosen in the EFM project.

In the third approach, the linear activity model, both the number of sectors and the number of available technologies can be varied in accordance with the availability of data. Thus, with this approach both engineering and input-output data can be utilized within the same framework.

As indicated above, the linear activity approach was chosen for the supply side of the EFM. This choice is motivated primarily by the ease with which particular technologies can be incorporated into or deleted from the model. Of course we could have used various kinds of models for different parts of the production system. But this would have augmented the problems connected with linking different parts of the complete model system. Thus, the same modelling approach was applied for the entire production system.

Before proceeding with a description of the EFM, a few general remarks about its features are needed. The basic feature of the EFM is that the rate of interest, the wage rate and the productivity of labor are exogenously determined variables in the model while the composition of the final consumption of goods and services is endogenously determined in the model. This means that economic growth in the EFM is the result of exogenously determined labor productivity increases. However, in an elaborated model of economic growth, the factor prices, productivity of labor and composition of final consumption of goods and services are interdependent endogenous variables.

Thus, the approach adopted here is very unsophisticated, but it can easily be defended. In order to determine factor prices endogenously in a model, the technological possibilities to substitute different factors of production for each other should be reasonably well incorporated in the model. This is not the case for the EFM. As was mentioned above a few sectors only is given an elaborate treatment in the model. It is quite clear that such a partial description of the economy's set of available technologies is likely to severly bias the estimates of the factor prices if these were endogenous in the model.

However, this observation does not solve the problem. Since factor prices and the productivity of labor are interdependent, the exogenous assumptions about these variables must be consistent with each other. This is potentially a very difficult problem, but in this particular case we can take advantage of the studies carried out by the Ministry of Finance, especially by T. Restad.[1] Thus, estimates of the development of factor prices, labor productivity and final consumption of goods and services can be obtained from Restad's studies and used as inputs for simulations using the EFM.[2]

This means that a prediction about the development of the Swedish economy is the point of departure for the present study.

This basic assumption about the development of the economy is called the "reference path". Then the EFM is used to simulate the growth of energy consumption along the reference path, and how these energy consumption patterns are changed as a result of energy policy measures.

---

1) See T. Restad, (47).

2) When the input data used in this study was collected, Restad's study was not finished. In Chapter 10 more is said about how Restad's figures were used in this study.

4.2 The Supply Model

We begin the description of the supply model with a very general formulation of the model in subsection 4.2.1. The similarities between this supply model and a complete general equilibrium model are also discussed. The problems connected with the stock of capital remaining at the terminal point in time are discussed in subsection 4.2.2. Then, in 4.2.3, it is shown how the supply model can be decomposed into a number of submodels. The treatment of foreign trade is described in 4.2.4. Some general remarks about the properties of the supply model are made in 4.2.5.

4.2.1 The Supply Model and its Relation to Economic Theory

The supply model is based on the assumption that there is a certain amount of productive capacity in the production sectors at the initial point in time. The final demand for each kind of commodity is exogenously determined for each period between the initial and terminal points in time. Each kind of commodity can be produced by means of other commodities, capital and labor, combined in a finite number of different proportions. All feasible combinations of production factors which yield an output are denoted "production processes".

"Capital" in this context refers to different combinations of commodities produced at least one period earlier. Thus, labor and the stock of capital existing at the initial point in time are the only primary factors of production in the model. Since the utilization of the stock of capital that exists at the initial point in time does not require any use of resources, labor is the only real production cost. As was mentioned above the wage rate is exogenously determined.

The supply model is solved by means of the assumption that producers minimize the present value of the costs connected with satisfying the exogenously determined final demands between the initial and terminal points in time. This means that the criterion function has two elements. The first is direct labor costs resulting from productive activities during the different periods. The second is the present value of the stock of useable capital existing at the terminal point in time.

The value assigned to one unit of capital in a given sector at the terminal point in time obviously has a considerable effect on the model solution. This problem will be dealt with below. We now focus our attention on the interpretation of an optimal solution to the supply model.

We begin with a general formulation of the supply model. Two observations should be made at the outset. First, the model contains one variable which is redundant at this stage of the exposition, $R_j(t)$, utilization during period t of the remaining share of the capacity in process j that existed at the initial point in time. The way this variable is utilized in our study will be shown in Section 4.2.5. The inclusion of the variable $R_j(t)$ implies that a distinction is made between capital existing at the initial point in time and endogenously accumulated capital. Second, "capital" is measured by its capacity to produce output. Thus, one unit of "capital" in sector j represents the amount of capital goods that can be used to construct sufficient capacity to produce one unit of output in sector j. It should also be noted that when an investment decision is made during period t, the new capacity is available in period t+1.[1] This means that no endogenously accumulated capital is available in the first period.

The model is formulated as follows. Let i denote a commodity and j a supply process. Assume that there are n commodities and m supply processes and that $m \geq n$. Assume further that a supply process, for either intermediate or final goods, has only one output and uses at least one input. The following symbols are used.

t = period index (t runs from 1 to T)

r = interest rate

$C_i(t)$ = final consumption of commodity i during period t

---

1) In the electricity and heat production sector, the construction lag is two periods for some plants, and in the residential heating sector there is no construction lag. In order to save symbols, however, the construction lag is assumed to be one period in all sectors in the general formulation of the supply model.

$X_j(t)$ = activity level of process j during period t

b_{ij} = output of commodity i when process j is utilized at unit level

$\Delta K_j(t)$ = capacity addition to process j

$K_j(t)$ = endogenously accumulated capacity stock of process j in period t, measured in output

$K_j(0)$ = initial stock of capacity, measured in output, in process j

$R_j(t)$ = utilization of the initial capacity stock of type j during period t; measured in output

δ_j = rate of depreciation of the capacity stock of process j

a_{ij} = input for immediate use of commodity i in process j when this process is utilized at unit level

A_{ij} = amount of commodity i required when the capacity of process j is increased by one unit

$n_j(t)$ = input of labor in process j when this process is utilized at unit level

$N(t)$ = employment in period t

$\omega(t)$ = wage rate during period t

$\psi_j(T)$ = factor by which one unit of capacity in sector j at the terminal point in time is valued at the initial point in time.

The symbols above can be classified as follows:

Endogenous variables

$X_j(t)$, $\Delta K_j(t)$, $K_j(t)$, $R_j(t)$, $N(t)$.

Exogenous variables[1)]

$C_i(t)$, $K_j(0)$, $n_j(t)$, $\omega(t)$, $\psi_j(T)$.

Parameters[1)]

a_{ij}, A_{ij}, b_{ij}, r, δ_j.

---

1) See note 1 on next page.

The function $\phi(t)$ is defined as

$$\phi(t) = (1+r)^{-(t-1)}.$$

In the following, endogenous variables are written on the left-hand side and exogenous variables on the right-hand side of the equations. The symbols in parenthesis on the extreme right-hand side of the constraints denote the dual variables associated with the corresponding constraint. The model then becomes:

Objective function to be minimized

$$F(T) = \sum_{t=1}^{T} \phi(t)\ \omega(t)\ N(t) - \sum_{j=1}^{m} \psi_j(t)\ K_j(T).$$

Commodity balances

$$\sum_{j=1}^{m} (b_{ij} - a_{ij})\ X_j(t) - \sum_{j=1}^{m} A_{ij}\ \Delta K_j(t) \geq C_i(t); \quad \forall i,\ t\ ;\ [\pi_i(t)].^{2)}$$

Capacity constraints

$$R_j(t) + K_j(t) - X_j(t) \geq 0\ ; \qquad \forall j,\ t\ ;\ [\beta_j(t)].$$

Use of labor

$$N(t) - \sum_{j=1}^{m} n_j(t)\ X_j(t) \geq 0\ ; \qquad \forall t\ ;\ [\alpha(t)].$$

Resource constraints

$$-R_j(t) \geq -(1-\delta_j)^t\ K_j(0)\ ; \qquad \forall j,\ t\ ;\ [\gamma_j(t)].$$

---

1) The distinction between "exogenous variables" and "parameters" is not obvious. In this study "exogenous variables" are dated variables determined outside the model, while "parameters" are constants.

2) The variables $\Delta K_j(t)$ are not defined for $t = T$. The reason for this is discussed in section 4.2.2.

Intertemporal links

$$\sum_{\tau=1}^{t} (1-\delta_j)^{t-\tau} \Delta K_j(\tau-1) - K_j(t) = 0 \; ; \qquad \forall j,\ t = 2\ldots,\ T \quad [\kappa_j(t)].$$

Non-negativity constraints

$$X_j(t),\ K_j(t),\ \Delta K_j(t),\ R_j(t),\ N(t) \geq 0 \qquad \text{for all } j \text{ and } t.$$

It should be noted that there is no constraint on total employment. However, when the empirical version of the model is utilized, the vectors $C(t) = (C_1(t), \ldots, C_n(t))$ are chosen so that the demand for labor by the production sectors is compatible with the estimated supply of labor in the different periods.

In a situation of general economic equilibrium the price system has the following properties:

i. If commodity h is the (only) output of process q, the price of commodity h is less than or equal to the marginal cost of utilizing process q, and there is equality if process q is utilized in equilibrium.

ii. The cost of one unit of additional capacity in process q is less than or equal to the present value of all future operating surpluses obtained from that capacity, and there is equality if investments in process q are carried out in an equilibrium solution.

We now investigate whether a price system with these properties can be associated with an optimal solution to the supply model of the EFM. If this can be accomplished, the price system can be regarded as a system of supply prices, conditioned by the model structure and the values of the parameters and exogenous variables of the model. Obviously it is interesting to study how such a price system is affected by various energy policy measures.

Prices are treated on the basis of a dual formulation of the supply model. This formulation becomes:[1)]

Objective function to be maximized

$$G(T) = \sum_{t=1}^{T} \{ \sum_{i=1}^{n} \pi_i(t)\ C_i(t) - \sum_{j=1}^{m} \gamma_j(t)\ (1-\delta_j)^t\ K_j(0)\}.$$

Constraints

$$\sum_{i=1}^{n} \pi_i(t)\ (b_{ij}-a_{ij}) - \alpha(t)\ n_j(t) - \beta_j(t) \leq 0\ ; \quad [1]\ ;\ [X_j(t)]$$

$$-\sum_{i=1}^{n} \pi_i(t)\ A_{ij} + \sum_{\tau=t+1}^{T} \kappa_j(\tau)\ (1-\delta_j)^{\tau-t-1} \leq 0\ ; \quad [2]\ ;\ [\Delta K_j(t)]$$

$$\beta_j(t) - \kappa_j(t) \begin{cases} \leq 0 & \text{when } 1 \leq t < T \quad [3]\ ;\ [K_j(t)] \\ \leq -\psi_j(T) & \text{when } t = T \quad [4]\ ;\ [K_j(T)] \end{cases}$$

$$\alpha(t) \leq \phi(t)\ \omega(t)\ ; \quad [5]\ ;\ [N(t)]$$

$$\beta_j(t) - \gamma_j(t) \leq 0\ ; \quad [6]\ ;\ [R_j(t)].$$

In order to demonstrate the properties of the supply model, we assume that the final demand for all commodities is positive and that it grows over time. We confine the discussion to period t^* where $1 < t^* < T$. Commodity h is assumed to be the only output commodity of process q. That is,

$$b_{iq} \begin{cases} = 1 & \text{when } i = h \\ = 0 & \text{when } i \neq h. \end{cases}$$

On the basis of these assumptions we will derive an expression for the price of commodity h in period t^*. Consider a case where process q is utilized during period t^* in an optimal solution ($X_q(t^*) > 0$). This

---

1) The primal variables corresponding to the dual constraints are written to the extreme right of each constraint.

means that [1] must be an equality for $t = t^*$ and $j = q$.[1] Since the remaining share of the initial capacity of process q is freely available $R_q(t^*)$ is positive whenever $X_q(t^*)$ is positive. Consequently [6] must be an equality for $t = t^*$ and $j = q$.

In any realistic case $n_q(t^*) > 0$. When both $X_q(t^*)$ and $n_q(t^*)$ are positive, $N(t^*)$ also has to be positive. Accordingly [5] must be an equality for $t = t^*$ in an optimal solution to the supply model.

Thus, from the assumption that $X_q(t^*) > 0$, we get

$$\pi_h(t^*) = \sum_{i=1}^{n} \pi_i(t^*)\, a_{iq} + \phi(t^*)\, \omega(t^*)\, n_q(t^*) + \gamma_q(t^*) \qquad [1']$$

$$\gamma_q(t^*) - \kappa_q(t^*) \leq 0 \qquad [3']$$

Next we define $P_i(t) \equiv \phi(t)^{-1} \cdot \pi_i(t)$ for all i, t. Given this definition, how should the variables $P_i(t)$ be interpreted? In order to answer this question, $\pi_h(t^*)$ is replaced by $\phi(t^*)\, P_h(t^*)$ in [1']. Multiplying by $\phi(t^*)^{-1}$ we get:

---

1) The following discussion is based on the equilibrium theorem for linear programming; see Lancaster (33), p. 33. Let the primal formulation of a linear programming problem be

$$\min\ Cx \quad \text{s.t}\ Ax \geq b,\ x \geq 0$$

where A is a matrix and C, x and b are vectors. The corresponding dual problem then becomes

$$\max\ y \cdot b \quad \text{s.t}\ y \cdot A \leq C,\ y \geq 0$$

According to the equilibrium theorem it then holds that if x*, y* are feasible for the primal and dual, they are optimal if and only if

(1) $y_i^* = 0$ whenever $\sum_j a_{ij}\, x_j^* > b_i$

(2) $x_j^* = 0$ whenever $\sum_i a_{ij}\, y_i^* < c_j$,

that is, the k^{th} variable in one program is zero whenever the k^{th} constraint in the other program is ineffective.

$$P_h(t^*) = \sum_{i=1}^{n} P_i(t^*)\, a_{iq} + \omega(t^*)\, n_q(t^*) + \phi(t^*)^{-1} \cdot \gamma_q(t^*).^{1)} \qquad [1'']$$

Thus, if we regard $\phi(t^*)^{-1}$. $\gamma_q(t^*)$ as the operating surplus per unit of output in process q during period t^*, $P_h(t^*)$ can be interpreted as the price of commodity h in period t^*. Accordingly $\pi_h(t^*)$ can be regarded as the present value, evalutated at the initial point in time, of the price of commodity h in period t^*. Moreover, since the model is linear, the right-hand side of [1'] can be interpreted as the marginal cost of commodity h in period t^*. This means that for each optimal solution to the supply model, there is a corresponding system of marginal cost determined commodity prices. We take advantage of this property in applications of the model.

We continue our discussion of the properties of the model by investigating the relation between the dual variables $\kappa_j(t)$ and $\gamma_j(t)$. The latter indicates the marginal value of an additional unit of initial capacity in process j. The variable $\kappa_j(t)$ represents the marginal value of an additional unit of capacity in process q constructed some time between the initial point in time and period t-1. In accordance with [3'], $\gamma_j(t)$ is less than or equal to $\kappa_j(t)$ for all $t < T$ and for all j. It thus holds for j=q and $t=t^* < T$.

---

1) If there is joint production in process q, we can derive the following expression in the same way as we derived [1''] :

$$\sum_{i=1}^{n} P_i(t^*) \cdot b_{iq} = \sum_{i=1}^{n} P_i(t^*)\, a_{iq} + \omega(t^*)\, n_q(t^*) + \phi(t^*)^{-1} \cdot \gamma_q(t^*). \qquad [1''']$$

If the variables $P_i(t^*)$ are interpreted in the same way as above, [1'''] implies that process q is utilized in period t^* in an optimal solution to the model if the marginal revenue is equal to the marginal cost of utilizing the process.

It follows from the equilibrium theorem of linear programming that [3'] is an equality for j=q and t=t* only if $K_q(t^*)$ is positive. However, $K_q(t^*)$ can be positive only if $\Delta K_q(t)$ is positive for some $t < t^*$. Whenever this is the case, $K_q(t)$ is positive for all $t>t^*$.[1)] Thus, once the need for capacity in process q is larger than the remaining share of the initial capacity, the marginal value of initial capacity becomes equal to the marginal value of newly constructed capacity.

When $\Delta K_q(t^{**})$ is positive, there is equality in [2] for j=q and $t=t^{**}$ and in [3'] for j=q and $t>t^{**}$. Moreover, [2] for j=q and $t=t^{**}$ and [3'] for j=q and $t>t^{**}$ contain the variable $\kappa_q(t)$.

Now, consider a solution where $\Delta K_q(t^{**})$ is positive. The dual constraint [2] for j=q and $t=t^{**}$ then becomes

$$\sum_{i=1}^{n} \pi_i(t^{**})\, A_{iq} = \sum_{\tau=t^{**}+1}^{T} \kappa_q(\tau)\, (1-\delta_q)^{\tau-t^{**}-1},$$

or, since $\pi_i(t^{**}) \equiv \phi(t^{**})\, P_i(t^{**})$,

$$\underbrace{\sum_{i=1}^{n} P_i(t^{**})\, A_{iq}}_{\text{I}} = \sum_{\tau=t^{**}+1}^{T} \underbrace{\phi(t^{**})^{-1}\, \kappa_q(\tau)}_{\text{II}}\, \underbrace{(1-\delta_q)^{\tau-t^{**}-1}}_{\text{III}} . \qquad [2']$$

The term denoted I above expresses the price, in period t^{**}, of one unit of capacity in process q. The term III indicates the share of some part of capacity, constructed in period t^{**}, that remains in each of the periods between t^{**} and T.

---

1) Capacity is subject to depreciation by a constant annual rate. Thus some part of capacity is never completely scrapped.

The investment in process q in period t^{**} made $\gamma_q(t)$ equal to $\kappa_q(t)$ for all $t^{**} < t < T$. In the terminal period, $\gamma_q(T)$ is equal to the sum of $\kappa_q(T)$ and $\psi_q(T)$, where $\psi_q(T)$ is the value of the capacity stock in process q that remains at the end of the terminal period. However, when we interpreted [1''] above, $\phi(t)^{-1}\ \gamma_q(t)$ was regarded as the operating surplus per unit of output in process q in period t. If we use this interpretation of $\phi(t)^{-1}\ \gamma_q(t)$ and take the discussion above into account, [2'] indicates that whenever an investment in process q is carried out, the present value of all future gross profits obtained from the additional capacity are equal to the price of that capacity.

By interpreting $\phi^{-1}\ \gamma_q(t)$ in this way, an optimal solution to the supply model is consistent with a situation of general economic equilibrium; it holds for all processes that the marginal revenue (the price of the output commodity) is less than or equal to the marginal cost of utilizing the process in question, and these magnitudes are equal whenever the process is utilized in an optimal solution. Further, the marginal cost of an investment is less than or equal to the marginal revenue of the investment (the present value of future operating surpluses), and these magnitudes are equal for each investment that is actually carried out. Thus, although the formulation of the supply model represents a substantial simplification of a complete general equilibrium model, the propositions about the nature of the price system, derived from general equilibrium theory, are reproduced by the supply model.

In a steady state, the operating surplus obtained from a unit of capacity should correspond to a rate of profit that is equal to the interest rate. Next we investigate whether this condition is fulfilled by the present model. First, we define:

$$\rho_j(t) \equiv \phi(t)^{-1}\ K_j(t)$$

and

$$P_{Kj}(t) \equiv \sum_{i=1}^{n} P_i(t)A_{ij}$$

and substitute these expressions in [2']. We then get

$$P_{Kq}(t^{**}) = \sum_{\tau=t^{**}+1}^{T} \phi(t^{**})^{-1} \phi(\tau) \rho_q(\tau) (1-\delta_q)^{\tau-t^{**}-1}.$$

Consider a case where the numerical values of the model's parameters and exogenous variables do not differ between periods. It then holds that $P_{Kq}(t)$ and $\rho_q(t)$ also remain constant over time. We recall that

$$\phi(t) = (1+r)^{-(t-1)}.$$

We then get:

$$P_{Kq} = \sum_{\tau=t^{**}+1}^{T} (1+r)^{t^{**}-\tau} \rho_q (1-\delta_q)^{\tau-t^{**}-1}.$$

Next, if the number of periods is extended to infinity, we can write

$$P_{Kq} = \frac{\rho_q}{1+r} + \frac{\rho_q(1-\delta_q)}{(1+r)^2} + \frac{\rho_q(1-\delta_q)^2}{(1+r)^3} + \ldots$$

which is an infinite geometrical progression where the constant term is $\rho_q/(1+r)$ and the quotient is $(1-\delta)/(1+r)$. It then follows that

$$P_{Kq} = \frac{\rho_q}{r+\delta_q} \Longleftrightarrow \rho_q = (r+\delta_q)P_{Kq}.$$

Thus, when the exogenous conditions of each of the model periods are identical, the optimal solution to the model can be interpreted as a steady state economic equilibrium. In such an equilibrium, a scarcity rent, $\gamma_j(t)$, is assigned to each unit of the remaining initial capacity in process j which is fully utilized. Whenever new investments are made in process j, the scarcity rent assigned to the initial capacity becomes equal to the sum of interest and depreciation on new capacity.

We can now conclude that the formulation of the supply model is such that an optimal solution to it is consistent with conventional general equilibrium theory. The basic difference between the supply model and a complete general equilibrium model is that the final demand for goods and services is exogenously determined.

4.2.2 The Terminal Conditions

The EFM was developed for analysis of an arbitrarily chosen finite time period. Regardless of the length of the time period chosen, some useable capacity will always remain in the production sectors at the terminal point in time. If no value at all is assigned to this capacity, the economic lifetime of a unit of capacity will be shorter, the later the investment is carried out. Accordingly the solutions to the supply model will be biased and the supply prices determined by the model will tend to increase over time. The solution for a particular period t^* will be affected by a change in the number of periods from T to T+1.

However, the distortions are more pronounced in the later periods of the model as compared to the earlier ones. This problem can, in practice, be circumvented by extending the number of periods. For instance, if we are interested in a model solution for T periods, it is solved for T+N periods where N is a large positive integer.

A special case of this method involves making the last period considerably longer than the other periods. But this means that a number of identical periods, or a period of constant growth in all sectors, are assumed to follow after the terminal point in time. In other words, the economy is assumed to adjust itself to a situation of uniform growth from the last period and onwards.

In practice it is very expensive to apply the first variant of this method in a large model. Thus, the latter variant has to be applied in one way or another. This can, in priciple, be carried out in two ways.

One method is to make explicit assumptions about the level and composition of the final consumption of goods and services at the terminal point in time as well as the future uniform rate of growth of that consumption. If the capital-output ratios and the composition of the capital stock in each sector are exogenously determined and constant over time, such assumptions can be transformed into capital stock requirements for all production sectors at the terminal point in time.

However, in an elaborated model where there are several alternative technologies available in the production sectors this approach is not well suited. The reason for this is that the relation between the growth of the final consumption of goods and services and the size of the terminal stocks of capital in the production sectors depends on the choice between the alternative technologies in the different sectors. Thus, the terminal capital stock requirements cannot be determined without introducing a bias in the choice between available technologies.

Another approach is to attach values to the terminal stocks of capital. This approach was adopted in the present study. Thus, it is assumed that all prices in the economy remain constant for the indefinite future after the terminal point in time. This means that there is a constant annual operating surplus from each unit of remaining capacity after the terminal point in time. In the preceding subsection it was shown that the steady state operating surplus of process j capacity, ρ_j, could be written

$$\rho_j = (r + \delta_j) P_{Kj},$$

where r is the interest rate, δ_j the rate of physical depreciation and P_{Kj} the steady state price of one unit of process j capacity.

As a consequence of these assumptions, the terminal capacity valuation factors, $\psi_j(T)$, become

$$\psi_j(T) = \sum_{\tau=T+1}^{\infty} (1+r)^{-\tau} \rho_j(1-\delta_j)^{\tau-T} \quad {}^{1)}$$

There are two interrelated problems connected with this approach. The first concerns the determination of the steady state prices of capital goods, P_{Kj}. In order to estimate these prices a more sophisticated model of the economy is needed. However, such a model is not available, and

---

1) Since $0 < \delta_j < 1$, this expression has a finite value whenever $r > 0$.

thus some approximate method must be adopted. In this study the capital goods prices prevailing at the initial point in time was used as estimates of the steady state capital goods prices.

The second problem concerns the investments in the last period before the terminal point in time. Since we have assumed that the productive capacity created by these investments will be available immediately after the terminal point in time, the amount of such investments will be entirely determined by the terminal valuations factors, $\psi_j(T)$. In combination with the linearity of the supply model, this makes the investment activity in the last period extremely sensitive to the numerical values of the valuation factors. Obviously both the amount and the sectoral composition of investments are likely to be inconsistent with the assumed uniform future growth of the final consumption of goods and services.

In order to avoid these problems the investments in the last period are not endogenously determined. Instead the demand for capital goods associated with the assumed growth of the final consumption of goods and services is calculated. Then the calculated demand for capital goods in the last period is added to the final demand for the output of the capital goods producing sectors.

This way of treating the terminal capacity problem is not satisfactory. However, in order to avoid distortions created by the terminal conditions the model is solved for five five-year periods in all simulations, but the results obtained for the fifth period are disregarded. The same applies in most cases for the results obtained for the fourth period.

4.2.3 Decomposition of the Supply Model into Submodels

As indicated in the introduction to this chapter, the supply model is constructed as a set of submodels. The submodels can either be used as separate models or be linked to each other in different combinations. One of these combinations constitutes the "complete" supply model.

The procedure involved in linking the different supply submodels causes to particular problems. Assume that the commodities $i = 1,2, \ldots, k$ are produced in a set of processes that is denoted H, while the commodities $i = k + 1, \ldots, n$ are produced by a set of processes denoted S. Further, let $P_i(t)$ denote the price of commodity i in period t.

Given these assumptions the economy can be partitioned into an H segment and an S segment. Let $L_i^{hs}(t)$ represent the activity level of process that delivers commodity i from the H segment of the economy to the S segment during period t. The value of the purchases of S commodities will appear in the cost function of the H segment, and the deliveries of H commodities to the S segment of the economy will appear as an additional, exogenously determined, final demand for H commodities. The decomposed model can then be written:

The H segment:

$$\min F(T) = \sum_{t=1}^{T} \phi(t)\{\omega(t)N^H(t) + \sum_{i=k+1}^{n} P_i(t)L_i^{sh}(t)\} - \sum_{j\in H} \psi_j(T)K_j(T)$$

$$\sum_{j\in H} (b_{ij}-a_{ij})X_j(t) - \sum_{j\in H} A_{ij}\Delta K_j(t) \geq C_i(t) + L_i^{hs}(t) \quad ; i = 1, 2,\ldots,k; \forall t$$

$$\sum_{j\in H} -a_{ij} X_j(t) - \sum_{j\in H} A_{ij}\Delta K_j(t) + L_i^{sh}(t) \geq C_i(t) \quad ; i = k+1, \ldots, n; \quad \forall t$$

$$R_j(t) + K_j(t) - X_j(t) \geq 0 \quad ; j\in H; \ \forall t$$

$$N^H(t) - \sum_{j\in H} n_j(t)X_j(t) \geq 0 \quad ; \forall t$$

$$-R_j(t) \geq -(1-\delta_j)^t K_j(0) \quad ; j\in H; \forall t$$

$$\sum_{\tau=1}^{t} (1-\delta_j)^{t-\tau}\Delta K_j(\tau-1) - K_j(t) = 0 \quad ; j\in H; \forall t$$

The S segment:

$$\min F(T) = \sum_{t=1}^{T} \phi(t)\{\omega(t)N^S(t) + \sum_{i=1}^{k} P_i(t)L_i^{hs}(t)\} - \sum_{j\in S} \psi_j(T)K_j(T)$$

$$\sum_{j\in S} - a_{ij} X_j(t) - \sum_{j\in S} A_{ij}\Delta K_j(t) + L_i^{hs}(t) \geq C_i(t) \quad ; i = 1, 2, \ldots, k; \forall t$$

$$\sum_{j\in S} (b_{ij}-a_{ij})X_j(t) - \sum_{j\in S} A_{ij}\Delta K_j(t) \geq C_i(t) + L_i^{sh}(t) \quad ; i = k+1, .., n; \forall t$$

$$R_j(t) + K_j(t) - X_j(t) \geq 0 \quad ; j\in S; \forall t$$

$$N^S(t) - \sum_{j\in S} n_j(t)X_j(t) \geq 0 \quad ; \forall t$$

$$-R_j(t) \geq -(1-\delta_j)^t K_j(0) \quad ; j\in S; \forall t$$

$$\sum_{\tau=1}^{t} (1-\delta_j)^{t-\tau}\Delta K_j(\tau-1) - K_j(t) = 0 \quad ; j\in S; \forall t$$

It can easily be checked that all $L_i^{hs}(t)$ and $L_i^{sh}(t)$ disappear from the constraints when the H and S models are added to each other row by row. Thus, the activity levels of these variables will be zero in an optimal solution to the aggregated model. Moreover, whenever the wage rate is positive no excess labor will be employed. In an optimal solution, the sum $N^H(t) + N^S(t)$ is identical to the variable $N(t)$ in the original formulation of the supply model. Thus, the aggregated H and S model is identical to the original supply model.

4.2.4 The Treatment of Foreign Trade

The Swedish economy is small and open. Many Swedish production sectors are exposed to foreign competition and the cost of production in Sweden has a limited influence on world market prices; Swedish producers are more or less price-takers. These conditions imply that foreign trade can easily be incorporated into the model. We simply designate one commodity as "foreign currency" and introduce a number of export and import processes. An export process uses a domestic product as input and yields foreign currency as output, while import processes use currency as input and yield foreign goods as output.[1) 2)]

The purpose of this subsection is to show how the general formulation of the supply model is changed when foreign trade is incorporated into the model. We also discuss the conditions under which a commodity is exported or imported, and both imported and produced domestically. As before, the analysis is based on the equilibrium theorem of linear programming.

The following additional notations are introduced:

$P_i^w(t)$ = world market price of commodity i in period t

$M_i(t)$ = number of imported units of commodity i in period t

$Z_i(t)$ = number of exported units of commodity i in period t

d_i = foreign transportation costs when one unit of commodity i is exported

$C_{n+1}(t)$ = an exogenously determined target current account surplus

Using these symbols, the primal formulation of the model should be enlarged with the following commodity balance:

$$\sum_{i=1}^{n} \left[P_i^w(t) - d_i\right] Z_i(t) - \sum_{i=1}^{n} P_i^w(t) \cdot M_i(t) \geq C_{n+1}(t) \; ; \; \forall t; \; [\varepsilon(t)].$$

This inequality remains unchanged when it is multiplied by the factor $\phi(t)$, defined in the same way as above.

In addition, all other commodity balances should include the net import and export of the commodity in question; that is

---

1) It goes without saying that no labor or capital services are used in trade processes.

2) This approach is the same as that used by Werin (52).

$$\bar{M}_i(t) - \bar{Z}_i(t) \; ; \qquad \forall i, t.$$

After these additions the dual formulation of the supply model becomes:

$$\max G(T) = \sum_{t=1}^{T} \{ \sum_{i=1}^{n} \pi_i(t)\, C_i(t) + \varepsilon(t)\, \phi(t)\, C_{n+1}(t) -$$

$$- \sum_{j=1}^{m} \gamma_j(t)(1-\delta_j)^t\, K_j(0)\},$$

subject to

$$\sum_{i=1}^{n} \pi_i(t)(b_{ij}-a_{ij}) - \alpha(t)\, n_j(t) - \beta_j(t) \leq 0 \; ; \; [1a] \; ; \; [X_j(t)]$$

$$- \pi_i(t) + \phi(t)\, |P_i^W(t) - d_i|\, \varepsilon_i(t) \leq 0 \; ; \; [1b] \; ; \; [Z_i(t)]$$

$$\pi_i(t) - \phi(t)\, P_i^W\, \varepsilon_i(t) \leq 0 \; ; \; [1c] \; ; \; [M_i(t)]$$

$$- \sum_{i=1}^{n} \pi_i(t)\, A_{ij} + \sum_{\tau=t+1}^{T} \kappa_j(\tau)(1-\delta_j)^{\tau-t-1} \leq 0 \; ; \; [2] \; ; \; [\Delta K_j(t)]$$

$$\beta_j(t) - \kappa_j(t) \begin{cases} \leq 0 \quad \text{when } 1 \leq t < T & ; \; [3] \; ; \; [K_j(t)] \\ \leq -\psi_j(T) \text{ when } t = T & ; \; [4] \; ; \; [K_j(T)] \end{cases}$$

$$\alpha(t) \leq \phi(t)\, \omega(t) \; ; \; [5] \; ; \; [N(t)]$$

$$\beta_j(t) - \gamma_j(t) \leq 0 \; ; \; [6] \; ; \; [R_j(t)].$$

Thus, introduction of foreign trade in the primal model affects the objective function of the dual model. Two inequalities concerning the relation between domestic and world market prices are also added.

In order to analyze the properties of this enlarged model, we assume that $Z_h(t^*)$ is positive in an optimal solution. Then [1b] for i = h, t = t* is an equality, which means that

$$\pi_h(t^*) = \phi(t^*)\, [P_h^W(t^*) - d_h]\, \varepsilon_h(t^*).$$

As was shown above, however, $\pi_h(t^*)$ can be interpreted as the present value, at the initial point in time, of the domestic price of commodity h in period t*. Thus, we obtain

$$\phi(t^*) \;\; P_h(t^*) \;\; = \;\; \phi(t^*) \left[P_h^W(t^*) - d_h\right] \varepsilon_h(t^*) \qquad [7]$$

or

$$P_h(t) \;\; = \;\; \left[P_h^W(t^*) - d_h\right] \varepsilon_h(t^*)$$

If [7] is inserted into [1c] for i = h, t = t* we get, provided $\varepsilon_h(t^*) \neq 0$,

$$P_h^W(t^*) - d_h - P_h^W(t^*) \leq 0$$

which is a strict inequality whenever $d_h > 0$. Thus, whenever there are transportation costs, a commodity which is exported in an optimal solution will not be imported in that solution. In the same way it can be shown that a commodity which is imported will not be exported. Moreover, if it holds that

$$P_h^W(t^*) - d_h < P_h(t^*) < P_h^W(t^*) \,,$$

commodity h will be neither imported nor exported in period t*.

Thus, when foreign trade is included in the supply model, the set of commodities is partitioned into three subgroups: exported, imported and non-traded commodities. The dividing line between the subgroups is determined by the dual variable corresponding to the current account constraint.

If two optimal solutions to the supply model, which differ only with respect to the wage rate, $\omega(t)$, are compared, the dual variable corresponding to the current account constraint, $\varepsilon(t)$, is positively related to the wage rate; if the latter is reduced, the former becomes lower.[1] Thus, the dual variable $\varepsilon(t)$ can be interpreted as the exchange

---

1) See note 1 on next page.

rate[2)] between the domestic and foreign currencies under given assumptions about world market prices, domestic costs and the predetermined current account surplus (deficit).

Next we investigate the conditions under which a particular commodity, h, will be imported as well as domestically produced in an optimal solution to the supply model. It follows from the discussion above that if commodity h is imported in period t* in an optimal solution, then the domestic price of that commodity will be equal to the world market price of commodity h times the exchange rate. That is,

$$P_h(t^*) = \varepsilon(t^*) \quad P_h^W(t^*).$$

As before, we assume that commodity h is the (only) output from process q. Now we also assume that q is the only process where commodity h is an output. From [1a] we then get

$$\varepsilon(t^*)P_h^W(t^*) - \sum_{i=1}^{n} P_i(t^*)a_{iq} - \alpha(t^*)n_q(t^*) \leq \beta_q(t^*); \ [1a']; \ [X_q(t^*)].$$

Utilization of process q in period t* implies equality in [1a']. Since $\beta_q(t^*)$ is a non-negative variable, $X_q(t^*)$ cannot be positive when the left-hand side of [1a'] is negative. If the short-run marginal cost of utilizing process q exceeds the world market determined price of commodity h, then this commodity will not be imported and domestically produced simultaneously. However, this would occur if the left-hand side of [1a'] is positive. Then the difference between the price and the marginal cost of commodity h in period t* will determine the scarcity rent earned by existing capacity in

---

1) To see this, consider [1a], [1b], [1c] and [5] above, and assume that we have an optimal solution to the model. Then, assume that $\omega(t^*)$ is reduced and the model solved again. In the new solution $\alpha(t^*)$ will be lower than before. Accordingly all $\pi_i(t^*)$ will be lower. Then, for all i where $Z_i(t^*)$ was positive in the previous solution, constraint [1b] will be violated unless ε* is reduced in relation to the previous solution.

2) Expressed in the domestic currency unit.

process q[1] during period t*. If this scarcity rent is sufficiently large, the capacity in process q will be increased and commodity h will not be imported, ceteris paribus, in period t* + 1.

4.2.5 Some General Remarks about the Properties of the Supply Model

The formulation of the supply model implies a number of assumptions about the supply system. In addition to the assumption about optimization behavior, the following points should be noted:

i. the final demand for goods and services is perfectly anticipated by the producers;[2]

ii. there is only one labor market;

iii. all relations in the model are linear.

As a result of the first assumption, there is no risk or uncertainty in the model economy. The third assumption implies that there are no indivisibilities or economies of scale. Market imperfections cannot prevail under these conditions and thus the rate of profit should be the same and equal to the exogenously determined rate of interest in all sectors in long-run equilibrium.

In spite of the substantial profit differentials between production sectors in the real world, this property of the model does not necessarily make it less realistic. The supply model is designed for analyzing the impact of changes in the set of available technologies,[3]

---

1) See [6] above and recall that $X_j(t) > 0$ implies $R_j(t) > 0$.

2) Moreover, it is completely inelastic with respect to price and income variations.

3) A change in a world market price can be conceived of as a change in the coefficients of the corresponding import and export processes.

resulting from the implementation of different energy policy measures, on the consumption of energy and the prices of final goods. The critical assumption, then, is that the contemplated energy policy measures should not affect the factors underlying the observed profit differentials between sectors. If this assumption is realistic, it is a useful simplification of the analysis in that risk and uncertainty are assumed away as are the factors governing the observed deviations from perfect market conditions.

The assumption that there is only one labor market in the model economy means that the composition of the labor force is the same in all sectors.[1)] This is certainly not the case in the real world. However, the current composition of the labor force in the different sectors of the economy is transitory, and could change substantially during a 10 - 20 year period, which is the time horizon of this study. It therefore seems reasonable not to distinguish different kinds of labor.

However, the linearity assumption is critical. There are significant indivisibilities in the electricity and heat production sector as well as in the residential heating sector. These circumstances in combination of the detailed treatment given to these sectors in the EFM call for some other approach than linear programming, for instance integer programming. However, the solution costs for integer programming models are significantly higher than the solution costs for linear programming models. For this reason the linear programming approach was chosen in spite of its implicit unrealistic assumptions about the technology in the above mentioned sectors.

4.3 The Demand Model

4.3.1 Introduction

As mentioned in Section 4.1, part of the final demand in the EFM is determined exogenously. Another part, the private demand for final

---

1) Alternatively it can be interpreted as a situation with complete wage equalization between different kinds of labor.

consumer goods and services, is determined endogenously. In accordance with conventional economic theory this demand, at given preference functions, should be determined by individuals' incomes and the relative prices of the commodities. A number of restrictions on the commodity demand functions can be derived on the basis of consumer theory.[1)] These restrictions can, in principle, be used to reduce the number of parameters to be estimated in empirical demand analysis.

However, empirical demand analysis always involves aggregation since it generally concerns the demand for certain groups of commodities by certain groups of individuals. Moreover, there is usually some aggregation over time and space as well. But the most important problem arises as a result of aggregation over individuals.

The restrictions derived from consumer theory concern the individual demand functions. They are valid for collective demand functions if the preference functions of individuals are

i. identical and

ii homothetic.

If these conditions are fulfilled the distribution of purchasing power has no impact on the market demand for goods and services. Consequently, demand is entirely determined by per capita incomes and relative prices.

Obviously very strong assumptions have to be made before the theorems of microeconomic demand theory can be applied in aggregate empirical demand analysis. Nevertheless, these theorems are utilized in one way or another in most applications involving so-called "systems

---

1) These restrictions are called the aggregation restriction, the homogeneity restriction and the symmetry restriction. The first states that total expenditures should add up to total income. The second implies that demand is invariant to proportional changes in nominal income and commodity prices. The implication of the symmetry restriction is that the elasticity of the compensated demand for commodity i with respect to the price of commodity j is equal to the elasticity of the compensated demand for commodity j with respect to the price of commodity i.

simultaneous of demand equations".[1] This procedure is not necessarily serious, however. For instance, the aggregation restriction (the sum of all expenditures equals income) should hold for collective demand functions. The symmetry restrictions, on the other hand, do not hold in this respect.

The linear expenditure system developed by Stone[2] is based on an explicit collective utility function. The indirect addilog model, developed by Houthakker[3], is based on an explicit indirect collective utility function. Both of these models satisfy all the restrictions that can be derived from demand theory, but, as we noted above, the collective utility functions underlying the models exist only under very special assumptions.

The system of double logaritmic functions[4] is not derived from an explicit utility function. However, the theorems derived from consumer theory can be used as restrictions on the parameters in order to reduce the number of parameters to be estimated. This means that the restrictions can be imposed on the basis of a goodness of fit criterion. The same applies to a very recent development in this field, the model derived by Christensen, Jorgenson & Lau.[5] This model is based on a local second-order approximation of a non-specified utility function. The main disadvantage of the former model is that all income elasticities are forced to unity when the aggregation restriction is imposed. In the case of the Christensen, Jorgensen & Lau model, the main drawback concerns estimation problems.

---

1) A survey of this field is included in Powell (45). See also Chapter VIII in Bergman <u>et al</u>. (8).

2) See Stone (48).

3) See Houthakker (27).

4) See Dahlman-Klevmarken (14).

5) See Christensen, Jorgenson & Lau (13).

The demand model chosen for the EFM is the so-called Rotterdam model, developed by Theil.[1] The application of this model was carried out by Björklund.[2] The choice was mainly based on the results of a study by Parks[3] where the performance of several different demand models were compared. Although Parks' results were somewhat inconclusive, they were in favor of the Rotterdam model.

There are two versions of the Rotterdam model, the relative price version and the absolute price version. The former is directly based on the Slutsky equation, which requires the existence of a collective utility function with the same properties as those assumed in individual utility functions. As indicated above, this is not the case unless very special assumptions are satisfied.

The absolute price version of the Rotterdam model is not based on any explicit utility function, but the restrictions derived from demand theory can be imposed in order to reduce the number of freee parameters. The restrictions can be imposed on the basis of a goodness of fit criterion. The absolute price version of the Rotterdam model is described below and the empirical version of the private demand model is presented in Section 4.3.3.

4.3.2 The Rotterdam Model

The following symbols are used in the private demand model:

C_i = private demand for commodity i = 1, 2, ..., n

P_i = price of commodity i = 1, 2, ..., n

m = total private expenditures on goods and services;

thus $m = \sum_{i=1}^{n} P_i \cdot C_i$

w_i = share of total expenditures allocated to purchases of

commodity i; thus $w_i = \frac{P_i\ C_i}{m}$.

---

1) See Theil (50).

2) This choice is motivated by Björklund in Chapter VIII of Bergman et al. (8).

3) See Parks (44).

Further, real income is denoted $\bar{m}$ and defined as the level of utility that can be attained at given money income and commodity prices. The demand for commodity i is written

$$C_i = C_i^*(P_1, P_2, \ldots, P_n, \bar{m}).$$

It is assumed that no saving takes place.

Differentation of the demand equation above yields

$$dC_i = \frac{\partial C_i^*}{\partial m} \cdot d\bar{m} + \sum_{j=1}^{n} \frac{\partial C_i^*}{\partial P_j} dP_j \quad ^{1)} . \qquad [1]$$

If [1] is multiplied by w_i/C_i we obtain

$$w_i \, d(\log C_i) = \frac{\partial (P_i C_i^*)}{\partial m} d(\log \bar{m}) + \sum_{j=1}^{n} \frac{P_i P_j}{m} \frac{\partial C_i^*}{\partial P_j} d(\log P_j) . \qquad [2]$$

Next we define

$$\mu_i = \frac{\partial (P_i C_i^*)}{\partial m} \quad \text{and}$$

$$\pi_{ij} = \frac{P_i P_j}{m} \cdot \frac{\partial C_i^*}{\partial P_j} ,$$

which mean that [2] can be written

$$w_i \, d(\log C_i) = \mu_i \, d(\log \bar{m}) + \sum_{j=1}^{n} \pi_{ij} \, d(\log P_j) . \qquad [3]$$

The term $d(\log \bar{m})$ is derived in as follows. Assume that all prices and the money income change infinitensimally. The change in real income then becomes

---

1) Observe that $\frac{\partial C_i^*}{\partial m} \equiv \frac{\partial C_i^*}{\partial \bar{m}}$ since partial derivatives imply constant prices.

$$d\bar{m} = dm - \sum_{k=1}^{n} C_k \cdot dP_k \ ,$$

which can be written

$$d(\log \bar{m}) = d(\log m) - \sum_{k=1}^{n} w_k \cdot d(\log P_k). \qquad [4]$$

If [4] is insert in [3] we obtain

$$d(\log C_i) = \frac{\mu_i}{w_i} \left[d(\log m) - \sum_{k=1}^{n} w_k \ d(\log P_k)\right] + \sum_{j=1}^{n} \frac{\pi_{ij}}{w_i} d(\log P_j). \qquad [5]$$

Thus the change in the demand for commodity i is determined by the share of total expenditures spent on commodity i, the change in nominal income and the change in prices of all final consumer goods and services.

Let e_i denote the income elasticity of commodity i and E^*_{ij} the compensated price elasticity of commodity i with respect to the price of commodity j.

The aggregation restriction implies that expenditures on all commodities add up to the total income. In formal terms this becomes

$$\sum_{i=1}^{n} w_i \ e_i = 1$$

$$\sum_{i=1}^{n} w_i \ E^*_{ij} = 0 \quad \text{for all } j = 1,2,\ldots, n.$$

From the definitions of μ_i and π_{ij} we obtain

$$\sum_{i=1}^{n} w_i e_i = \sum_{i=1}^{n} \frac{P_i C_i}{m} \cdot \frac{\partial C_i / C_i}{\partial m / m} = \sum_{i=1}^{n} \mu_i = 1 \qquad [6]$$

$$\sum_{i=1}^{n} w_i \cdot E^*_{ij} = \sum_{i=1}^{n} \frac{P_i C_i}{m} \cdot \frac{\partial C^*_i / C_i}{\partial P_j / P_j} = \sum_{i=1}^{n} \pi_{ij} = 0 \ ; \quad j=1,2,\ldots, n. \qquad [7]$$

The homogeneity restrictions imply that the demand equations are homogenous of degree zero. That is, a proportional change in all prices and nominal income leaves the demand for goods and services unaffected. In formal terms this becomes

$$\sum_{j=1}^{n} E^*_{ij} = 0 \quad \text{for all} \quad i = 1,2,\ldots, n.$$

From the definition of π_{ij} we obtain

$$\sum_{j=1}^{n} E^*_{ij} = \sum_{j=1}^{n} \frac{\partial C^*_i/C_i}{\partial P_j/P_j} = \sum_{j=1}^{n} \pi_{ij} = 0 \;; \quad i = 1,2,\ldots, n \,. \qquad [8]$$

The symmetry restriction, finally, implies that the compensated cross-price effect of the different equations is symmetric; that is

$$\frac{\partial C^*_i}{\partial P_j} = \frac{\partial C^*_j}{\partial P_i} \,.$$

From the definition of π_{ij}, it follows that if the symmetry restriction is satisfied, it holds that

$$\pi_{ij} = \pi_{ji} \quad \text{for} \quad i, j = 1,2,\ldots, n \,. \qquad [9]$$

There are $n+n^2$ free parameters in [5]. However, there are at most n aggregation, n homogeneity and $\frac{1}{2}(n-1)n$ symmetry restrictions. Thus, if all of the restrictions are imposed the number of free parameters is reduced to $\frac{1}{2}(n+2)(n-1)$. The estimated parameters μ_i and π_{ij} can easily be transformed into income and compensated price elasticities in the following way:

$$\frac{m}{P_i\ C_i} \cdot \mu_i = \frac{m}{P_i\ C_i} \quad \frac{\partial (P_i\ C_i)}{\partial m} = e_i$$

$$\frac{\pi_{ij}}{P_i\ C_i} = \frac{m}{P_i\ C_i} \cdot \frac{P_i\ P_i}{m} \cdot \frac{\partial C^*_i}{\partial P_j} = E^*_{ij}.$$

Since the parameters μ_i and π_{ij} are constants, it follows that both the income and compensated price elasticities are variable.

4.3.3 The Empirical Version of the Demand Model

In practice the demand model has to be formulated in terms of finite changes. Thus, if we define

$$DP_i(t) = \log P_i(t) - \log P_i(t-1)$$

$$Dm(t) = \log m(t) - \log m(t-1)$$

$$DC_i(t) = \log C_i(t) - \log C_i(t-1)$$

$$w_i^*(t) = \frac{w_i(t) + w_i(t-1)}{2} ,$$

the stochastic specification of the model becomes

$$w_i^*(t)\ DC_i(t) = \alpha_i(t) + \mu_i \left[Dm(t) - \sum_{i=1}^{n} w_i^*(t)\ DP_i(t)\right] + $$

$$+ \sum_{j=1}^{n} \pi_{ij}\ DP_j(t) + \varepsilon_i(t) \ ; \quad i = 1,2,\ldots, . \qquad [10]$$

Three points should be noted in regard to this formulation. First, when the model is formulated in finite changes, the coefficients π_{ij} can no longer be interpreted as compensated price effects. Instead they express the response of consumers, in terms of their demand for commodity i, when the price of commodity j and their nominal incomes are changed simultaneously so that the initial commodity basked can be bought at the new price. When infinitesimal changes are considered, this is equivalent to a compensation that allows the consumers to remain on the initial utility level.

Second, when [10] is used for forecasting purposes, the weighted average $w_i^*(t)$ has to be replaced by $w_i(t-1)$. The bias introduced in this way depends on the sensitivity of the value shares to price and income variations.

Third, an additional term, $\alpha_i(t)$, has been included in [10]. This term represents the reallocation of private expenditures which is independent of changes in prices and income. The aggregation restriction requires that the price and income-independent terms, summed over the demand equations, add up to zero.

There are ten different final consumer commodities in the EFM. However, in order to simplify the linking of the supply and demand models of the EFM, the demand for one of the ten consumer goods - housing - is exogenously determined.[1] Thus, the private demand model allocates the total current household expenditures among nine different commodity groups.

The elimination of housing from the demand model is questionable on theoretical grounds; it implies that the demand for housing is quite independent of economic variables. However, when housing was included in the demand model it turned out that very few of the observed variations in the demand for housing could be explained by price and income-variations.[2]

This result is not surprising, considering the market imperfections and various kinds of subsidies which characterize the market for housing. Thus, although questionable on theoretical grounds, the results obtained from the EFM are not likely to be distorted by treating the demand for housing exogenously.

Different restrictions were imposed in the estimation procedure.[3] The aggregation and homogeneity restrictions, as well as zero restrictions on individual cross-price terms (π_{ij}) were imposed. The zero restrictions were imposed on π_{ij}'s with very low t-values.

---

1) The demand for housing appears in two places in the EFM. First, there is demand for unheated apartments. This commodity is delivered from the "non-energy commodity supply model". A1 on p. 62. Second, there is demand for heat and light for these apartments. These services are delivered from the residential heating services supply model, A2 on p. 62.

2) The $\bar{R}^2$ obtained was very low.

3) The problems encountered in estimating the demand model are discussed in Bergman et al. (8), pp. 271 - 283.

The results of the final round of estimations are listed in Table 4:1. At that stage the aggregation and homogeneity restrictions had been imposed along with 35 zero restrictions. It can be seen in the table that not all of the estimated parameters differ significantly from zero at the 10 % level. Moreover, the $\bar{R}^2$ values are not particularly high.

From an analytical point of view it is convenient to transform the estimated parameters into elasticities. This was done by means of price and expenditure data for 1973. The results are shown in Table 4:2.

The most surprising results, of course, are the positive own price elasticities for food and clothing and the negative income elasticity for cultural goods and services. However, the latter two results are not significant at the 10 % level. Moreover, there is a positive trend in the demand for cultural goods and services.

The positive own price elasticity of the demand for clothing, however, is significant and has a very high numerical value. This seems quite implausible, although it is similar to the result obtained by Dahlman & Klevmarken[1)] in their application of the double logarithmic model.

As in all studies of this kind, data problems were encountered. The price indices used in the estimations were obtained by dividing the value of the observed consumtion of a given group of commodities, measured in current prices, by the same magnitude measured in constant prices. Thus, the higher the constant prices, the lower the resulting price estimate.

For a commodity group such as clothing, where style and fashion seem to be more important than quality in a measureable sense, it is tempting to assume that a measure of consumption is particularly difficult to

---

1) See Dahlman & Klevmarken (14).

Table 4:1. The estimated parameters of the private demand model

	Tot. exp.	Price food	Price drink	Price clothing	Price cultural	Price hygiene	Price travel	Price leisure	Price furniture	Price others	Inter-cept	$\bar{R}^2$	D/W
Food	0.157**	0.0343	0.0692**	-0.107**	0	0	0	0	0.0777*	-0.0747	-0.0012	0.460	2.72
	(0.0460)	(0.0231)	(0.0229)	(0.0368	0	0	0	0	(0.0391)	(0.0486)	(0.0013)		
Drink	0.109**	0.0223	-0.0669**	0	0	0	0.0342	-0.0262	0	0.0366	0.0007	0.763	1.35
	(0.0256)	(0.0196)	(0.0145)	0	0	0	(0.0210)	(0.0152	0	(0.0323)	(0.0008)		
Clothing	0.212**	0	-0.0915**	0.127**	-0.0169	0	0.172**	0.0129	-0.108*	-0.0961	0.0017	0.619	2.40
	(0.0687)	0	(0.0292)	(0.0541)	(0.0200)	0	(0.0440)	(0.0330)	(0.0581)	(0.0617)	(0.0019)		
Culture	-0.0087	0	-0.0200*	0.0238*	-0.0013	0	0.0236*	0	-0.0261*	0	0.0012	0.198	1.67
	(0.0173)	0	(0.0078)	(0.0129)	(0.0063)	0	(0.0099)	0	(0.0147)	0	(0.0004)		
Hygiene	0.0316**	0	0.0066*	0	0	-0.0135*	0	0	0.0068	0	-0.0003	0.337	1.33
	(0.0098)	0	(0.0037)	0	0	(0.0060)	0	0	(0.0059)	0	(0.0002)		
Travel	0.252**	0	0.0342*	-0.0764*	0.0182	0	-0.152**	0.0728*	0.104*	0	0	0.696	1.91
	(0.0357)	0	(0.0196)	(0.0327)	(0.0187)	0	(0.0314)	(0.0295)	(0.0364	0	0		
Leisure	0.0280	-0.0566*	0.0220	0.0634*	0	-0.0263	0.0426*	-0.0451*	0	0	0.0031**	0.312	2.17
	(0.0307)	(0.0188)	(0.0164)	(0.0222)	0	(0.0172)	(0.0241)	(0.0204)	0	0	(0.0009)		
Furni-ture	0.162**	0	0.0463**	-0.0601*	0	0.0398*	-0.0757**	0	-0.0233	0.0730*	-0.0038**	0.798	2.38
	(0.0248)	0	(0.0126)	(0.0257)	0	(0.0150)	(0.0221)	0	(0.0212)	(0.0274)	(0.0009)		
Others	0.0638*	0	0	0.0290	0	0	-0.0445	-0.0143	-0.0314	0.0612*	0	0.239	1.77
	(0.0360)	0	0	(0.0302)	0	0	(0.0287)	(0.0240)	(0.0341)	(0.0297)	0		

* = significant at the 10 % level, **= significant at the 1 % level.

Homogeneity, aggregation and 35 zero restrictions were imposed in the estimation.

Table 4:2. Income and compensated price elasticities computed by means of 1973 data

	Income	Price food	Price drink	Price clothing	Price cultural	Price hygiene	Price travel	Price leisure	Price furniture	Price others	Intercept
Food	0.55	+ 0.12	+ 0.24	- 0.37	-	-	-	-	+ 0.27	- 0.26	neg
Drink	1.04	+ 0.21	- 0.64	-	-	-	+ 0.33	- 0.25	-	+ 0.35	pos.
Clothing	2.21	-	- 0.95	+ 1.32	- 0.18	-	+ 1.79	+ 0.13	- 1.13	- 1.0	pos.
Cultural	- 0.15	-	+ 0.36	+ 0.43	- 0.02	-	+ 0.42	-	+ 0.47	-	pos.
Hygiene	1.37	-	+ 0.29	-	-	- 0.59	-	-	+ 0.30	-	neg.
Travel	1.77	-	+ 0.24	- 0.54	+ 0.13	-	- 1.07	+ 0.51	+ 0.73	-	-
Leisure	0.41	- 0.83	+ 0.32	+ 0.93	-	- 0.39	+ 0.63	- 0.66	-	-	pos.
Furniture	2.16	-	+ 0.62	- 0.80	-	+ 0.53	- 1.01	-	- 0.31	+ 0.97	neg.
Others	0.43	-	-	+ 0.19	-	-	- 0.30	- 0.10	+ 0.21	- 0.41	-

construct in constant prices. Thus, the development of real clothing consumption might have been underestimated and, accordingly, the development of the price of clothing overestimated. This may provide a partial explanation to the positive own price elasticity of clothing.

4.4 Solution of the Model

It was shown in Section 4.2.3 that the process of linking the different supply submodels of the EFM did not cause any particular solution problems; it was merely a question of the size of the linear programming problem. On the other hand, there is no such straightforward procedure for linking the complete supply model and the demand model.

The linking of the supply and the demand models involves two problems, The first concerns the definition of commodities in the model, while the second concerns the interaction between the supply and demand models.

The available input-output statistics are based on the so called SNI-classification[1)] of the production sectors, while the consumer goods and services are classified in accordance with SNA.[2)] This means that in order to link the supply and demand models, a transformation between the SNI and the SNA classifications has to be established. In the EFM this is accomplished by the introduction of "dummy commodities", that is, commodities that are defined as linear combinations of a number of other commodities in the model. Thus, each of the nine consumer commodities for which the demand is endogenously determined is defined as a linear combination of production sector outputs.

When dealing with the interaction between the supply and demand models, the critical point is not the mere existence, uniqueness and stability of a solution to the complete model. In addition the solution should be reached after a very small number of iterations; otherwise the

1) Svensk Näringslivsindelning.

2) Standard National Accounts.

solution costs might be too high. The difficulty of the solution problem basically concerns the slopes of the supply and demand curves of the commodities of the model. In some special cases, however, a solution to the complete model can easily be arrived at. For instance, if the supply prices for all commodities are independent of the demand for the commodities in question, all commodity markets can be cleared in two steps.[1)]

This condition is not fulfilled by the EFM; there is more than one scarce factor of production and thus relative commodity prices depend on the size and composition of the final demand. However, the simulations using the supply part of the EFM showed that the supply prices of consumer commoditites are almost unaffected by variations in the growth and composition of final demand.[2)] These observations have led to the conclusion that at the present stage of development no endogenous market clearing mechanism is needed in the EFM, provided that it is used for simulation of different growth paths of the economy.[3)]

4.5 How the Model is Used in this Particular Study

It is important to note that the EFM was not developed in order to carry out this particular study. The present study to a large extent relies on the EFM, but only a few of all kinds of simulations that can be carried out have in fact been carried out. The purpose of this section is to briefly indicate how the EFM has been utilized in this study.

4.5.1 The General Approach

The empirical part of this study is based on a long-term projection about the development of the Swedish economy carried out by the Ministry

---

1) Since relative prices are entirely cost determined in this case, the equilibrium price system can be determined in the first step. Then this price system is inserted into the demand model in order to determine the equilibrium quantities.

2) The main reasons behind this is that there is only one kind of production process in most sectors, and that the prices of consumer commodities are not very sensitive to energy price changes.

3) Chapter 10 contains a description of how the supply and demand models are linked in practice.

of Finance.[1] The long-term projection yields estimates concerning the development of employment, labor productivity, final demand, exports, imports, etc. These estimates can be used as exogenous variables in the EFM. This long-term projection is transformed by means of the EFM, into a reference development path for the consumption of energy and the prices of energy and non-energy commodities. It is then possible to study how the implementation of various energy policy measures are likly to make the development of the economy deviate from the reference path. These calculations enable us to draw certain conclusions about the sensitivity of the economy, in various respects, to different energy policy measures and, in particular, about the sensitivity of the demand for energy.

Four of the five submodels in the EFM were used in the calculations. The refinery sector model was omitted because only two kinds of energy policy measures are studied, namely energy taxation and direct regulation of the maximum number and type of nuclear power plants in the power sector. The decision to neglect the refinery sector is also related to the treatment of foreign trade, which is discussed in the next section.

4.5.2 The Treatment of Foreign Trade

The foreign trade sector of the Swedish economy is large; more than 20 per cent of the GNP is exported. Many of the most important export sectors (paper and pulp, iron and steel, mining) are very energy intensive. It cannot be ruled out that access to cheap domestic energy (hydro power) has contributed significantly to the creation and maintenance of Sweden's comparative advantages in the production of the above mentioned raw materials.

Needless to say, the impact of a contemplated energy policy measure on the cost of production in the exporting sectors is an important aspect. However, the competitiveness of the Swedish export sectors depends on the development of their production costs in relation to that develop-

---

1) This long-term projection is outlined in some detail in Chapter 10.

ment in other countries, expressed in a common currency. It is obviously very difficult to make a reasonable guess as to how the development of these cost relations is likely to be affected by energy policy strategies that differ between countries. The same applies to the impact of increases in crude oil prices on international production cost relations.

For these reasons, foreign trade in non-energy commodities is exogenously determined in all the calculations carried out in this study. The assumptions made about the development of Sweden's foreign trade are based on the Ministry of Finance long-term projection mentioned above. Thus, the energy policy measures covered here are entirely domestic. The analysis of the impact of these measures on the competitiveness of the exporting sectors is confined to a discussion of the effects on domestic production costs.

4.5.3 A Behaviour Assumption

The power sector is at the center of this analysis; considerable attention is focused on the impact of the choice of technology in the power sector on the rest of the economy. The power sector affects the rest of the economy partly through its purchases of inputs and partly by the prices of its outputs. In order to evaluate the impact of the choice of technology on different energy policy measures the model has to reflect the pricing behavior of power producers.

Swedish power producers cooperate closely and the pricing principles of the State Power Board have a significant influence on electricity pricing in Sweden. The basic principles underlying the high-voltage electricity tariffs employed by the State Power Board[1)] are that

i. the tariffs should reflect the long-run marginal cost of production;

ii. the tariffs should result in revenues large enough to yield a predetermined rate of profit on invested capital.

---

1) These principles are described in some detail in Chapter 8.

These principles imply that the Swedish high-voltage electricity prices basically are determined by the cost of additional electricity generation capacity. This procedure is reasonable from a social efficiency point of view if the additional capacity actually is needed. However, if demand falls short of capacity, the prices should be lower than the long-run marginal cost; from a social efficiency point of view, existing capacity should be used as soon as the marginal revenue which can be earned from that capacity is greater than the marginal cost of utilizing it. This means that socially efficient prices should reflect short run marginal costs of production whenever demand falls short of capacity. If demand tends to exceed capacity, the price should be increased so that all excess demand is eliminated. Investments should be made only when the price is high enough to cover the cost of additional capacity. The pricing principles applied by the power producers of the model economy are consistent with these rules.

Since there is some excess capacity in the Swedish power sector at the present time,[1] we are obviously confronted with a complex problem. Should we investigate the most efficient uses of the economy's resources or should we try to simulate the behavior of the power producers? In the first case the calculated prices of electricity would be very low during an initial period, and the model economy's demand for energy would increase, particularly in the residential heating sector where the substitutability of different resources is modelled in detail. In the second case, the calculated prices would reflect the full cost of new capacity and excess capacity would probably persist for a few periods.

The choice between these approaches obviously depends on the purpose of the study and the extent to which power producers are likely to apply the above pricing principles in a situation of excess supply. In this study an attempt is made to simulate the behavior of the power producers.

---

1) See p. 211.

This has been accomplished in the following way. For each kind of capacity[1] existing at the initial point in time a "cost of using capital"[2] in sector j, $\rho_j(t)$ is defined as

$$\rho_j(t) = (r + \delta_j)\, P_{Kj}(0),$$

where

r = interest rate

δ_j = rate of depreciation of the capacity in sector j

$P_{Kj}(0)$ = cost of one unit of capacity, measured in output, in process j at the initial point in time.

Obviously the $\rho_j(t)$ defined here are the same as those used to define the terminal valuation factors $\psi_j(T)$; see p. 82. The period index in $\rho_j(t)$ is included in order to make it possible to set

$$\rho_j(t) \begin{cases} = 0 \text{ for } 1 \leq t \leq T \\ > 0 \text{ for } t > T, \end{cases}$$

that is, to transform the supply model into a pure optimization model. By applying this special assumption and using the same symbols as before, the general formulation of the supply model becomes

$$\min F(T) = \sum_{t=1}^{T} \phi(t)\, \{\omega(t)\, N(t) + \sum_{j=1}^{m} \rho_j(t)\, R_j(t)\} - \sum_{j=1}^{m} \psi_j(T)\, K_j(T)$$

subject to

$$\sum_{j=1}^{m} (b_{ij}-a_{ij})X_j(t) - \sum_{j=1}^{m} A_{ij}\, \Delta K_j(t) \geq C_i(t) \;;\quad \forall i,\, t \;;\; [\pi_i(t)]$$

$$R_j(t) + K_j(t) - X_j(t) \geq 0 \;;\quad \forall j,\, t \;;\; [\beta_j(t)]$$

---

1) This assumption was also applied to the sectors of the "non-energy commodity supply sub-model".

2) This terminology was used by Johansen (30).

$$N(t) - \sum_{j=1}^{m} n_j(t)\, X_j(t) \geq 0 \quad ; \quad \forall t \quad ; \quad [\alpha(t)]$$

$$- R_j(t) \geq - (1-\delta_j)^t\, K_j(0) \quad ; \quad \forall j,\, t \quad ; \quad [\gamma_j(t)]$$

$$\sum_{\tau=1}^{t} (1-\delta_j)^{t-\tau}\, \Delta K_j(\tau-1) - K_j(t) = 0 \quad ; \quad \forall j,\, t \quad ; \quad [\kappa_j(t)]$$

$$X_j(t),\, K_j(t),\, \Delta K_j(t),\, R_j(t),\, N(t) \geq 0 \quad ; \quad \forall j,\, t.$$

The corresponding dual formulation of the model then becomes:

$$\max G(T) = \sum_{t=1}^{T} \{ \sum_{i=1}^{n} \pi_i(t)\, C_i(t) - \sum_{j=1}^{m} \gamma_j(t)(1-\delta_j)^t\, K_j(0) \}$$

subject to

$$\sum_{i=1}^{n} \pi_i(t)(b_{ij}-a_{ij}) - \alpha(t) n_j(t) - \beta_j(t) \leq 0 \quad ; \quad [1] \quad ; \quad [X_j(t)]$$

$$- \sum_{i=1}^{n} \pi_i(t)\, A_{ij} + \sum_{\tau=1+1}^{T} \kappa_j(\tau)(1-\rho_j)^{\tau-t-1} \leq 0 \quad ; \quad [2] \quad ; \quad [\Delta K_j(t)]$$

$$\beta_j(t) - \kappa_j(t) \begin{cases} \leq 0 & \text{for } 1 \leq t < T \quad ; \quad [3] \quad ; \quad [K_j(t)] \\ \leq -\psi_j(T) & \text{for } t = T \quad ; \quad [4] \quad ; \quad [K_j(T)] \end{cases}$$

$$\alpha(t) \leq \phi(t)\, \omega(t) \quad ; \quad [5] \quad ; \quad [N(t)]$$

$$\beta_j(t) - \gamma_j(t) \leq \phi(t)\, \rho_j(t) \quad ; \quad [6] \quad ; \quad [R_j(t)].$$

The effect of the behavor assumption is seen in the criterion function of the primal formulation and in constraint [6] in the dual formulation.

To demonstrate how the supply model works in this case, we assume that commodity h, which is produced by process q only, is demanded in period 1. In accordance with the equilibrium theorem of linear programming[1)] we then get equality in [2], [5] and [6] for j = q and t = 1. Moreover, assume that the existing capacity in process q is not fully utilized. This means that $\gamma_q(1)$ is zero.

Substitution for j = q and t = 1 in [1] and division of all terms in that equation by $\phi(1)$ yields

$$P_h(1) = \sum_{i=1}^{n} P_i(1)\, a_{iq} + \omega(1) \cdot n_q(1) + \rho_q(1)$$

where, as before $P_i(t) \equiv \phi(t)^{-1} \cdot \pi_i(t)$.

Thus, although there is excess capacity in process q, the price of the output commodity is equal to the long-run marginal cost of that commodity.

1) See p. 76.

5. THE NON-ENERGY COMMODITY SUPPLY MODEL

The model introduced in this chapter depicts that part of the economy which purchases energy and labor from the outside and delivers final goods and services for investment or consumption in the household, public, energy and residential heating sectors. It is a very straightforward application of the general formulation of the supply model presented in the preceeding chapter. There are four differences between the two model formulations.

First, the model presented here contains only one domestic production process in each sector. Each commodity is the output of only one production process and there is only one kind of output in each process. In other words, the model is simply a multiperiod input-output model.

Second, in addition to labor, different kinds of energy are treated as primary factors of production.[1] This means that secondary energy prices are exogenously determined and that the cost of energy appears in the criterion function of this model.

Third, in order for the model to calculate the commodity prices at purchasers' values, indirect taxes, subsidies and duties have to be included. This means that a few terms will have to be added to the criterion function of the model.

Fourth, in order to keep the empirical version of the supply model within manageable size, the unit time period has been set equal to five years. This in turn will affect the formulation of the discount function $\phi(t)$ and the treatment of investments.

---

1) There are no quantitative restrictions on the supply of labor or on the supply of energy.

We now turn to a brief discussion of the parameters, commodities, etc. of the non-energy commodity supply model.

5.1 Units of Measurement

Energy commodities are measured in physical units (ton, m^3, kWh), while non-energy commodities are measured in 1968 purchasers' prices. Labor is measured in man-hours. The <u>numéraire</u> of all prices in the model is the 1968 level of consumer goods prices.

5.2 The Input-Output Coefficients (a_{ij})

The input-output coefficients representing the flow of intermediate inputs between the production sectors are obtained from the Ministry of Finance. The figures are based on input-output statistics for the year 1968. The unit of measurement is that amount of a given commodity which was worth one million Sw.Cr. in 1968 purchaser's prices. The future development of the input-output coefficients has been projected at the Ministry of Finance and the values obtained for 1980 have been used in the long-term projection. Since our exogenous assumptions about variables such as domestic final demand, foreign trade and labor productivity are obtained from the Ministry of Finance projection the 1980 input-output coefficients have been used in this study as well; cf. Table A.5:2.

The coefficients of the matrix that transforms the production sector outputs into consumer goods and services were calculated by Björklund for the Energy Forecasting Model (EFM) project. The figures refer to 1968 and are not extrapolated as are the coefficients discussed above. This means that there is an inconsistency in the data base of the model. However, available data did not allow preparation of transformation matrices of this kind for other years than 1968; cf. Table A.1:1.

The energy input coefficients were calculated by Bergström for the EFM project. These figures refer to 1971 and are expressed in physical units per unit of output. Unfortunately, the development of the energy input coefficients could not be extrapolated to 1980. The main reason for this is that energy input coefficients for the production sectors included in the present model are not readily available from official energy statistics. Thus, the preparation of the energy input coefficients in the model's data base is a time-consuming work, which, due to the time-limit of the EFM-project, could not be extended to cover more than a single year. The energy input coefficients used in the simulations discussed in Chapter 10 are shown in Table A.5:3.

5.3 The Capacity Expansion Coefficients (A_{ij})

These coefficients which represent the amount of commodity i that is required when the capacity of sector j is to be increased by one unit were estimated in the EFM project. The two types of data needed for the calculation are the marginal capital output ratios for the different sectors and data about the composition of the gross investments in each sector.

Figures on marginal input-output coefficients are not available and in the same way data about the marginal capital output ratios are very difficult to obtain. Thus, average values have to be used. These figures are endogenously determined in the long-term projection model used by the Ministry of Finance, but the figures were not available early enough to be incorporated into the first version of the EFM. Instead the capital output ratio estimates published by the National Central Bureau of Statistics were used.

The matrix which defines the composition of the gross investments in the different sectors was obtained from the Ministry of Finance. The figures refer to 1968 and have not been published. The projected matrix of the pattern of investment goods deliveries was published in SOU (66).

If σ_{ij} represents the share of real investment goods purchases in sector j that are delivered from sector i and v_j the capital output ratio of sector j, the coefficients A_{ij} are defined by

$$A_{ij} = \sigma_{ij} \cdot v_j.$$

The figures calculated in this way are listed in Table A.1:5.

5.4 The Labor Input Coefficients and the Wage Rate

The labor input coefficients were calculated in the following way. The figures for 1975 were used as the starting point. These figures were then adjusted, for each sector, on the basis of the Ministry of Finance projection of the growth in output per man-hour between 1975 and 2000.

The wage rates used represent an average wage per worked hour in the economy outside the public sector. The point of departure is the 1975 real wage rate[1)] (18.25 Sw.Cr./hour). This wage rate then grows at the same rate as the average output per worked hour in the non-public sector of the economy.

5.5 The Treatment of Taxes, Customs and Duties

The commodity prices determined by the model should be purchaser's prices, that is, prices actually paid by the households. This means that the price of a commodity should be the sum of production costs, distribution costs and indirect taxes. In the same way the prices of imported commodities should include customs and import duties. To accomplish this, indirect taxes, customs and duties are included in the objective function of the model. When taxes and duties appear only in the objective function, they do not represent any use of resources but will always be included in the calculated prices of the commodities. Thus, in this way the calculated commodity prices are expressed in purchaser's values.[2)]

---

1) That is, the 1975 wage rate expressed in the 1968 level of consumer goods prices.

2) The treatment of taxes and duties in this study is the same as in Werin (52).

In the model the unit indirect tax, less subsidies, on commodity i is ξ_i, where net subsidy implies $\xi_i < 0$. Similarly, import processes delivering commodity i may be subject to a unit custom or import duty, $\xi_i^m \geq 0$, while export processes exporting commodity i may receive a unit export subsidy, $\xi_i^z \leq 0$. This way of treating taxes, customs and duties implies that the objective function will contain terms such as:[1)]

$$\sum_j \xi_i \, b_{ij} \, X_j(t) = \text{net commodity taxes on commodity i}$$

$$\xi_i^m \, M_i(t) = \text{customs or import duties on commodity i}$$

$$\xi_i^z \, Z_i(t) = \text{export subsidies to producers of commodity i.}$$

5.6 The Treatment of Imports in Certain Sectors

It is usual to make a distinction between the domestic production sectors which are exposed to foreign competition and the rest of the production system. Of course this distinction is somewhat artificial and particular production sectors will certainly be reclassified as a result of technical change and changing world market prices. Anyhow, in the EFM the production sectors either belong to the K-segment of the economy, which is exposed to foreign competition, or to the S-segment which is net.

However, on the level of aggregation of the EFM there are imports which are classified as being the same kind of commodities as the outputs of production sectors belonging to the S-segment of the economy. In the EFM these imports are treated as complementary imports, that is, import of commodities which are not producible within the economy. The importation of these commodities is assumed to be proportional to the gross production in the corresponding production sectors of the S-segment of the economy. This approach implies that there is no trade in the commodities produced within the S-segment of the economy.

---

1) The symbol b_{ij} expresses the output of commodity i when process j is utilized at unit level.

5.7 The Unit Time Period

The unit period of time in the model is five years. If the unit period had been shorter, the size of the model would have been larger and, accordingly, the solution costs higher. This length of the unit time period implies an assumption of constant activity levels within the five-year periods, while the model endogenously determines changes between the different five-year periods. As a consequence the index t is used to denote five-year periods and the index τ to denote individual years. Thus, the discount factor of the objective function becomes

$$\phi(t) = (1+r)^{-5(t-1)} \{ \sum_{\tau=1}^{5} (1+r)^{-(\tau-1)} \}.$$

That is, the costs of inputs in individual years within five-year periods are first discounted to the beginning of the five-year period and then discounted to the present. The length of the prediction period can be parametrically changed between one and five five-year periods. The initial year is 1975, so that in the model

Period t	Time interval
1	1976 - 1980
2	1981 - 1985
3	1986 - 1990
4	1991 - 1995
5	1996 - 2000

Due to the assumption of constant activity levels within the five-year periods, capacity additions take place only between these periods. So as not to distort the solutions of the model it is assumed that one fifth of the investments take place during each of the five individual years within the periods.

5.8 The Commodities of the Model

Altogether there are 54 different commodities in the model. Many of these are "dummy commodities". Some commodities appear on different levels of aggregation in different parts of the model. For instance, the commodity "Resources for investments in the electricity and heat sector" appears as a single aggregated commodity in the non-energy commodity supply model, where it is produced. In the electricity and heat submodel, however, this commodity is disaggregated into two commodities, one for investments in nuclear plants and one for investments in non-nuclear plants.

The commodities of the model can be grouped in the following way:

Commodity number	Kind of commodity
1 - 10	Consumer goods
1 - 10	Final commodities for private consumption purposes, defined in accordance with the SNA.[1] These commodities are linear combinations of commodities 11 - 32 and 46 - 54.
11 - 45	Other non-energy final goods
11 - 32	Final commodities, producible within the economy, defined in accordance with the SNI.[2] Commodities 11 - 24 are traded on an internationally basis.
33 - 38	Final goods, not producible within the economy, defined in accordance with the SNI.
39 - 43	Dummy commodities used for investment or current purposes in the electricity, petroleum refining and residential heating sectors.
44	Foreign currency.
45	Residential heating services.[3]
46 - 54	Energy commodities. Different kinds of primary and secondary energy.

---

1) 2) and 3) See p. 121.

Table 5:1. Commodities and supply options

No.	Commodities	Commodity classification number			Supply options in the model			Delivered from sub-model
		SNA	SNI	LU 1)	One domestic process	Several domestic processes	Import	
	Private consumption goods (dummy commodities)							
1	Food				x			
2	Beverages and tobacco				x			
3	Clothing				x			
4	Cultural goods and services	2)			x			
5	Hygiene				x			
6	Private transport				x			
7	Leisure activities				x			
8	Furniture				x			
9	Other goods and services				x			
10	Housing services				x			
	Output of domestic production sectors exposed to foreign competition							A1
11	Forestry and logging		12	2	x		x	
12	Mining and quarrying		20	3	x		x	
13	Imports - manufacture of competing food		3)	5	x		x	
14	Manufacture of beverages and tobacco		313,314	6	x		x	
15	Textile, wearing apparel and leather industries		32	7	x		x	
16	Manufacture of wood, wood products, paper prod.		33,341	8	x		x	
17	Printing and publishing		342	9	x		x	
18	Manufacture of rubber products		355	10	x		x	

1) Classification used in the Ministry of Finance projections.
2) See page 121.
3) 3113, 3114, 3115, 3119, 3121, 31

Table 5:1 continued

No.	Commodities	Commodity classification number: SNA	SNI	LU	Supply options in the model: One domestic process	Several domestic processes	Import	Delivered from sub-model
19	Manufacture of chemicals, chemical products and plastic products		351,352 356	11	x		x	
20	Iron, steel and ferro-alloys industries and non-ferrous metal industries		37	14	x		x	
21	Manufacture of fabricated metal products, machinery, equipment, electrical machinery, apparatus, appliances and supplies		38 ./. ./. 3841	15	x		x	
22	Shipbuilding and repairing		3841	16	x		x	
23	Other manufacturing industries		39	17	x		x	
	Output of domestic production sectors not exposed to foreign competition							
24	Agriculture, hunting and fishing		11,13	1	x		x	
25	Manufacture of protected food		1)	4	x			
26	Manufacture of non-metallic mineral products		36	13	x			
27	Construction		50	19	x			
28	Wholesale and retail trade		61,62	20	x			
29	Transport, storage and communication		71,72	21	x			
30	Letting of dwellings and use of owner - occupied dwellings		83101	22	x			
31	Other private services		2)	22	x			
32	Water and electricity distribution services		Part of 40	Part of 18	x			
	Non-competitive imports to domestic prod.sectors							A1
33	Agriculture, hunting and fishing						x	
34	Manufacture of protected food						x	
35	Manufacture of non-metallic mineral products						x	
36	Wholesale and retail trade						x	

1) 3111, 3112, 3116, 3117, 3118; 2) 63,81,82,83102,83103,832,833, 9 priv.

Table 5:1 continued

No.	Commodities	Commodity classification number			Supply options in the model			Delivered from sub-model
		SNA	SNI	LU	One domestic process	Several domestic processes	Import	
37	Transport, storage and communication						x	
38	Other private services not classified elsewhere						x	
	<u>Other dummy commodities</u>							
39	Resources for immediate use in the electricity and hot water sector				x			
40	Resources for investments in the electricity and heat sector 1)				x			
41	Resources for immediate use in the petroleum refining sector 1)				x			A1
42	Resources for investments in the petroleum refining sector				x			
43	Resources for use in the residential heating sector				x			
44	<u>Foreign currency</u>					x		
45	<u>Residential heating</u>							A2
	<u>Energy commodities</u>							
46	Electricity			Part of 18				A3
47	Hot water			-"-				
48	Uranium						x	
49	Coal							A1
50	Crude oil 1)			12			x	
51	Gasoline			12			x	
52	Light fuel oil			12			x	A4
53	Heavy fuel oil			12			x	
54	Gas			Part of 18	x			A1

1) Disaggregated into different commodities in some parts of the model.

As stated above, the non-energy commodities are measured in 1968 purchasers' prices while energy is measured in kWh, m^3 or ton. Labor is measured in man-hours. All of the commodities in the model are listed in Table 5:1 along with the corresponding supply options and indications as to the supply submodel from which they are supplied.

Commodity	SNA-classification
1.	11000, 71320, 71360
2.	12000, 13000, 14000
3.	21110, 21120, 22100, 22200, 82200 (part of)
4.	72300, 72400, 73100, 73200, 73300, 86200
5.	45200, 51200, 81100, 81210, 81220
6.	61100, 62100, 62200, 62300, 63000
7.	41140, 52000, 61200, 62100, 62200, 71100, 71210, 71220, 71230, 71240, 71310, 71330, 71340, 71350, 71400, 72100, 72200, 82100, 82200
8.	41110, 41120, 41130, 42100, 43100, 44100, 45110, 71250
9.	46000, 64000, 82300, 83000, 85000, 86100, 86300, 87000, 88000, 89000, 91000
10.	31100, 31200, 31300, 31400, 32100, 32200, 32300

5.9 Equations and Inequalities of the Non-energy Commodity Supply Submodel

We are now ready to present the equations and inequalities of the non-energy commodity supply submodel. We begin by defining the variables and parameters of the model.

---

1) Standard National Accounts.

2) Svensk Näringslivsindelning.

3) Commodity 45 never appears explicitly in the model; it is a catch-all for the demand constraints of the residential heating supply submodel.

Endogenous variables

$Z_i(t)$	real exports of commodity i; i = 11, 12, ..., 23
$X_j(t)$	activity level of production process j
$L_i(t)$	delivery process for commodity i; i = 46,47,51,52,53
$M_i(t)$	real imports of commodity i; i = 11,12,...,23,33,..., 38,48,49,..., 53
$K_j(t)$	productive capacity of production sector j, measured in real output
$\Delta K_j(t)$	increase in the productive capacity of sector j
$R_j(t)$	utilization of the initial capital stock of type j during period t; measured in real output
$N^F(t)$	employment in the final commodity supply sector during period t.

Exogenous variables

$C_i(t)$	private final consumption of commodity i during period t. i = 1,2,..., 10[1)]
$G_i(t)$	public consumption commodity i or the use of commodity i for construction; i = 11,12,..., 32
$G_{44}(t)$	target net flow of foreign currency on current account during period t
$L_i(t)$[2)]	real consumption or investment of commodity i in the electricity, petroleum refining or residential heating sectors; i = 39, ..., 43
$P_i^*(t)$	world-market price of commodity i
$P_i(t)$	domestic price of commodity i[3)]

---

1) $C_{10}(t)$ is the private demand for dwellings. This demand is the sum of rents and inputed rents only and the cost for residential heating is excluded.

2) Observe that this exogenous variable of this submodel is an endogenous delivery process of some other submodel.

3) All exogenously determined prices are assumed to include commodity taxes.

$n_j(t)$	amount of labor, required when process j is utilized at unit level, measured in man-hours
$\omega(t)$	real wage rate
$\rho_j(t)$	cost of using capital in sector j
$(1-\delta_j)^t\ K_j(0)$	amount of initial productive capacity of type j remaining in period t, measured in real output
r	interest rate
$\phi(t,r)$, $\psi(t,r,\rho_j)$	discount factors.

Parameters

a_{ij}	amount of commodity i required when production process j is utilized at unit level
m_{ij}	amount of non-competitive imports of commodity i required when production process j is utilized at unit level
A_{ij}	amount of commodity i required in order to increase the productive capacity of process j by one unit measured in real output
b_{ij}	amount of commodity i produced when production process j is utilized at unit level
δ_j	rate of capital depreciation in process j
d_i	foreign transportation cost for commodity i
ξ_i	net of per unit subsidy and tax on commodity i; net subsidy implies $\xi_i < 0$
ξ_i^m	per unit import duty on commodity i; $\xi_i^m > 0$
ξ_i^z	per unit export subsidy on commodity i; $\xi_i^z < 0$.

It should be noted that the commodity index runs from 1 to 54 while j, the process index, belongs to one of the sets defined below. Delivery processes have a commodity index. The symbol $\in$ means "belong to the set".

Processes producing commodity i[1]	Notation
$i = 1,2,\ldots, 10$	$j \in H$
$i = 11,12,\ldots, 23$	$j \in K$
$i = 24,25,\ldots, 32,54$	$j \in S$
$i = 11,12,\ldots, 32,54$	$j \in \Omega = K \cup S$
$i = 39,40,\ldots, 43$	$j \in D$

The set H thus contains the processes producing goods and services for final consumption in the household sector. All these processes are "dummy processes" without direct input of capital and labor; they simply aggregate production sector outputs into consumer goods and services. The set K contains the production sectors that are exposed to foreign competition while the set S contains the rest of the domestic production sectors outside the public sector. Thus, Ω, the union of K and S contains all domestic production sectors outside the public sector. The set D, finally, contains the "dummy processes" which aggregate production sector outputs, energy and labor into inputs used in the electricity and heat, refinery and residential heating sectors.

The following sets of commodities are also defined:

$\Delta = \{i \mid i = 11,12,\ldots, 32,54\}$

$\varepsilon = \{i \mid i = 46,47,51,52,53\}$

$\Lambda = \{i \mid i = 11,12,\ldots, 23,33,\ldots, 38,49\}$

In the model no taxes are levied upon "dummy commodities", (1 - 10, 39 - 43) since these are linear combinations of the commodities 11 - 32 and 46 - 54. Moreover, the commodities characterized as "complementary imports" (33 - 38) are not, accordingly, produced within the economy. It follows that the set Δ contains all commodities on which taxes are levied. Further, the set ε contains secondary energy produced outside the non-energy commodity supply model and the set Λ contains imported goods.

With respect to the constraints, exogenous variables are written on the right-hand side and endogenous variables on the left-hand side. Except for [15] these constraints hold for all t.

---

1) The commodity list can be found on p. 118.

Objective function to be minimized

$$F(T) = \sum_{t=1}^{T} \phi(t) \{\omega(t) N^F(t) + \sum_{j\in\Omega} \rho_j(t) R_j(t) + \sum_{i\in\varepsilon} P_i(t) L_i(t) +$$

$$+ \sum_{i\in\Delta} \sum_{j\in\Omega} \xi_i b_{ij} X_j(t) + \sum_{i\in\Lambda} \xi_i^m M_i(t) + \sum_{i=11}^{23} \xi_i^z Z_i(t)\} -$$

$$- \sum_{j\in\Omega} \psi_j(T) K_j(T)$$

where

$$\phi(t) = (1+r)^{-5(t-1)}\{\sum_{\tau=1}^{5} (1+r)^{-(\tau-1)}\}$$

$$\psi_j(T) = \sum_{\tau=5\cdot T+1}^{\infty} (1+r)^{-\tau} \rho_j(\tau) (1-\delta_j)^{\tau-5\cdot T}.$$

The first term within the brackets of the objective function is total labor costs in the economy outside the public sector. The second term is a consequence of our treatment of the initial stock of capital;[1] it reflects the cost of using the initial stock of capital. The third term reflects the total cost of deliveries from the energy sector. The next term represents total indirect taxes paid by the domestic production sectors. The fifth term within the brackets represents customs and duties on imported goods and services, while the sixth term represents total export subsidies. The last term of the objective function represents the present value of the stock of capital existing at the terminal point in time.

Commodity balances

$$X_j(t) \geq C_i(t) \;;\; i = 1,2,\ldots, 10, \quad j \in H \qquad [1]$$

The inequalities [1] simply state that the output from each of the dummy processes aggregating production sector outputs into consumer goods and services should be greater than or equal to the exogenously determined demand for the goods and services in question.

---

1) See Section 4.5.3.

$$\sum_{j\in H} -a_{ij} X_j(t) + \sum_{j\in\Omega} (b_{ij}-a_{ij}) X_j(t) - \sum_{j\in D} a_{ij} X_j(t) - \sum_{j\in\Omega} A_{ij} \frac{\Delta K_j}{5}(t) - Z_i(t) + M_i(t) \geq G_i(t) \;;\; i = 11,\ldots, 23 \;; \qquad [2]$$

These inequalities hold for the commodities produced within the K-segment of the economy. Accordingly trade variables are included. The first term in [2] represents the use of commodity i as an input in the dummy processes "producing" consumer goods and services (commodities 1 - 10). The second term represents the gross output of commodity i less its use as an intermediate input within the domestic production system. The third term represents the use of commodity i as an input in the dummy processes "producing" the aggregated inputs used in the electricity and heat, refinery and residential heating sectors. The fourth term represents the use of commodity i as a capital good in the production system. The fifth and sixth terms represent export and import respectively of commodity i. Thus, the left-hand side of [2] represent all endogenously determined supplies of and demands for commodity i. The term on the right-hand side of [2] represents the exogenously determined demand for commodity i.

$$\sum_{j\in H} -a_{ij} X_j(t) + \sum_{j\in\Omega} (b_{ij}-a_{ij}) X_j(t) - \sum_{j\in D} a_{ij} X_j(t) - \sum_{j\in\Omega} A_{ij} \frac{\Delta K_j}{5}(t) \geq G_i(t) \;;^{1)} \quad i = 24,\ldots, 32 \;; \qquad [3]$$

These inequalities hold for the commodities produced within the S-segment of the economy. In accordance with the discussion in Section 5.6 no trade variables are included. That is the only difference between [2] and [3].

$$\sum_{j\in S} - m_{ij} X_j(t) + M_i(t) \geq 0 \;; \qquad i = 33,\ldots, 38 \;; \qquad [4]$$

---

1) When i = 32 $G_i(t)$ includes the low voltage charges paid by the residential heating sector.

In accordance with the discussion in Section 5.6 the commodities covered by [4] are treated as complementary imports to the S-segment of the economy. Accordingly there is no domestic production of these commodities, and they are used in the S-segment of the economy only.

$$X_j(t) \geq L_i(t) \; ; \qquad i = 39,\ldots, 43 \; ; \; j \in D \qquad [5]$$

These inequalities state that the output from each of the dummy processes aggregating production sector outputs into aggregated inputs to be used in the electricity and heat, refinery or residential heating sectors, should be greater than or equal to the exogenously[1)] determined demand for the aggregated input in question.

$$\sum_{i=11}^{23} \left[P_i^*(t) - d_i\right] Z_i(t) - \sum_{i=11}^{23} P_i^*(t) M_i(t) - \sum_{i=33}^{38} P_i^*(t) M_i(t) - P_{49}^*(t) M_{49}(t) \geq G_{44}(t) \qquad [6]$$

Inequality [6] represents the current account constraint and its interpretation is straight-forward; the net of export earnings and import expenditures must be greater than or equal to the exogenously determined current account surplus (or deficit).

$$\sum_{j \in \Omega \cup D \cup H} -a_{ij} X_j(t) + L_i(t) \geq G_i(t) \; ; \quad i = 46,47 \; ; \qquad [7]$$

$$\sum_{j \in \Omega} -a_{49,j} X_j(t) + M_{49}(t) \geq G_{49}(t) \; ; \qquad [8]$$

$$\sum_{j=1}^{10} -a_{ij} X_j(t) - \sum_{j \in \Omega} a_{ij} X_j(t) + L_i(t) \geq G_i(t); \quad i=51,52,53; \qquad [9]$$

---

1) When the non-energy commodity supply model is linked to the other supply submodels of the EFM, the demands for commodities 39 - 43 are endogenously determined.

$$\sum_{j=1}^{10} -a_{54,j}\ X_j(t) + \sum_{i\in\Omega} (b_{54,j} - a_{54,j})\ X_j(t) \geq G_{54}(t)\ ; \qquad [10]$$

Inequalities [7] - [10] hold for energy commodities. Electricity, heat and petroleum products (commodities 46, 47, 51, 52 and 53) are delivered from the sectors of the economy covered by the electricity and heat and the refinery sector models. Coal (commodity 49) is entirely imported, while the production of gas (commodity 54), in fact, is carried out within a sector of the economy covered by the non-energy commodity supply model. Uranium and crude oil (commodities 48 and 50 respectively) are not used at all in the sectors of the economy covered by the non-energy commodity supply model.

Capacity constraints

$$R_j(t) + K_j(t) - X_j(t) \geq 0\ ; \qquad j \in \Omega \qquad [11]$$

Use of labor

$$N^F(t) - \sum_{j\in\Omega\cup D} n_j(t)\ X_j(t) \geq 0\ ; \qquad [12]$$

Resource constraints

$$-\ R_j(t) \geq -\ (1-\delta_j)^t\ K_j(0)\ ; \qquad j \in \Omega \qquad [13]$$

Intertemporal links

$$\sum_{\tau=1}^{t} (1-\delta_j)^{t-\tau}\ \Delta K_j(\tau-1) - K_j(t) = 0\ ;\ j \in \Omega;\ \ t = 2,3,\ \ldots,\ 5. \qquad [14]$$

APPENDIX 1.

1. Notations

Commodities are denoted by index i and processes by index j. Each process index consists of a commodity index and a serial number. The first serial number is 00. Thus, j=800, for instance, denotes the production process, or the first of the production processes, where commodity 8 is an output.

2. Tables

See p. 130.

3. Sources

See p. 142.

Table A. 1:1. Input of commodity i when production process j is utilized at unit level (mill. Sw. Cr.)

i \ j	100	200	300	400	500	600	700	800	900	1000	i \ j
11										0.005	11
12											12
13	0.263										13
14		1.0									14
15			0.977		0.086		0.024	0.175			15
16					0.042		0.001	0.257			16
17				0.502				0.001			17
18			0.017		0.020	0.046	0.002			0.003	18
19					0.498		0.035	0.135	0.001		19
20								0.001			20
21					0.049	0.310	0.439	0.382	0.001		21
22							0.073		0.001		22
23					0.017		0.196	0.008		0.001	23
24	0.213										24
25	0.524										25
26								0.041			26
27											27
28											28
29						0.221			0.162		29
30										0.823	30
31			0.006	0.492	0.288	0.201	0.187		0.835		31
32											32
46										x) 0.8	46

x) GWh/mill. Sw.Cr.

cont.

cont. Table A. 1:1

i \ j	100	200	300	400	500	600	700	800	900	1000	i \ j
47											47
49											49
51						xx) 0.227	xx) 0.0429				51
52										xx) 0.462	52
53						xx) 0.123	xx) 0.030				53
54										xx) 12.5	54

xx) 1000 m^3/mill. Sw. Cr.

Table A.1:2.

The coefficient a_{ij} where $j \in \Omega$ and $i \in \Delta$. The amount of commodity i required when production process j is utilized at unit level (measured in mill. Sw.Cr./ mill. Sw.Cr.)

i \ j	1100	1200	1300	1400	1500	1600	1700	1800
11	0.01143	0	0.00326	0	0	0.19967	0	0
12	0.00156	0.06535	0	0	0	0.00431	0	0
13	0	0	0.14269	0.00337	0	0.00087	0	0
14	0	0	0	0.01181	0	0	0	0
15	0.00182	0	0	0	0.19579	0.01427	0.00286	0.09123
16	0.00364	0.00429	0.03138	0.01055	0.00861	0.16560	0.11643	0.01212
17	0	0	0.00892	0.00436	0.00702	0.00425	0.04256	0.00784
18	0	0	0	0	0.00362	0.00105	0.00123	0.03350
19	0.00364	0.01026	0.01098	0.00380	0.04818	0.03571	0.02230	0.11547
20	0	0.00956	0	0	0	0.00175	9.00123	0
21	0.03689	0.03405	0.01801	0.00633	0.00532	0.03675	0.00307	0.04490
22	0	0	0	0	0	0.00076	0	0
23	0	0	0	0	0.00170	0.00012	0	0
24	0	0	0.15435	0.02053	0.00936	0	0	0.02637
25	0	0	0.05762	0.00851	0.00851	0	0	0
26	0	0.02295	0.01389	0.00478	0	0.00116	0	0
27	0.01091	0.01377	0.00240	0.00098	0.00213	0.00530	0.00186	0.00428
28	0.11665	0.02334	0.23735	0.14033	0.29512	0.08632	0.06957	0.16037
29	0.10522	0.22188	0.01132	0.00183	0.00915	0.01188	0.03663	0.01283
30	0	0	0	0	0	0	0	0
31	0.01221	0	0.02144	0.01209	0.02010	0.02971	0.08676	0.02994
32	0.00351	0.00451	0.00241	0.00046	0.00293	0.00492	0.00297	0.00250
x) 54	-	-	0.37042	0.00968	0.02079	0.00033	0.94956	0.09722

cont.

x) Measured in 1000 m^3/mill. Sw.Cr.

cont. Table A.1:2

1900	2000	2100	2200	2300	2400	2500	2600	2700
0.00107	0	0	0	0	0.00059	0	0	0.00030
0.01100	0.18637	0.00028	0	0.00743	0.00332	0	0.01879	0.01350
0.00939	0	0.00017	0	0	0.07912	0.02474	0	0
0	0	0	0	0	0	0	0	0
0.00295	0.00086	0.00444	0.00201	0.00464	0.00391	0.00049	0.00146	0.00720
0.01650	0.00799	0.00800	0.01978	0.01300	0.00462	0.01487	0.01757	0.10908
0.01704	0.00281	0.00659	0.00369	0.01486	0	0.00299	0.00561	0.00343
0.00322	0.00097	0.00896	0.00168	0	0.00154	0	0	0.00266
0.23051	0.02658	0.01847	0.02548	0.02321	0.06479	0.00494	0.02269	0.01168
0.00309	0.34129	0.09564	0.14750	0.08914	0.00083	0.00090	0.01928	0.03899
0.01959	0.04635	0.20623	0.23835	0.00929	0.01291	0.00716	0.02025	0.13480
0	0	0.00320	0.07543	0	0.00746	0	0	0.00252
0.00027	0	0.00025	0	0.01207	0.00024	0	0	0.00027
0.00094	0	0	0	0.00557	0.04453	0.31250	0	0.00047
0.00523	0	0	0	0	0.01066	0.22917	0	0
0.00859	0.01556	0.00805	0.00603	0	0.01019	0	0.19253	0.07952
0.00443	0.00627	0.00425	0.00570	0.00371	0.06834	0.00229	0.00830	0
0.15967	0.10102	0.12919	0.05598	0.38069	0.16250	0.17648	0.07906	0
0.00792	0.01048	0.01503	0.01106	0.00836	0.02428	0.00167	0.02440	0.01205
0	0	0	0	0	0	0	0	0
0.02442	0.02593	0.03251	0.02849	0.02228	0.04536	0.02113	0.03831	0.06888
0.00364	0.00454	0.00309	0.00283	0	0.01146	0.00166	0.00116	0.00134
0.04191	0.10230	0.36234	0.13446	0.12522	-	0.46254	0.01161	-

cont.

cont. Table A.1:2

2800	2900	3000	3100	3200	x) 5400	i \ j
0	0	0	0			11
0	0	0	0		0.000081	12
0	0.00235	0	0.01726			13
0	0.00150	0	0.01323			14
0.00403	0.00372	0	0.00418			15
0.02605	0.00470	0.00934	0.00774	0.00157	0.000003	16
0.02522	0.01222	0.00078	0.01726	0.00574	0.0000022	17
0.00282	0.00889	0	0.00306			18
0.01282	0.00307	0.00642	0.01470	0.00211		19
0	0.00059	0	0.00201			20
0.00255	0.01817	0.00414	0.04620	0.00712		21
0	0.01438	0	0.00074			22
0.00032	0.00020	0	0.00066			23
0.00065	0.00183	0.00193	0.00793			24
0	0.00804	0	0.03908			25
0	0	0.00114	0.00453			26
0.00588	0.08913	0.11035	0.01633	0.08621	0.0000052	27
0	0	0	0.00271	0.01121	0.0000084	28
0.1268	0.12625	0.00078	0.02631	0.00563	0.0000008	29
0	0	0	0			30
0.11337	0.08096	0.03609	0.14735	0.03597	0.0000026	31
0.00522	0.00230	0.01392	0.00647			32
-	-	-	0.37288	0.00063	-	54

x) Measured in mill. Sw.Cr./1000 m^3.

Table A.1:3. Input of energy commodity i when production process j is utilized at unit level (a_{ij} where $i \in \varepsilon$ and $j \in \Omega$)

i \ j	1100	1200	1300	1400	1500	1600
46 (GWh)	0.08603	0.63161	0.04841	0.01575	0.05432	0.65455
47 (GWh)	-	0.00029	0.01290	0.00001	0.00945	0.02223
49 (1000 m^3)	-	0.05946	0.00001	0.00000	0.00001	0.00026
51 (1000 m^3)	0.01965	0.00208	0.00131	0.00112	0.00274	0.01899
52 (1000 m^3)	0.02367	0.02199	0.00410	0.00266	0.00482	0.00801
53 (1000 m^3)	-	0.05670	0.01674	0.00813	0.01774	0.11216

i \ j	1700	1800	1900	2000	2100	2200
46	0.05486	0.18382	0.54110	0.76440	0.07708	0.08688
47	0.00092	0.00011	0.04765	0.00376	0.00130	0.00013
49	0.00004	0.00002	0.00952	0.00429	0.00001	-
51	0.00582	0.00395	0.06910	0.00206	0.00286	0.00086
52	0.00393	0.00848	0.00561	0.01426	0.00732	0.00850
53	0.00497	0.05153	0.05549	0.08334	0.01147	0.01125

i \ j	2300	2400	2500	2600	2700	2800
46	0.02547	0.10843	0.06695	0.33117	0.02498	0.10683
47	0.00026	-	0.00292	0.00022	-	0.03693
49	-	-	0.00027	0.39042	-	-
51	0.00717	0.01994	0.00203	0.00887	0.00527	0.01816
52	0.00358	0.04561	0.00717	0.04352	0.02322	0.02562
53	0.00268	0.01536	0.01841	0.19672	0.00338	0.00977

i \ j	2900	3000	3100	3200	5400 x)
46	0.14557	0.03777	0.11343	0.22227	0.00007
47	-	0.02732	0.01494	-	-
49	-	0.00112	0.00788	-	0.00147
51	0.04581	0.00007	0.00472	0.00026	0.00020
52	0.04253	0.04289	0.02125	0.00253	0.00002
53	0.01337	0.01405	0.00653	0.00039	0.00000

x) The output from process 5400 is measured in 1000 m^3.

Table A.1:4. Input of commodity i when (dummy) process j is utilized at unit level (a_{ij} where $i \in \Delta$ and $j \in D$)

i \ j	3900	4001	4002	4101	4102	4103	4104	4105	4200	4300	4302	4303
17								0.04				
19				1.0	1.0			0.236				
21	0.20	0.60	0.65			0.5		0.280	0.70	1.0		
27		0.40	0.35			0.5		0.008	0.30			
28							1.0					
30								0.002				
31	0.20							0.430				
32								0.004			1.0	1.0

Process	Output
3900	Resources for immediate use in the electricity and hot water sector
4000	Investment resources for the electricity and hot water sector
	4001 For non-nuclear plants
	4002 For nuclear plants
4100	Resources for immediate use in the petroleum refining sector
	4101 Tetra etyl lead
	4102 Hydrogen
	4103 Maintenance resources
	4104 Trade margins
	4105 Other resources for immediate purpose

Process	Output
4200	Investment resources for the refinery sector
4300	Resources for energy conservation in the residential heating sector
4302	Resources for distribution of electricity in the residential heating sector
4303	Resources for distribution of hot water in the residential heating sector

Table A. 1:5. Input of commodity i required in order to increase the productive capacity of process j by one unit (1 mill. Sw.Cr.); (A_{ij} where $i \in \Lambda$ and $j \in \Omega$)

j \ j	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100
11	0.3834										
12											
13											
14											
15	0.0075	0.0086	0.0024	0.0079	0.0053	0.0122	0.0087	0.0080	0.0083	0.0135	0.0048
16	0.0372	0.0607	0.0140	0.0318	0.0319	0.0578	0.0394	0.0321	0.0370	0.0610	0.0218
17											
18											
19											
20											
21	0.8151	1.2560	0.3000	0.7470	0.7394	1.2747	0.8930	0.7306	0.8106	1.3455	0.4865
22											
23											
24											
25											
26											
27	0.2568	0.8747	0.1837	0.4133	0.2234	0.5554	0.3589	0.3292	0.2442	0.3800	0.2869

Table A. 1:5 cont'd.

i \ j	2200	2300	2400	2500	2600	2700	2800	2900	3000	3100	3200	5400 x/
11												
12												
13												
14												
15			0.0314	0.0030	0.0142	0.0023	0.0051	0.0227		0.0045	0.057	0.00000456
16	0.0113	0.0173	0.1543	0.0163	0.0569	0.0114	0.0250	0.1371	0.0019	0.0207	0.297	0.00002380
17												
18												
19												
20												
21	0.2366	0.4138	3.3755	0.3695	1.2380	0.2493	0.5506	3.0119	0.0224	0.4548	6.519	0.00052152
22	0.1465							0.5525		0.0126		
23										0.0220		
24												
25												
26												
27	0.4056	0.0690	0.7988	0.1113	0.4909	0.0370	0.4193	2.0858	18.6757	0.7545	23.127	0.00185000

x) The output of process 5400 is measured in 1000 m^3.

Table A. 1.6. Input of commodity i (complementary imports) when process j is utilized at unit level. (m_{ij} where $i \in \Lambda$ and $j \in S$)

i \ j	2400	2500	2600	2800	2900	3100
33	0.2240					
34		0.0614				
35			0.1410			
36				0.0223		
37					0.0904	
38						0.0342

Table A.1:7. Net unit tax, ξ_i, and unit import duty, ξ_i^m, on commodity i

i	ξ_i	ξ^m	i	ξ_i	ξ^m
11	–	0.1148	28	–	
12	0.0007	0.0108	29	–	
13	0.0650	0.3498	30	–	
14	0.6961	0.3320	31	0.0327	
15	0.0722	0.3349	32	–	
16	0.0316	0.1327	33		0.2245
17	0.0315	0.1006	34		0.0490
18	0.0609	0.2302	35		0.1617
19	0.0512	0.1570	36		–
20	0.0095	0.0984	37		–
21	0.0524	0.0654	38		0.0199
22	0.0084	0.0098	x)46	0.007	
23	0.1359	0.4134	47	–	
24	0.0120		48		–
25	0.0507		xx)49		0.012
26	0.0524		xx)51	0.57	
27	–		xx)52	0.06	
			xx)53	0.016	

x) Measured in mill. Sw.Cr./Gwh

xx) Measured in mill. Sw.Cr./1000 m^3

Table A. 1:8. The rate of depreciation, δ_j, and the amount of initial productive capacity, $K_j(0)$, in process j

j	δ_j	$K_j(0)$
1100	0.035	3,710
1200	0.028	2,870
1300	0.039	8,560
1400	0.039	8,450
1500	0.039	10,300
1600	0.036	23,590
1700	0.036	6,690
1800	0.046	2,130
1900	0.046	10,750
2000	0.031	11,600
2100	0.036	57,380
2200	0.036	4,740
2300	0.050	1,650
2400	0.032	14,380
2500	0.039	19,590
2600	0.033	6,680
2700	0.071	33,100
2800	0.041	29,550
2900	0.036	23,520
3000	0.015	18,570
3100	0.026	33,430
3200	0.014	4,464
3900		
5400	x) 0.015	xx) 450,000

x) Measured in mill. Sw.Cr./1000 m^3

xx) Measured in 1000 m^3

3. Sources

A.1.1 Björklund, A: "Den privata konsumtionen i EPM," EFI, Stockholm 1975 mimeographed.

A.1.2 SOU 1976:42 and this study.

A.1.3 Bergman, L. & Bergström, C., Energipolitik och energianvändning, EFI, Stockholm 1974.

A.1.4 This study.

A.1.5 A_{ij} is defined by $A_{ij} = \sigma_{ij} v_j$. σ_{ij} is obtained from the Ministry of Finance and v_j from the National Accounts, SM N 1974:89, supplement 1974:52.

A.1.6 The Ministry of Finance

A.1.7 The Ministry of Finance

A.1.8 The δ_j:s are obtained from the National accounts and $K_j(0)$ from the Ministry of Finance. The parameters ρ_j are defined by $\rho_j = \sum_i P_i(0) A_{ij}(r+\delta_j)$ where r is the interest rate that is, a parameter in the model.

6. THE ELECTRICITY AND HEAT SUPPLY SUBMODEL

This chapter deals with the electricity and heat supply submodel (A2 in the figure on page). The "producers" in this model deliver electricity and heat to users in the non-energy commodity, refinery, residential heating, public and household sectors. The exogeneously supplied inputs used in this part of the model economy are capital goods, various fuels and a number of intermediate inputs. All intermediate inputs are "dummy commodities" originating in the non-energy production sector.

This submodel is a linear, multi-period activity model with processes for production, investment and scrapping. Some of the production processes yield a joint supply of electricity and hot water. Ten different types of plants are distinguished in the model, but each plant of the same type is assumed to be homogeneous. Thus, differences between individual production units due to size, location or vintage are not taken into consideration.

As was discussed in Chapter 4, the linearity of the model implies constant returns to scale and perfect divisibility in all processes. Although hardly true in reality, these assumptions are acceptable in the model. This is because an individual plant is relatively small as compared to normal annual changes in demand,[1] which means that

---

1/ This argument is strengthened by the fact that the unit period of the model is five years.

a capacity addition to the system can be interpreted as addition of a number of plants of optimum size.[1/]

As indicated above, the demand for electric energy and hot water from 1975 until the terminal period T is exogenous to the model. Given initial capacities, the model chooses that set of production, investment and scrapping activities which simultaneously satisfies the exogenous demand and minimizes the present value of the total costs. The dual formulation of the model determines the marginal costs of electricity and heat in the different time periods.

The problems analyzed and the model used in this part of the study are influenced by the tradition which originated in the planning carried out at the Electricité de France (EDF) in the late 1940s. Since then, these planning tools have been applied in many countries and the models have been developed with respect to both size and complexity; see Anderson (1). In addition, models of the electricity sector have been linked to larger models of the energy sector or the whole economy; see Hoffman (25), Finon (19) and Manne (38). Accordingly, this study is not the first Swedish effort in the EDF tradition. Models have been developed by Lindqvist (34) for the Swedish Power Board and by Bergendahl (3). As a background, we present a brief description of the nature of these earlier Swedish models.

The model developed by the Swedish Power Board is a dynamic programming model which simulates the least cost operation of the electric power system during a 30-year period, under the assumption of given demand and production capacities. Solution of the model thus gives the total variable costs associated with an exogenously determined plant structure for which the fixed costs are known. A preferred production system is arrived at by means of exogenous variations in the plant structure. The Power Board model is a refined tool, well-suited to solving the traditional problem of the Swedish power industry - the optimum use of thermal plants in a system based on hydro power. However, for our purposes the main requirement is not a detailed

1/ All cost parameters in the model are computed on the assumption that each plant is of optimum size.

operations model for the electricity sector, but rather a somewhat less detailed model where operation of the different plants and capacity additions are endogenously determined. Moreover, the Power Board model only covers the state-owned part of the power industry, whereas we are interested in the entire electricity and heat sector.

Bergendahl's model is rather similar to the one used in this study. Apart from a few minor dissimilarities, the main difference lies in the treatment of heat production. The production of heat is exogenously determined in Bergendahl's model and endogenously in the present model. The reason for the more elaborate treatment of heat production in this model is twofold. First, the competitiveness of combined oilfired power plants depends to a large extent upon oil prices. An exogenously determined expansion path for this kind of plant is, ceteris paribus, relevant only for a certain set of oil prices. Bergendahl's model is thus not well-suited for experiments with varying oil prices. Second, since district heating is an important potential source of energy in the residential heating sector, a supply model for heat is required in this study.

The present model diverges from the mainstream of the EDF tradition in various respects other than the inclusion of heat production. Two of these deviations are noteworthy. First, demand in this model is denoted by the demand-load curve, while the load-duration curve represents demand in most of the other models.[1/] The advantage of the approach chosen in this study is that it leads to an interesting development of the complete model. That is, if the time pattern of the electricity and heat consumption of important sectors can be specified, the input coefficients for electricity and heat in these sectors can be replaced by vectors where the components represent the input of energy during particular time-segments.[2/] With this change in the model, the shape of the aggregate load curve becomes endogenous.

1/ See note 1/ page 146.

2/ The industrial demand for electricity and heat is related to the rate of industrial production, while the household demand for these kinds of energy mainly is related to climatic conditions. Thus the load characteristics of the industrial and household sectors are quite different.

The present submodel differs from the general description of the supply model (cf. Section 4.2) in the following respects:

i) outputs and productive capacities are measured in physical units

ii) there is joint production of two or more outputs in several processes

iii) each time period is divided into a number of time segments

6.1 Special Features of Electricity Demand and Supply and Their Implications for Capacity Measurement

Countrary to most other commodities, electric energy must be produced and consumed simultaneously. In addition, the demand for electricity varies systematically over the day, week and year. Due to these circumstances, the measure of productive capacity in the electricity sector has two dimensions. First, in order to produce the quantity of energy

---

1) Note from page 145
If the demand load is plotted on the MW-time plane, something like Figure a emerges.

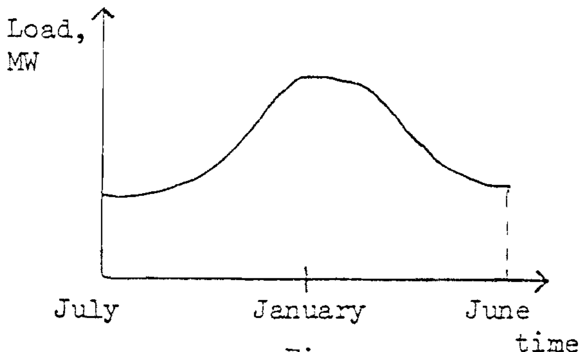


Fig. a

These data can be used to compare the duration of the load at each level. These calculations result in something like Figure b.

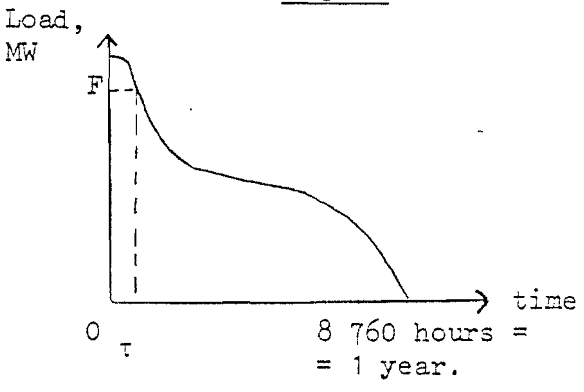


Fig. b

It can, for example, be seen from Figure b that there is a load of F MW or more during τ hours of the year.

Clearly, there is a single load-duration curve which corresponds to each demand-load curve, but many different demand-load curves can result in the same load-duration curve.

demanded, the system has to have an average capacity for the whole year. Second, time variations in demand necessitate a certain amount of peak capacity. Both of these concepts, peak and average capacity, are necessary. For example, a thermal plant with high reliability in continuous production has a peak capacity close to average capacity. On the other hand, a hydro power plant normally has a peak capacity which is much higher than its average capacity (due to limitations in the water supply).

The capacity measures of the model can be defined by means of the concepts peak and average capacity. Assume that the installed capacity of plant type s is F_s MW. Every year, each plant has to close down for planned maintenance work. Then τ_s hours of the whole year (8 760 hours) remain. The availability[1] of the plant, i.e. the share of the τ_s hours that the plant is expected to be in operation or can be called into operation, is a_{ws}. Thus, the average capacity of the

---

1) Unfortunately, the frequently used concept of "availability" has many definitions, e.g. time availability, capacity availability, energy availability; see KTH (60). With respect to the definition of availability, however, this study adheres to what seems to be accepted practice in the Swedish power industry; see CDL (55), page 22. Thus the average availability

$$a_{ws} = \frac{\text{expected time in operation + expected stand-by time}}{\text{the whole year less the time for planned maintenance work}},$$

while peak availability is defined as

$$a_{ps} = \frac{\text{expected time in operation during peak hours + expected stand-by time during peak hours}}{\text{number of peak hours}}$$

One drawback of the time availability definition, of which this is a version, is its implicit assumption that if a plant can be used at all, then it can be used at full capacity. However, this may not always be the case. Thus it might appear more advantageous to use the energy availability definition (that is, the so-called capacity factor) which takes the degree of capacity utilization into consideration. However, the problem in using this definition is that it is impossible to ascertain whether an observed capacity utilization less than full capacity was planned or unplanned. In order to investigate the importance of the availability figure, parametric variations will be made.

plant becomes:

$$\text{Average capacity} = F_s \frac{\tau_s \cdot a_{ws}}{8\ 760} \text{ MW.}$$

It is a matter of indifference whether supply capacity and demand are measured at the power station or at the consumption site as long as these quantities are measured at the same point. In this study, the demand for energy and the supply capacities are measured at the point of consumption, which means that capacities are measured net of distribution losses. If the average distribution losses are $(1 - \eta_m)$ 100 %, the average capacity of plant s at the consumption point becomes:

$$\text{ACC} = \text{Average Capacity at the Consumption point} = F_s \frac{\tau_s \cdot a_{ws} \cdot \eta_m}{8\ 760} \text{ MW.}$$

Now, during a one-year period, the installed capacity of plant s has a certain ability to deliver energy to consumers. This amount, ACC 8 760, will be called the "potential production of energy", denoted Y_s and expressed in GWh (1 GWh = 1 000 MWh). Thus:

$$Y_s = F_s \cdot \tau_s \cdot a_{ws} \cdot \eta_m \quad \text{MWh} = F_s \cdot \tau_s \cdot a_{ws} \cdot \eta_m \cdot 10^{-3} \text{ GWh.}$$

In the following, all investment and maintenance costs will be expressed per unit of "potential production of energy".

During peak hours the availability of the F_s MW installed capacity of plant type s is expected to be a_{ps}[1] and the peak distribution losses are expected to be $(1 - \eta_{min})$ 100 %[2]. Thus, the expected peak capacity of plant s is:

$$\text{Peak capacity at the consumption point} = F_s \cdot a_{ps} \cdot \eta_{min} \quad \text{MW.}$$

---

1) See footnote 1 on page 147.

2) $\eta_{min} = 0{,}89$, $\eta_m = 0{,}91$; Hedbom & Rundström (22), p. 3.

Next, the relation between the "potential production of energy" and peak capacity is defined by means of the following quotient

$$f_s = \frac{F_s \cdot a_{ps} \cdot \eta_{min}}{Y_s} \frac{MW}{GWh} = \frac{a_{ps} \cdot \eta_{min} \cdot 10^3}{\tau_s \cdot a_{ws} \cdot \eta_m} \frac{MW}{GWh},$$

that is, if the potential production of energy in plant s is Y_s GWh per year, the peak capacity of plant s will be $Y_s \cdot f_s$ MW.

In addition to the two-dimensional capacity measure, some types of plants are characterized by joint production of electric energy and heat. Since both of these energy forms have a market value, a model designed to depict the optimal plant structure of the electricity sector has to take this possibility of joint production into account. Thus, the demand side in this model includes the demand for both electricity and heat[1]. It follows that in a few cases, the "potential production of energy" has two components: the main product and the by-product. In most cases the main product is electricity. The by-product is always heat. Thus, if there is joint production in plant s, the following notations are employed:

potential production of the main product = Y_s GWh

potential production of the by-product = $Y_s \cdot h_s$ GWh.

The definitions of the capacity measures clearly indicate that the availability of a certain plant is an important parameter in power system planning (e.g. in the determination of reserve capacity and capital costs per GWh produced).[2]

---

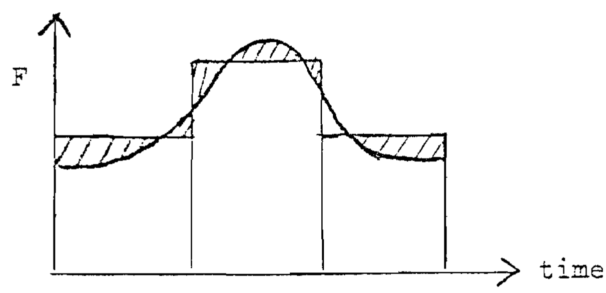
1) Heat and electricity have many similarities: The load of heat demand varies systematically over time and heat can be stored to a limited extent only.

2) The figures used in this study can be found in Table 8.3, p. 204. Unfortunately, there is no common agreement as to the correct magnitude of these numbers, especially for nuclear power. This means that the sensitivity of the solutions should be tested with respect to the availability of nuclear power.

The problem for planners in the power industry is to assign a composition of different plants to the production system such that, given the expected demand, the probabilities of peak capacity deficiency and potential production deficiency are kept below a predetermined level and costs are minimized. Due to the shape of the demand-load curve, optimization will result in a mixture of plants. In an optimum operations plan the utilization times of plants where capital costs make up a major share of total cost are long, while plant types with the opposite cost structure are used to satisfy peak-load demand and to provide reserve capacity.

To what extent can this optimization process be simulated in a linear activity model? The problem inherent in such a simple model is that the demand load curve cannot be specified as a continuous function of time. Theoretically, of course, the continuous function can be approximated by a stepwise function with a great number of steps. There is a trade-off, however, between the quality of the load curve approximation and the size of the model. Thus - although risking oversimplification - the demand load curves for electricity and hot water in this study are represented by stepwise functions with seven steps only, i.e. the year is divided into seven time segments. The probable bias in the solutions of the model is discussed in conjunction with the constraints of the model; see p.

The quality of the load-curve approximation depends on not only the number of time-segments; there is also an optimal time segmentation for each number of time segments. This problem can be illustrated by means of the following figure where F represents the load. The bell-shaped curve is the true load-curve which is approximated by three linear segments. The shaded areas represent the deviation between the true and the approximate load-curves.



Obviously the concept "optimum time segmentation" can be defined in several ways. One is the segmentation that minimizes the total shaded area. Another is the segmentation that makes the maximum shaded area among the time segments as small as possible. In this study, however, the choice of time segmentation was guided by the latter of these criteria, but it was carried out in a quite informal way.

Any given time segmentation can be discribed in terms of its "relattive demand intensities". In order to define this concept the following notations are introduced:

$E_i(t)$ = demand for electricity during time segment i, period t (MWh)

$E(t)$ = demand for electricity during period t (MWh)

$W_i(t)$ = demand for heat during time segment i, period t (MWh)

$W(t)$ = demand for heat during period t (MWh)

H_i = number of hours during time segment i

H = number of hours during one year (8 760)

$\overline{F}_i(t)$ = average load in time segment i, period t (MW)

$\overline{F}(t)$ = average load during period t (MW)

If demand is met it holds that

$$E_i(t) = H_i\,\overline{F}_i(t)$$

$$E(t) = H\,\overline{F}(t),$$

and we can define the relative demand intensity of time segment i, as

$$\gamma_i = \frac{\overline{F}_i(t)}{\overline{F}(t)} = \frac{E_i(t)/H_i}{E(t)/H}$$

Since the total yearly demand is thus allocated to different time segments, so must the "potential productions". For the thermal power plants this allocation is accomplished by means of fixed numbers, α_{is}, which are assumed to apply to old as well as to new plants. This means that if the "potential production of energy" in plant s, period t is $Y_s(t)$, then the corresponding magnitude for time segment i becomes $\alpha_{is}\,Y_s(t)$.

The potential supply of electricity from hydro power plants during time segment i, period t is constrained either by the available capacity or by the supply of water.

6.2 The Processes covered by the Model

The model contains the following five types of processes:

i) production of energy
ii) investment in new capacity
iii) scrapping of existing capacity
iv) delivery of resources from the rest of the economy and abroad to the electricity and heat sector
v) regulation of the flow of water in the river system [1/]

Among these processes only scrapping may require some clarification. When a power station is built, operating costs only are relevant for decision-making. However, a very limited share of these operating costs are directly linked to the production of energy, while the remaining costs are related to keeping the station available for energy production. Thus, for some input prices, it might be optimal not to use a particular station for regular production but to keep it available for stand-by purposes, whereas another set of input prices might induce actual scrapping of the plant. The inclusion of scrapping processes in the model makes this two-stage scrapping procedure explicit, and the economic lifetime of the plants also becomes endogenous. [2/]

The fact that construction of a new power station takes a considerable time has to be taken into account in the model. However, since the model is solved for five-year periods, this construction lag also has to be expressed in five-year periods. It has thus been assumed that it takes ten years (two five-year periods) from the investment decision until a nuclear power station is completed. The corresponding time for other types of plants is five years. This menas that all capacities in the first five-year period and nuclear power capacity in the second period are exogenously determined.

1/ This process is discussed below in conjunction with constraint [10].

2/ Technically, a scrapping process can be regarded as a "disinvestment" process; maintenance cost reductions are attained at the expense of capacity reductions. Of course the initial investment outlay can never be recovered. This relation between investment and scrapping processes is visualized in Fig. A2.1, p.171.

The production and capacity (investment and scrapping) processes of the model are listed in Table 6.1 where

$x_{ij}(t)$ = activity level in production process j during time segment i in period t

$\Delta y_s(t)$ = activity level in investment process s during period t (note that t refers to the time of the investment decision)

$\Delta z_s(t)$ = activity level in scrapping process s during period t

At present, the Swedish power system contains all the types of plants listed in Table 6.1, except combined nuclear plants and coal-fired plants.

As is clear from Table 6.1, there are no investment and scrapping processes for hydro power in the model, i.e. all changes in hydro power capacity are exogenously determined. The main reason for this treatment of hydro power is that the linearity assumption is hardly fulfilled in the construction of hydro power stations; the investment cost is to a large extent determined by site-specific conditions. In addition, the remaining investment opportunities in hydro power in Sweden are limited for environmental reasons.

The delivery processes of the model supply fuels and other resources from the rest of the economy and abroad to the electricity sector. In order to keep the model as small as possible, the non-fuel inputs have been aggregated. Thus, all resources used to operate the plants or to maintain the plants for stand-by purposes have been aggregated into a single resource, "resources for immediate use", while resources used for investment purposes form the aggregate "investment resources for non-nuclear plants" and "investment resources for nuclear plants". The delivery processes of the model are listed in Table 6.2.

Table 6.1. The production and capacity processes of the model

Type of station	s	Production during time segment i, period t, $x_{ij}(t)$	Investment during period t, $\Delta y_s(t)$	Scrapping during period t, $\Delta z_s(t)$
Nuclear power plants	1	$x_{i1}(t)$	$\Delta y_1(t)$	$\Delta z_1(t)$
Nuclear power plants for combined generation of electricity and hot water	2	$x_{i2}(t)$ Condensed steam power production $x_{i3}(t)$ Back pressure power production	$\Delta y_2(t)$	$\Delta z_2(t)$
Oil-fired, base-load condensed steam power plants	3	$x_{i4}(t)$	$\Delta y_3(t)$	$\Delta z_3(t)$
Coal-fired, base-load condensed steam power plants	4	$x_{i5}(t)$	$\Delta y_4(t)$	$\Delta y_4(t)$
Oil-fired, peak-load condensed steam power plants	5	$x_{i6}(t)$	$\Delta y_5(t)$	$\Delta z_5(t)$
Oil-fired, power plants for combined generation of electric energy and hot water, old type	6	$x_{i7}(t)$	-	$\Delta z_6(t)$
Oil-fired, power plants for combined generation of electric energy and heat, new type	7	$x_{i8}(t)$ Condensed steam power production $x_{i9}(t)$ Back pressure power production	$\Delta y_7(t)$	$\Delta z_7(t)$
Gas turbines	8	$x_{i10}(t)$	$\Delta y_8(t)$	$\Delta z_8(t)$
Hot water generating plants	9	$x_{i11}(t)$	$\Delta y_9(t)$	$\Delta z_9(t)$
Hydro power plants	10	$x_{i12}(t)$	-	-

Table 6.2. The delivery processes of the model and their output when utilized at unit activity levels

Activity level $L_q(t)$	Type of resource q	Unit quantity
$L_{39}(t)$	Resources for immediate use	1 mill. Sw. Cr. in 1968 prices
$L_{48}(t)$	Uranium	kg.
$L_{49}(t)$	Coal	ton
$L_{53}(t)$	Oil	m^3
$L_{4001}(t)$	Investment resources for non-nuclear plants	1 mill. Sw. Cr. in 1968 prices
$L_{4002}(t)$	Investment resources for nuclear plants	1 mill. Sw. Cr. in 1968 prices

6.3 The Equations and Inequalities of the Model

We now introduce the equations and inequalities of the electricity and heat production model. First all the variables and parameters of the model are defined. Then the definitions of key variables are repeated along with the presentation of the constraints.

Endogenous variables

$L_q(t)$ = activity level for delivery process q during period t

$x_{ij}(t)$ = activity level for production process j during time segment i, period t

$x_{46}(t)$, $x_{47}(t)$ = aggregate annual production of electricity and heat, respectively, during period t

$\Delta y_s(t)$, $\Delta z_s(t)$ = activity level for investment and scrapping process a, respectively, during time period t. s = 1,2,..., 9.[1/]

$R_s(t)$ = utilization of exogenously determined capacity in period t. s = 1,2,..., 9; measured in GWh

$R_{10}(t)$ = utilization of (exogenously determined) hydro capacity in period t; measured in MW

$\pi(t)$ = amount of water passing the hydro power stations without going through the turbines, during period t; measured in energy units

$K_{vs}(T)$ = Capacity of type s, vintage existing at the terminal point in time.

Exogenous variables

$y_s(t)$[2/] = exogenously determined potential production of energy at plant type s, period t

$X_{10}(t)$ = potential production of energy at hydro power station corresponding to normal yearly water flow

$\mu(t)$ = minimum acceptable flow of water in the river system during the summer of period t

E(t), W(t) = demand for electricity and heat, respectively, during period t

---

1/ The process $Y_6(t)$ is not defined. See p.

2/ Observe that $Y_1(t)$ and $Y_{10}(t)$ are not constant over time since there are exogenously determined investments in nuclear and hydro power plants in the model.

$P_q(t)$ = price of resource q in period t

r = rate of interest

$\rho_s(t)$ = cost of using capacity s in period t (see p. 106)

$\psi_{vs}(t)$ = The value at the initial point in time of one unit of capacity of type s, vintage ν.

<u>Parameters</u>

a_{qj} = input of resource q for production process j when utilized at unit level

$\hat{a}_{qs}$, $\hat{a}_{qs}$ = input of resource q for investment process s and output of resource r from scrapping process s, respectively, when utilized at unit level

g_{sj} = realization of potential production for plant type s when production process j is utilized at unit level

f_s, $(-f_s)$, h_s, $(-h_s)$ = addition to (reduction from) available peak capacity and available hot water capacity which follows from the utilization of investment (scrapping) process s at unit level; $f_s, h_s \geq 0 \ \forall s$

$b_{46,j}$ = output of electricity when production process j is utilized at unit level

$b_{47,j}$ = output of heat when production process j is utilized at unit level

α_{is} = share of total potential production of energy at plant type s available during time segment i; $\sum_i \alpha_{is} = 1; \forall s$

e_i, w_i = share of electricity and heat demand, respectively, located to time segment i

H_i = number of hours during time segment i; $\sum_{i=0}^{6} H_i = H = 8760$

u_s = necessary construction time for plant type s

As before, endogenous variables are written on the left-hand side and exogenous variables on the right-hand side.

a. Objective function to be minimized

There are three cost items included in the objective function of the model: the cost for fuels and other resources for immediate use, the cost of using the exogenously determined capacity[1/], and the cost for investment resources. The last item in the objective function is the value at the initial point in time of the terminal stock of endogenously determined capacity.

The value of the terminal stock of capacity depends on its age-structure. Thus we have to define a new variable, $K_{\nu s}(T)$, which denotes the amount of capacity of type s, vintage ν which exists at the terminal point in time. The vintage index, ν, refer to the period for the investment decision. Thus, capacity of type s, vintage ν became available for energy production in period $\nu + u_s$[1/]. The terminal amount of capacity s, vintage ν is written

$$K_{\nu s} = \Delta y_s(\nu) - \Delta z_s(\nu + u_s + 1)$$

The treatment of scrapping in this expression implies that if a plant of type s is scrapped in period $t+u_s + 1$, it is assumed that the decision to build the plant was made in period t. This is not a perfect solution, but such a solution would require a distinction between different vintages in the capacity constraints which would dramatically increase the size of the model and thus the solution cost. The bias introduced by the formulation here is unimportant.

It is assumed that the stock of capital in the electricity and heat production sector is depreciated at the annual rate δ_E. Thus the terminal valuation factor for one unit of capacity s of vintage ν becomes

$$\psi_{\nu s}(T) = \sum_{\tau=T+1}^{\infty} (1+r)^{-\tau} \rho_s(\tau)(1-\delta_E)^{\tau-5(\nu+u_s+1)}.$$

1/ See p. 106.

2/ The period u_s is the necessary construction time for capacity of type s.

The total value at the initial point in time of the terminal stock of endogenous capital in the electricity and heat sector is the present value of the sum of the terminal values of the individual plants of different types and vintages. We thus get the following expression:

$$\sum_{s=1}^{9} \sum_{\nu=1}^{T-u_s} \psi_{\nu s}(T)\, K_{\nu s}(T) =$$

$$= \sum_{\tau=T+1}^{\infty} (1+r)^{-\tau} \{ \sum_{\nu=1}^{4} \sum_{s=1}^{T-u_s} [\rho_s(\tau)(1-\delta_E)^{\tau-5(\nu+u_s+1)}]\, [\Delta y_s(\nu)-\Delta z_s(\nu+u_s+1)]\}$$ [1/]

The objective function of the electricity and heat supply submodel can now be written:

$$F_E(T) = \sum_{t=1}^{T} \phi(t) \{ \sum_{q \in A} P_q(t)\, L_q(t) + \sum_{s=1}^{10} \rho_s(t)\, R_s(t)\} +$$

$$+ \sum_{t=1}^{T} \xi(t) \sum_{q=4001}^{4002} P_q(t)\, L_q(t) - \sum_{s=1}^{9} \sum_{\nu=1}^{T-u_s} \psi_{\nu s}(T)\, K_{\nu s}(T)$$

where $A = \{q \mid q = 39,48,49,53\}$ [2/]

and $\phi(t) = (1+r)^{-5(t-1)} \{ \sum_{\tau=1}^{5} (1+r)^{-(\tau-1)} \}$

$\xi(t) = (1+r)^{-5(t-1)}$

The unit period of time is five years and there are T periods between the initial and terminal points in time. This means that investment and scrapping decisions can only be made every fifth year and are assumed to take place at the beginning of each period. This explains the definitions of $\phi(t)$ and $\xi(t)$. The last term in the objective function, the value of the terminal stock of endogenous capital, is the only contribution from this submodel to the objective function of the complete model.[3/]

1/ This expression reveals a slight inconsistency in the model; between the initial and terminal points in time there is no depreciation of the installed capacity. Thus the model tends to underestimate the capital costs in the electricity and heat production sector.

2/ See the commodity list on p. 118.

3/ See section 4.2.3.

b. Demand constraints

As mentioned previously the generation of electricity (commodity 46 in the model) and/or heat (commodity 47), respectively, has to be equal to the demand in each time segment for all periods. Further, the shape of the load curves are assumed to be constant over time and determined in accordance with Table 8.2 on p. 203. Formally we then get, for all t:

$$\sum_{j=1}^{12} x_{ij}(t)\, b_{46,j} - e_i\, X_{46}(t) = 0; \ \forall i; \qquad [1]$$

$$\sum_{j=1}^{12} x_{ij}(t)\, b_{47,j} - w_i\, X_{47}(t) = 0; \ \forall i; \qquad [2]$$

$$X_{46}(t) = E(t); \qquad [3]$$

$$X_{47}(t) = W(t). \qquad [4]$$

On the output side, this model is linked to the rest of the supply model through equations [3] and [4] where the exogenous variables E(t) and W(t) of this model represent the use of electricity and heat in other parts of the economy.

c. Input resources constraints

On the input side, this model is linked to the rest of the supply model through the following inequalities. The endogenous delivery processes in constraints [5] through [7] are exogenous variables of the other supply submodels.

$$\sum_{i=0}^{6} \sum_{j=1}^{12} -a_{39,j}\, x_{ij}(t) - \sum_{\tau=1}^{t-u_s} \sum_{s=1}^{9} \hat{a}_{39,s}\, \Delta y_s(\tau) + \sum_{\tau=1}^{t} \sum_{s=1}^{9} \hat{a}_{39,s}\, \Delta z_s(\tau) + L_{39}(t) \geq \sum_{s=1}^{9} \hat{a}_{39,s}\, y_s(t) \qquad [5]$$

$$\sum_{s=1}^{9} - \hat{a}_{qs}\, \Delta y(t-u_s) + L_q(t) \geq \sum_{s=1}^{10} \hat{a}_{qs} \left[y_s(t)-y_s(t-1)\right]; \qquad [6]$$

$q = 4001,\ 4002;$

$$\sum_{i=0}^{6} \sum_{j=1}^{12} -a_{qj}\, x_{ij}(t) + L_q(t) \geq 0; \quad q = 48,\ 49,\ 53. \qquad [7]$$

Constraints [5] and [6] warrant a few comments. The parameter u_s represents the lag between the investment decision and the date on which the plant becomes available. The lag is two periods for nuclear power plants (s=1,2) and one period for other types of plants.

The exogenous term in [5] represents maintenance costs in exogenously determined plants. This term can be interpreted as follows. In order to have exogenously determined plants available, the electricity and heat sector has to pay the maintenance costs. When the plants are in use, this sector also has to pay the cost of using capacity, $\rho_s(t)$.

d. Capacity constraints

The capacity constraints of the thermal plants differ slightly from those of the hydropower plants. We begin with the former.

For each type of thermal plant (s=1,..., 9), the supply of energy from the processes utilizing the plant in question may not be greater than the sum of the remaining exogenous and endogenous productive capacity. "Productive capacity" refers to the potential production of energy (see p. 146). This condition yields

$$\sum_{j\in J_s} x_{ij}(t)\cdot g_{sj} - \alpha_{is} \{ \sum_{\tau=1}^{t-u_s} \Delta y_s(\tau) - \sum_{\tau=1}^{t} \Delta z_s(\tau) + R_s(t) \} \leq 0 \qquad \forall i \; ; \; s=1,\ldots,9 \qquad [8]$$

where α_{is} thus denotes the share of the potential production of energy in plant s which is available in time segment i. Each set J_s contains the processes that utilize plant s (see Table , p.).

Further, the utilization of exogenous productive capacity can be no greater than the existing exogenous capacity

$$R_s(t) \leq y_s(t) \; ; \; s=1,2,\ldots, 9. \qquad [9]$$

The corresponding constraint on the utlization of hydro power looks quite different. First, total production cannot be greater than the total "normal" flow of water passing the stations. That is

$$\sum_{i=0}^{6} x_{12,i}(t) \leq X_{10}^{t} \; ; \quad \forall t \qquad [10]$$

where

$X_{10}(t)$ = production of energy corresponding to the flow of water during a normal year.

It should be noted that when the "producers" of the model use exogenous thermal capacity they have to pay a unit cost per utilized GWh (potential production of energy). In contrast, when hydro capacity is used, the unit cost is charged per unit of utlized MW. Accordingly, there is no cost for water in the rivers, which means that $X_{10}(t)$ becomes a free resource.

However, the hydro capacity utilization rate is constrained by the available peak hydro capacity, which can be expressed formally as:

$$\frac{x_{i,12}(t)}{H_i} - R_{10}(t) \leq 0 \; ; \qquad \forall i \qquad [11]$$

$$R_{10}(t) \leq y_{10}(t)\, f_{10}. \qquad [12]$$

e. Institutional constraints

Every electric power system runs the risk of capacity deficiency, due to either unplanned outages or unexpected peaks in demand. In the power industry, the decision as to the magnitude of this risk is a question of policy. The Swedish power industry has accepted an average capacity deficiency of ten hours in a ten-year period.[1)] This degree of capacity deficiency acceptance can be transformed into a reserve capacity factor,[2)] which is 1.20 in Sweden. Since our measure of peak capacity has already taken the probability of unplanned outages into consideration, our reserve capacity factor should be reduced to 1.13 at an expected average peak availability of about 0.90.[3)] Thus, the

1) CDL, (55) p. 7.

2) That is, $1 + \beta = \frac{\text{installed capacity}}{\text{expected peak demand}}$. See Edblad (17) and KTH (60).

3) See Hedbom & Rundström (22) p. 18.

available peak capacity should be no less than 1.13 times the maximum expected load. On the basis of the assumption that the shape of the load curve is unchanged throughout the prediction period, it follows that there is a constant relation between the total annual demand for electricity and the maximum expected peak demand. Further, in accordance with constraint [3], the total annual supply of electricity, $X_{46}(t)$ is equal to total annual demand. Thus there is a constant relation between the total annual supply of electricity and the maximum expected peak demand. Let μ_{46} denote units of maximum expected peak demand (MW) per unit of annual supply (GWh). We then get

$$\sum_{\tau=1}^{t-u_s} \sum_{s=1}^{8} \Delta y_s(\tau)\, f_s - \sum_{\tau=1}^{t} \sum_{s=1}^{8} \Delta z_s(\tau)\, f_s + \sum_{s=1}^{8} R_s(t)\, f_s + R_{10}(t) - \mu_{46}\, X_{46}(t) \geq 0. \qquad [13]$$

Since heat - in contrast to electricity - is not distributed by means of an interconnected, nationwide network, local peaks in demand cannot be met by distant production units where demand is not at peak level. This means that the reserve capacity factor has to be greater in heat production than in the production of electric energy. In this study the heat reserve capacity factor is set equal to 1.5 times the demand for heat in time segment 0. That is the peak capacity in the heat production system should be no less than 1.5 $w_o \cdot W$ which, using constraint [4] and the load-curve assumption, can be defined as μ_{47}, a constant relation between annual heat production and the maximum expected peak demand for heat.

$$\sum_{s=1}^{9} h_s\, \alpha_{os} \left\{ \sum_{\tau=1}^{t-u_s} \Delta y_s(\tau) - \sum_{\tau=1}^{t} \Delta z_s(\tau) + R_s(t) \right\} - \mu_{47}\, X_{47}(t) \geq 0 \qquad [14]$$

f. Technical constraints

For technical reasons, there are limited possibilities of making short-time regulations in the capacity utilization of base load plants. Thus, the solutions to the model are constrained so that capacity utilization at these plants is equal during the day and at night, that is[1)]

$$\frac{x^t_{0j} + x^t_{1j}}{H_0 + H_1} = \frac{x^t_{2j}}{H_2} ; \quad \forall t, \ j = 1,4,5$$

$$\frac{x^t_{02} + x^t_{03} + x^t_{12} + x^t_{13}}{H_0 + H_1} = \frac{x^t_{22} + x^t_{23}}{H_2} ; \quad \forall t$$

$$\frac{x^t_{i-1,j}}{H_{i-1}} = \frac{x^t_{ij}}{H_i}, \quad \forall t ; \ i = 4,6, \ j = 1,4,5 \qquad [14]$$

$$\frac{x^t_{i-1,2} + x^t_{i-1,3}}{H_{i-1}} = \frac{x^t_{i2} + x^t_{i3}}{H_i} ; \quad \forall t ; \ i = 4,6.$$

The constant 24-hour production rate at the base load stations should, of course, be no greater than the lowest demand load during these hours. It is now assumed that the capacity utilization at base load plants cannot be changed more often than once a week. Accordingly, the sum of base load capacity in operation must not exceed the weekly minimum demand load. Again, the load-curve assumption, along with constraint [3], implies that there is a constant relation between the average weekly minimum demand in time segment i and total annual production. Let the constants λ_i denote these relations.

$$\sum_{j \in B} \frac{x_{ij}(t)}{H_i} - \lambda_i \cdot X_{46}(t) \leq 0 ; \quad i = 2,4,6; \qquad [15]$$

where the set B denotes base load production processes, that is

$$B \doteq \{j \mid j = 1,2,\dots, 5\}.$$

---

1) In the combined nuclear power stations (s=2), the sum of the activity levels of both processes that utilize this capacity (j=2,3) must be equal during the day and at night.

These constraints may be overly restrictive, especially for fossil fueled plants, but they may also prove to be ineffective in an optimal solution to the model. This is simply because the profitability of base load plants depends heavily on the length of the utilization time. Therefore, in spite of low running costs, it is not profitable to keep base load plants available in order to meet loads of short duration.

g. Environmental constraints

For environmental reasons, the flow of water in the river system during the summer may not be less than a certain amount, M(t), in each period. Thus, the solutions to the model have to meet the following condition:

$$\sum_{i=5}^{6} x_{i,12}(t) + \pi(t) \geq M(t) \qquad [16]$$

where

$\pi(t)$ = amount of water passing the stations without going through the turbines.

Electricity and heat production gives rise to a set of emissions into the environment. The solutions to the model can be constrained so that total emissions of three important pollutants from the electricity sector do not exceed a predetermined level, $D_n(t)$, that is

$$\sum_{i=0}^{6} \sum_{j=1}^{11} d_{nj} \, x_{ij}(t) \leq D_n(t) \qquad [17]$$

where

n	Pollutant
1	Cooling water
2	Sulphur dioxide
3	Soot, ash.

However, since environmental policy in Sweden is not formulated in terms of restrictions on total emissions, constraints [17] are arranged so that they are always ineffective. However, it is easy to include total emission levels in comparisons of different solutions to the model.

6.4 Some Remarks about the Properties of the Model

The feasible set of solutions to the model has been defined by means of constraints 1 through 17 and non-negativity constraints on the activity levels. We now have to analyze the extent to which this feasible set of solutions coincides with the power industry's opportunity set as conceived by its planners. The crucial point is the effect of the substitution of a step function for the continuous load curve. The problem can be clarified by means of the figure below, where the day and night curves represent upper and lower bounds, respectively, for the variation in demand load.

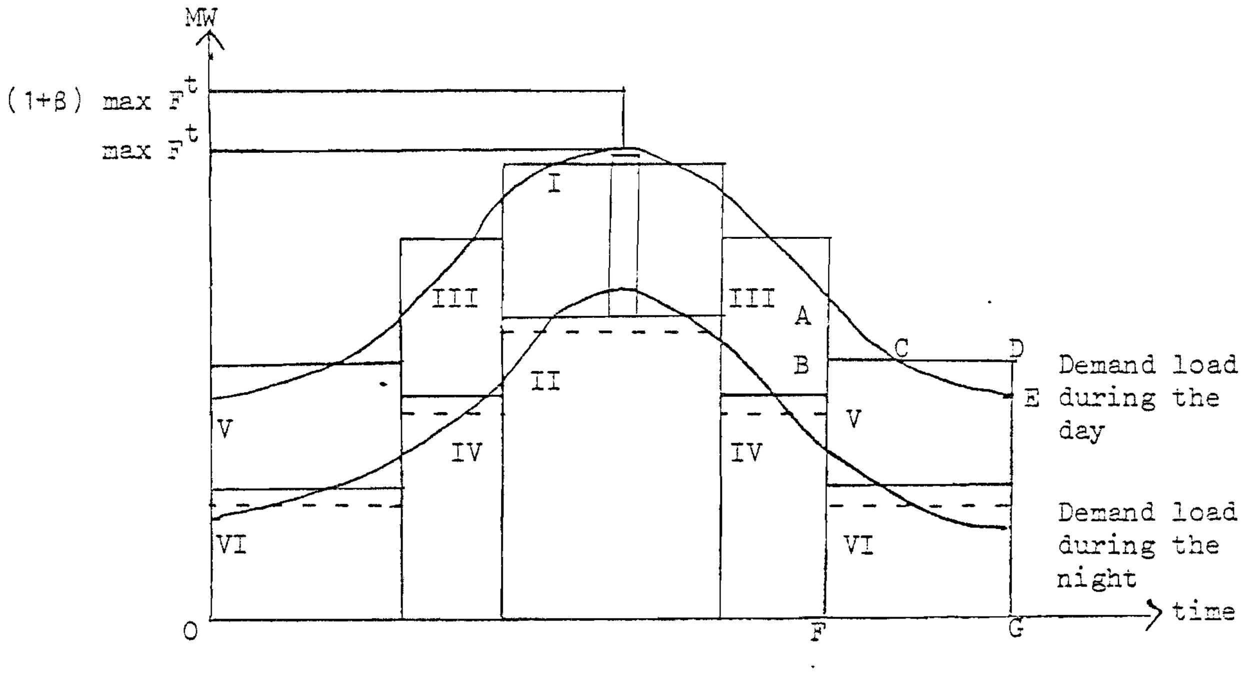


Figure 6.1.

|- - - - -| = min $\bar{F}_i^t$ OG = one year

(The area of the rectangles is equal to the area under the load curve.)

The constraints introduced above guarantee that the total potential production of energy is not less than the total demand for energy. In addition, the expected peak capacity of the system exceeds expected peak demand by the prescribed margin. However, the composition of the sector's total capacity might differ from the composition that would be generated by more refined planning tools. It can be explained by a closer look at the figure.

In the figure, the area ABC is approximately equal to the area CDE. However, this does not mean that the supply CDE can satisfy the demand ABC, since this is a case where supply and demand do not occur simultaneously. The demand ABC can be met only if the system has the available capacity AF MW. The model, however, "believes" that the energy amount AEGF can be produced by the utilization of BD MW during FG hours. Thus, the model permits the producing units to be utilized longer than is possible in the real world. This tends to favor plant types where operating costs are low in comparison to total costs, that is, base load power plants. In addition, peak load plants may never be called into operation, which means that time differentiation of the marginal costs will not appear in the solutions. This quality of the model should be kept in mind when the results of simulations with the model are interpreted.

6.5 The Empirical Basis of the Model

The empirical basis of the model i presented in Appendix 2. All additional data and assumptions underlying the results obtained from simulations with this submodel are presented in Chapter 8.

APPENDIX 2

Table A 2.1. Time-segmentation adopted in the model

Time segment	Hours of the day	Number of weeks	Season
0	7 - 19	2	Mid-winter
1	7 - 19	6	Winter
2	19 - 7	6	Winter
3	7 - 19	18	Late autumn and late winter
4	19 - 7	18	Late autumn and late winter
5	7 - 19	26	Spring, summer, autumn
6	19 - 7	26	Spring, summer, autumn

Table A 2.2. Share of the potential production of energy in thermal plant type s, available in time segment i, α_{is}

Time segment i	Number of hours H_i	α_{is}			
		s = 1,2	s = 3,..., 7	s = 8	s = 9
0	134	0.0178	0.0172	0.0166	0.0156
1	538	0.0712	0.0688	0.0664	0.0624
2	672	0.089	0.086	0.083	0.078
3	1,518	0.200	0.196	0.188	0.176
4	1,518	0.200	0.196	0.188	0.176
5	2,190	0.211	0.218	0.229	0.246
6	2,190	0.211	0.218	0.229	0.246
Σ	8,760	1.000	1.000	1.000	1.000

Table A 2.2 is based on the assumption that planned maintenance is carried out during the summer season (i = 5,6)

Table A 2.3. Estimated exogenously determined thermal capacity in different periods, MW

S	Type of plant	F_s = Installed capacity, MW		
		Year		
		1974	1975-1980	1980-2000
1	Nuclear power plants	450	5 560	10 400
2	Combined nuclear power plants	-	-	-
3	Base load oil-fired plants	2 100	2 100	2 100
4	Base load coal-fired plants	-	-	-
5	Peak load oil-fired plants	1 070	1 070	1 070
6	Combined oil-fired plants, old type	580	580	580
7	Combined oil-fired plants, new type	720	1 370	1 370
8	Gas turbines	1 130	1 240	1 600
9	Heat generating plants	53 000	53 000	53 000

Sources: CDL, Kraftutbyggnaderna 1975 - 1990, Stockholm, 1972
Industridepartementet.

Table A 2.4. Exogenously determined capacity (MW) and potential production of electricity (GWh) in hydro power plants

Period	Installed capacity MW	Water flow GWh
1	15,000	61,000
2	16,000	63,000
3	16,000	63,000
4	16,000	63,000
5	16,000	63,000

Source: See Table A 2.3.

Table A 2.5. Inputs in and outputs from the production processes at unit activity levels; coefficients a_{qj}, b_{ij} and d_{nj}

j	Fuel oil m^3	Uranium kg.	Coal ton	Commodity 39 mill. Sw.Cr.	Electricity GWh	Heat GWh	Cooling water GWh	Sulphur dioxide ton	Soot, ash ton
1		4.59		0.0005	1		2,19		
2		4.93		0.0005	1		2.43		
3		6.56		0.0005	1	3.39			
4	248			0.0020	1		1.38	4.71 s*	
5			400	0.0040	1		1.36	8.00 s*	0.45
6	281			0.0020	1		1.60	5.34 s*	
7	545			0.0020	1	3.30		10.35 s*	
8	259			0.0020	1		1.45	4.92 s*	
9	300			0.0020	1	1.65		5.70 s*	
10	410			0.0010	1		0.88	6.85 s*	
11	109			0.0015		1		2.07 s*	
12					1				

* s = Percentage share of sulphur per unit of weight.

Source: See Hedbom & Rundström (22) and their references.

Figure A 2.1 <u>The relation between investment and scrapping processes.</u>

<u>Investment process s</u> <u>Scrapping process s</u>

$$\Delta y_s(t) \left[\begin{array}{c} -\hat{a}_{rs} \\ -a_{vs} \\ 1 \\ f_s \\ \hline 0 \\ -a_{vs} \\ 1 \\ f_s \\ \hline \vdots \end{array}\right] + \dots + \Delta z_s(t) \left[\begin{array}{c} 0 \\ a_{vs} \\ -1 \\ -f_s \\ \hline 0 \\ a_{vs} \\ -1 \\ -f_s \\ \hline \vdots \end{array}\right] \begin{array}{l} \left.\begin{array}{c} \\ \\ \\ \\ \end{array}\right\} \text{Period } t+u_s \\ \left.\begin{array}{c} \\ \\ \\ \\ \end{array}\right\} \text{Period } t+u_s+1 \\ \\ \end{array}$$

$\Delta y_s(t)$ = activity level in investment process s, period t

$\Delta z_s(t)$ = activity level in scrapping process s, period t

$\hat{a}_{rs}$ = input of investment resource r in investment process s.

a_{vs} = input of resource v for maintenance of one unit of capacity of type s.

f_s = addition to available peak capacity which follows from the utilization of investment process s at unit level.

u_s = necessary construction time for capacity type s.

If $\Delta y_s(t) = \Delta z_s(t)$ the net effect is a waste of investment resources equal to the amount $\Delta y_s(t)\ \hat{a}_{rs}$.

7. THE RESIDENTIAL HEATING SERVICES SUPPLY MODEL*)

The household sector's observed demand for energy for residential heating purposes is the result of a number of interdependent choices made by the households. These choices can be classified in the following way:

i) The choice between housing and other expenditures, given a budget constraint

ii) The choice between indoor climate and e.g. the size and type of house to live in, given housing expenditures

iii) The choice of heating technology, given the indoor climate.

However, in the EFM only the third of these choices is endogenous; both the demand for housing and the indoor climate are exogenously determined. The choice of heating technology is determined in the residential heating services supply model, which is described in this chapter.

In principle it would have been possible to determine the demand for housing endogenously within the EFM. However, when the parameters of the econometric demand model, presented in section 4.3, were estimated, it turned out that price- and income-variations could explain the changes in the demand for housing only to a very small extent.1/ This result is not very surprising for a number of reasons. For instance, there is a system of rent subsidies in Sweden. The size of the subsidy is determined by the level of the income and the rent as well as by the number of children in the family. This means that the actual rent for a given apartment may differ between various potential tenants. Further, for a large share of the existing stock of buildings, the nominal rents are not equilibrium rents.2/

With this background we have abstained from trying to make the demand for housing an endogenous variable in the model. The same applies to the indoor climate; lack of data prevent us from a more sophisticated treatment of this variable.

---

*) The work on this model has been partly financed by the Swedish Council for Building Research.

1/ See p. 99.

2/ The privately owned multi-family houses in the cities were until recently subject to rent control.

The output from the residential heating sector of the model economy is a set of residential heating services such that a predetermined indoor climate is maintained in the exogenously determined stock of residential buildings. The inputs used in the residential heating sector are various kinds of energy and energy conservation equipment. The model presented in this chapter simulates the develpment of the Swedish residential heating sector on the assumption that the present value of the total cost of residential heating, given the indoor climate, is minimized. Thus, the model determines the energy consumption patterns in the residential heating sector which are consistent with cost minimization under the given constraints.

Obviously the energy consumption patterns determined by the model should be regarded as prescriptions rather than predictions. This is, however, nothing particular for the residential heating services supply sub-model; the entire supply part of the EFM can be interpreted as a normative model.[1/]

However, this feature of the model is not in conflict with the purpose of this study. In the introductory chapter it was stated that the purpose of this study is to evaluate the flexibility of the energy consumption patterns in the Swedish economy. Given the above mentioned features of the model we are in fact studying the changes of Swedish energy consumption patterns resulting from perfectly rational adaptions to existing and expected relative prices. One can say that we are investigating the potential flexibility of the Swedish energy consumption patterns. In order to transform our results into predictions about the future, many additional factors should be taken account of. However, in this study we confine the analysis to the potential flexibility of the energy consumption patterns in Sweden.

To my knowledge, the approach used in this study has not previously been applied in analyses of the aggregate consumption of energy in the entire residential heating sector. In engineering studies, the choice of heating technology is usually analyzed as a cost minimization

---

1/ Provided that the parameters $\rho_j(t)$, the cost of using existing capital of type j, are all set equal to zero for $t \leq T$. See p. 106.

problem but the analysis is generally confined to individual houses.[1/] Analyses of the aggregate energy demand for residential heating purposes are often performed on the basis of econometric methods.[2/]

7.1 The Model

Formally, the model is a linear programming model where the objective is to minimize the present value of the future cost of maintaining a target indoor climate in all homes during a certain number of periods. The model can control the total cost by switching between different heating technologies as relative prices of energy and energy conservation equipment change.

The model distinguishes between a number of different types of residences. One type of residence can differ foom another with respect to the kind of building in which it is located (one-family, multi-family, etc.) and age. For each type of residence there exists a set of feasible heating technologies. A heating technology is uniquely defined by the amount and kind of energy it requires in order to maintain the target indoor climate in a residence during one year. This definition of heating technology implies that if a small change is implemented, such as additional insulation which would reduce the specific use of energy, a switch has in fact been made from one heating technology to another. There is always a cost associated with such a switch.

Our model approach is based on the assumption that a limited number of categories of residences can be found, where the individual residences in each category are approximately homogenous in the following two respects:

1/ See e.g. the Appendix in Hagman (20).

2/ See e.g. Andersson (2), Halvarson (21) and Nelson (39).

i) the cost of swithing between two specified heating technologies is approximately equal for all individual residences in the group

ii) a given input of oil, electricity or hot water yields the same indoor climate in all individual residences in the group

If these conditions are satisfied, a set of heating technologies can be defined in a meaningful way for each category of residences.

As was mentioned above the residences are classified according to age and type of building. Three classes in each dimension are distinguished. Available statistics indicate that the classification adopted in this study ensures a fairly high degree of homogeneity, in terms of standard of insulation, between the residences in each category.[1/] This menas that the conditions mentioned above can be expected to be reasonably well fulfilled.

However, the necessary energy input can differ between individual residences in a category as a result of differences in size and geographical location. These aspects are nevertheless neglected in our classification of residences. This is because differentiation as to size of residences and regionalization of the model would, if they could be accomplished, radically increase its size and thereby the solution cost.

All parameters are computed on the assumption that the residence in question is of standard size. The standard size, of course, differs between different kinds of residences. Temperature is used as a proxy for indoor climate.

1/ See SOU (63) p. 174.

Notations

The index s denotes type of residence and j denotes heating technology. The set of heating technologies that can be used in residence s is denoted H_s. The index i denotes inputs for immediate use[1)] while h denotes investment resources.

In the present empirical version of the model it holds that

$s = 1,2,\ldots, \bar{8}$

$i = 32,46,47,52$; $h = 43$ (See the commodity list on p.).

$j = 1,2,\ldots, n_s$, where n_s is the number of heating technologies that can be used in residence s. In general $20 \leq n_s \leq 25$.

"Investment resources" constitute the single aggregated commodity number 43.

$x_j(t)$ = utilization of heating technology j during period t, where the target indoor climate is maintained in the residence in question during one year

$y_j(0)$ = initial number of units of heating technology i

$\Delta y_{qj}(t)$ = conversion of one unit of heating technology q into one unit of heating technology j during period t

$\Delta z_j(t)$ = scrapping of one unit of heating technology j during period t (this variable has to be included because the number of units of certain types of residences is reduced over time

1) Inputs for immediate use are various kinds of energy and in some cases a low-voltage charge for electricity. This charge has to be included in the model because the price of electricity determined by the electricity and heat supply submodel is the price for high-voltage electricity.

e_{ij}	= amount of input of type i used by heating technology j during one year
a_{qj}	= amount of investment resources used when one unit of heating technology q is converted into one unit of heating technology j
$L_i(t)$, $L_h(t)$	= delivery of input i and investment resources, respectively, to the residential heating sector during period t; i = 32,46,47,52; h = 43
$P_i(t)$, $P_h(t)$	= price of input i and investment resources, respectively, during period t
$B_s(t)$	= number of residences of type s existing in period t
$S(T)$	= amount of resources invested in the residential heating sector and existing at the terminal point in time
$D_{is}(t)$	= number of residences of type s located in communities with district heating systems
r	= interest rate
T	= number of time periods in the model

As in the other parts of the model the unit period of time is set at five years. The general formulation of the model becomes:

a. Objective function to be minimized[1)]

$$F_R(T) = \sum_{t=1}^{T} \{\phi(t) \sum_{i \in E} P_i(t)\, L_i(t) + \psi(t)\, P_{43}(t)\, L_{43}(t)\} - (1+r)^{-5T}\, P_{43}(T)S(T$$

where S(T) is defined below (see f), $E = \{i | i = 32,46,47,52\}$ and

$$\phi(t) = (1+r)^{-5(t-1)} \{ \sum_{\tau=1}^{5} (1+r)^{-(\tau-1)} \}$$

$$\psi(t) = (1+r)^{-5(t-1)}.$$

1) When this model is linked to the other supply submodels, only the last term of this objective function appears explicitly in the objective function of the complete model. See p. 83.

b. Equality between the number of heating technologies utilized and the number of residences.

$$\sum_{j \in H_{is}} x_j(t) = B_s(t) \; ; \quad \forall s, t. \qquad [1]$$

c. Equality between the number of utilized[1] and existing heating technologies

$$x_j(t) - \sum_{\tau=1}^{t} \sum_{q \in Q_j} \Delta y_{qj}(\tau) + \sum_{\tau=1}^{t} \sum_{q \in J_q} \Delta y_{jq}(\tau) + \sum_{\tau=1}^{t} \Delta z_j(\tau) = y_j(0); \qquad [2]$$

$$\forall j, t;$$

where the set Q_j consists of those heating technologies which can be converted into heating technology j, and the set J_q consists of those technologies to which technology j can be switched.[2]

d. Commodity balances

$$L_i(t) - \sum_{j \in H} e_{ij} \, x_j(t) \geq 0 \; ; \qquad i = 32,46,47,52 \qquad \forall t; \qquad [3]$$

$$L_{43}(t) - \sum_{q \in Q_j} \sum_{j \in H} a_{qj} \, \Delta y_{qj}(t) \geq 0 \; ; \qquad \forall t; \qquad [4]$$

where the set H is defined by $H = H_1 \cup \ldots \cup H_8$.

e. Constraints on the utilization of district heating systems

For each category of residences some units are located in areas where district heating systems are installed. Obviously the number of heating technologies based on district heating that can be utilized in a given type of residence cannon exceed the number of residences of this type

---

1) Note that one way of "utilizing" a unit of a heating technology is to scrap it.

2) The fact that not all changes from q to j, where both q and j belong to the same set H_s, are feasible is explained in Appendix 3.

located in district heating communities. Thus the model has to contain the following kind of constraints, where the set

- D contains all heating technologies based on district heating systems;
- $Q_j \cap \complement D$ contains those technologies which can be converted into technology j and which are not based on a district heating system;
- $H_s \cap D$ contains those heating technologies that can be used in residences of type s and that are based on a district heating system.

$$\sum_{\tau=1}^{t} \sum_{q \in Q_j \cap \complement D} \sum_{j \in H_s \cap D} [\Delta y_{qj}(\tau) - \Delta y_{jq}(\tau)] \leq - \sum_{j \in H_s \cap D} y_j(0) + D_s(t); \quad [5]$$

$$\forall s, t;$$

f. Definition of the terminal stock of capital

$$S(T) - \sum_{t=1}^{T} L_{43}(t)\, f(t) = 0 \quad [6]$$

where the coefficients $f(t)$ denote the fraction of resources invested in a dwelling during period t that remains at the terminal point in time. All kinds of energy conservation capital is thus treated in a somewhat different way than the capital stocks in the production sectors.

7.2 The Empirical Version of the Model

The model distinguishes among eight types of residences and three kinds of fuels (electricity, oil and hot water delivered from a district heating system). The different types of residences are defined in Table 7.1. The initial number of each kind of residence is shown, as well as the net annual energy input needed to maintain the predetermined indoor temperature.[1/] The percentage shares of heating technologies based on the different fuels used for various types of residences are shown on the right-hand side of Table 7.1.

1/ Approximately + 22°C.

Table 7.1.

j	Type of residence	Number of units in 1975, $B_s(0)$	Net[1)] annual energy input, MWh		Heating technology based on		
			Total	Light, etc.	Electricity %	Oil %	District heating %
1	One-family houses, built before 1950	737,000	28	4.2	7	93	0
2	One-family houses, built between 1950 and 1975	395,000	27	4.2	25	72	3
3	One-family row-houses, built between 1950 and 1975	315,000	24	3.8	65	29	6
4	Multi-family houses, built before 1950	735,000	17	3.3	3	90	7
5	Multi-family houses, built between 1950 and 1975	1,163,000	16	3.3	4	58	38
6	One-family houses, built after 1975	–	24*	3.6*	–	–	–
7	One-family row-houses built after 1975	–	21*	3.3*	–	–	–
8	Multi-family houses, built after 1975	–	15*	3.0*	–	–	–

* Estimates

1) Energy utilized inside the residence.

The assumed efficiencies of various fuels are shown in Table 7.2. These figures represent the quotient of the net annual energy input and the gross annual energy input, that is, the relation between utilized and delivered energy.[1)]

Table 7.2. Net energy input in relation to gross energy input for technologies based on different fuels

Fuel	i	Type of residence s = 1,2,3,6,7	s = 4,5,8
Oil	52	50 %	80 %
Electricity	46	100 %	100 %
Hot water	47	97 %	97 %

On the basis of Tables 7.1 and 7.2 the total gross use of energy for residential heating purposes in 1975 was 99.4 TWh, of which 71.9 TWh was oil, 20.1 TWh electricity and 7.4 TWh hot water.

Estimates were made of the cost and resulting energy savings with respect to various measures that can be taken in the different kinds of residences. By means of this set of estimates and the figures presented in Tables 7.1 and 7.2, a number of "heating technologies" were defined for each kind of residence.[2)] The procedure was as follows.

Assume that residence j has an initial heating technology α where the annual gross input of energy is $e_{s\alpha}$. Assume further that additional roof insulation would cost a Sw.Cr. and yield an energy saving of ΔeMWh. Thus, if α is heating technology 1, we can define heating technology 2 by the energy input coefficient $(e_{s\alpha} - \Delta e)$. Accordingly the sum a Sw.Cr. becomes the cost of switching from technology 1 to technology 2, that is, the coefficient a_{12}.

1) The point of delivery is the wall of the residence.

2) All of these figures and estimates were compiled by N.E. Lindskoug of Sven Tyrén AB.

Additional heating technologies can be defined by adding additional energy conservation measures. Thus, each heating technology in the empirical version of the model can be regarded as a chain of measures taken by the owner of the residence. Each chain may or may not begin with a change of fuel.

The choice of heating technology with respect to new residences is represented as a swith from a zero technology to some other technology. Of course, the zero technology does not belong to the set H_s, the set of useful technologies feasible in residence s.

All of the heating technologies in the present version of this model are defined in Appendix 3. These definitions indicate, among other things, that a switch can only be made from a given heating technology to a subset of those heating technologies which can be used in the type of residence in question.

It should be noted that the statistical material underlying the data base of the model allows for the inclusion of a large number heating technologies for each kind of residence. However, in order to keep the solution cost within reasonable limits only 25 technologies for each kind of residence were included in the data base. Among these are technologies where solar energy or heat pumps are utilized; that is, heating technologies with very low energy input coefficients.

7.3 A Few Comments About the Empirical Version of the Model

The general problems arising from linear representations of non-linear problems were touched on in section 4.2. One important non-linearity which applies to residential energy demand models is that both electricity and hot water tariffs in Sweden have fixed as well as variable components. The fixed components apply to the costs of production and distribution equipment and the variable parts reflect fuel costs. There are in general no quantity discounts, so the marginal price of electricity and hot water is independent of the quantity demanded.

Accordingly the average price of electricity and hot water is a declining function of the quantity demanded. This quality of real world energy pricing is not taken into account in the present model. This is simply because the energy prices determined by the electricity and heat supply submodel reflect the long-run cost of production. That is, these prices pertain to both capital and fuel costs.

When this model is used separately, however, it is fairly easy to take the two-part tariff into account in the present model structure. The fixed component can be linked to the installation of a heating technology based on electricity or district heating, respectively. Then the only cost item associated with the utilization of the heating technologies becomes the marginal kWh-cost of electricity and heat, respectively.

The problem is, however, that the size of the fixed component of the tariff is not independent of the number of residences connected to the local network for electricity or heat distribution. In the case of electricity this problem is not serious; the local electricity distribution network is built regardless of the number of residences heated by means of electric heating. In the case of heat distribution by means of district heating systems, however, there are important economies of scale. In this model the expansion of the local district heating systems is exogenously determined and the cost of connection is independent of the number of units connected to the district heating network. The cost estimates are based on past experience about the average cost of connection to district heating systems. With this approach we have obviously disregarded an important non-linearity in the real world. It follows that if a solution to the model implies a large scale switch to district heating, that solution has to be interpreted with great care.

Appendix 3

Notations

The index s denotes type of residence and index j denotes heating technology. The code number for a heating technology consists of the residence index plus a serial number. For instance, j = 401 denotes the heating technology with serial number 1 among those that can be used in residence of type 4.

Table A 3.2. Cost in relation to the resulting saving of (net) energy for different types of measures. Sw. Cr./MWh.

Kind of / Residence Types	Converting heating systems					Extra insulation		
	A	B	C	D	E	F	G	H
1	6/10	6/0	6/0	11,5/0	7/5	1,5/2,2	5,5/3,5	3/1
2	5,5/0	β2 6/0 β1 15/0	5,5/0	11/0	7/5	1,5/2,2	5,5/1	4/1,4
3	5,5/0	β2 5/0 β1 12/0	5,5/0	11/0	7/5	1/1,5	5/1	3/1
4	1/0	β1 5/0	2/0	2,5/0	6/2	0,5/0,5	1/1	2,5/1
5	1/0	β1 0,5/0	2/0	2,5/0	6/2	0,5/0,5	1/0,3	2,5/1
6	10/0	9/0	6/2	9/2	5/2	1/0,5	2/1	1,3/1,8
7	10/0	9/0	6/2	9/2	5/2	1/0,5	5/1	4/1,4
8	5/0	2,5/0	2,5/0	3/0	4,5/4	-	1/1	1/1

Table A 3.2 cont'd

Kind of / Residence Types	Extra insulation				Special systems			
	I	K	L	M	O	P	R	S
1	7/5,7	4,5/3,2	8,5/4,5	10/6,7	10/4	12/10	11/3,5	4/5
2	7/3,2	5,5/3,6	9,5/2,4	11/4,6	10/4	12/10	11/3,5	4/4,5
3	6/2,5	4/2,5	8/2	9/3,5	10/4	11/7	11/3,5	4/4
4	1,5/1,5	3/1,5	3,5/2	4/2,5	6/3	7/10	6/3,5	2/3
5	1,5/1	3/1,5	3,5/1,3	4/1,8	6/3	7/10	6/3,5	2/3
6	3/1,5	2,3/2,3	3,3/2,8	4,3/3,3	18/10	10/10	7/3,5	2/4
7	6/1,5	5/1,9	9/2,4	10/2,9	10/4	10/7	11/3,5	4/3,5
8	1/1	1/1	2/2	2/2	5/3	7/10	2/3,5	1,5/2

Table A 3.1. Codes and descriptions of different measures

Code	Description	
	s = 1,2,...,5	s = 6,7,8
A	Conversion of individual heating with oil to district heating	Use of individual heating with oil
B	Conversion of electricity to district heating	Usê of district heating
C	Conversion of individual heating with oil to electric boilers	Use of electric boilers
D	Conversion of individual heating with oil to accumulated electric heating	Use of accumulated electric heating
E	Conversion of individual heat-ing with oil to direct electric heating	Use of direct electric heating
F	Additional insulation of roofs	
G	Additional insulation of walls	
H	Triple pane windows	
I	Additional insulation of roofs + walls	
K	Additional insulation of roofs + triple pane windows	
L	Additional insulation of walls + triple pane windows	
M	Additional insulation of roofs + walls + triple pane windows	
O	Solar energy	
P	Heat pump	
R	Heat exchanger	
S	Control system	

Table A 3.3. Definition of heating technologies

Heating technology j	Residence	
	s = 1,2,..., 5	s = 6,7,8
S00	-	A useless "dummy" technology installed in new residences
S01	α : Individual oil furnace	α : Individual oil furnace
S02	β1: Direct electric heating	β2: Electric boiler
S03	γ : District heating	β1: Direct electric heating
S04	-	β3: Accumulated electric heating
S05	α + F	γ : District heating
S06	α + S	α + H
S07	-	α + S
S08	-	α + H + S
S09	α + F + S	β2 + H
S10	-	β2 + S
S11	β1 + F	β2 + H + S
S12	β1 + S	β1 + H
S13	β1 + F + S	β1 + S
S14	γ + F	β1 + H + S
S15	γ + S	β3 + H
S16	γ + F + S	β3 + S
S17	β2: Electric boiler	β3 + H + S
S18	β2 + F	γ + H
S19	β2 + S	γ + S
S20	β2 + F + S	γ + H + S
S21	α + F + S + O	α + H + O
S22	β1 + F + S + O	β1 + H + O
S23	β2 + F + S + O	β2 + H + O
S24	γ + F + S + O	γ + H + O

Heating technology j	Residences							
	s=1	s=1	s=3	s=4	s=5	s=6	s=7	s=8
S25	α+P	α+P	β1+P	α+I	γ+P	β1+H+P	β2+H+P	γ+H+P

Table A 3.4. Gross consumption of energy for different heating technologies, MWh/year

j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$	j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$	j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$
Residence Type 1				Residence Type 2				Residence Type 3			
101	47.6	4.2		201	45.6	4.2		301	40.4	3.8	
102		23.0		202		22.0		302		19.0	
103		4.2	23.8	203		4.2	22.8	303		3.8	20.2
105	43.2	4.2		205	41.2	4.2		305	37.4	3.8	
106	37.6	4.2		206	36.6	4.2		306	32.4	3.8	
109	33.2	4.2		209	32.2	4.2		309	29.4	3.8	
111		20.8		211		19.8		311		17.5	
112		18.0		212		17.5		312		15.0	
113		15.8		213		15.3		313		13.5	
114		4.2	21.6	214		4.2	20.6	314		3.8	18.7
115		4.2	18.8	215		4.2	18.3	315		3.8	16.2
116		4.2	16.6	216		4.2	16.1	316		3.8	14.7
117		28.0		217		27.0		317		24.0	
118		25.8		218		24.8		318		22.5	
119		23.0		219		22.5		319		20.0	
120		20.8		220		20.3		320		18.5	
121	25.2	4.2		221	24.2	4.2		321	21.4	3.8	
122		11.8		222		11.3		322		9.5	
123		16.8		223		16.3		323		14.5	
124		4.2	12.6	224		4.2	12.1	324		3.8	10.7
125	27.6	4.2		225	25.6	4.2		325	12.0		

Table A 3.4. cont'd

Residence Type 4

j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$
401	17.375	3.3	
402		15.2	
403		3.3	13.9
405	16.75	3.3	
406	13.625	3.3	
409	13.0	3.3	
411		14.7	
412		12.2	
413		11.7	
414		3.3	13.9
415		3.3	10.9
416		3.3	10.4
417		17.2	
418		16.7	
419		14.2	
420		13.7	
421	9.25	3.3	
422		8.7	
423		8.7	
424		3.3	7.4
425	15.5	3.3	

Residence Type 5

j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$
501	16.375	3.3	
502		14.4	
503		3.3	13.1
505	15.75	3.3	
506	12.625	3.3	
509	12.0	3.3	
511		13.9	
512		11.4	
513		10.9	
514		3.3	12.6
515		3.3	10.1
516		3.3	9.6
517		16.4	
518		15.9	
519		13.4	
520		12.9	
521	8.25	3.3	
522		8.0	
523		9.9	
524		3.3	6.6
525	3.3	4.8	

Table A 3.4 cont'd

j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$	j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$	j \ e_{ij}	Oil $e_{52,j}$	Electricity $e_{46,j}$	Hot water $e_{47,j}$
Residence Type 6				Residence Type 7				Residence Type 8			
600	0	0	0	700	0	0	0	800	0	0	0
601	40.8	3.6		701	35.4	3.3		801	14.375	3.0	
602		22.0		702		19.0		802		10.5	
603		22.0		703		19.0		803		14.5	
604		22.0		704		19.0		804		14.5	
605		3.6	20.4	705		3.3	17.7	805		3.0	11.5
606	37.2	3.6		706	32.6	3.3		806	13.125	3.0	
607	32.8	3.6		707	28.4	3.3		807	11.25	3.0	
608	29.2	3.6		708	25.6	3.3		808	10.0	3.0	
609		20.2		709		17.6		809		9.5	
610		18.0		710		15.5		810		8.0	
611		16.2		711		14.1		811		7.0	
612		20.2		712		17.6		812		13.5	
613		18.0		713		15.5		813		12.0	
614		16.2		714		14.1		814		11.0	
615		20.2		715		17.6		815		13.5	
616		18.0		716		15.5		816		12.0	
617		16.2		717		14.1		817		11.0	
618		3.6	18.6	718		3.3	16.3	818		3.0	10.5
619		3.6	16.4	719		3.3	14.2	819		3.0	9.0
620		3.6	14.6	720		3.3	12.8	820		3.0	8.0
621	25.2	3.6		721	28.6	3.3		821	11.9	3.0	
622		15.2		722		15.6		822		12.5	
623		15.2		723		15.6		823		8.5	
624		3.6	14.0	724		3.3	14.7	824		3.0	9.8
625		12.2		725		10.0		825		3.0	5.2

Table A 3.5. Investment costs, a_{qj}, in 1,000 Sw.Cr. associated with switches from heating technology q to heating technology j.

Residence Type 1			Residence Type 2			Residence Type 3		
q	j	a_{qj}	q	j	a_{qj}	q	j	a_{qj}
101	102	7.0	201	202	7.0	301	302	7.0
101	103	6.0	201	203	5.5	301	303	5.5
101	105	1.5	201	205	1.5	301	305	1.0
101	106	4.0	201	206	4.0	301	306	4.0
101	125	12.0	201	225	12.0	305	309	4.0
105	109	4.0	205	209	4.0	306	309	1.0
106	109	1.5	206	209	1.5	302	303	12.0
102	103	15.0	202	203	15.0	302	311	1.0
102	111	1.5	202	211	1.5	302	312	4.0
102	112	4.0	202	212	4.0	302	325	11.0
111	113	4.0	211	213	4.0	311	313	4.0
112	113	1.5	212	213	1.5	312	313	1.0
103	114	1.5	203	214	1.5	303	314	1.0
103	115	4.0	203	215	4.0	303	315	4.0
114	116	4.0	214	216	4.0	314	316	4.0
115	116	1.5	215	216	1.5	315	316	1.0
117	102	5.0	217	202	5.0	317	302	5.0
117	103	6.0	217	203	6.0	317	303	5.0
117	118	1.5	217	218	1.5	317	318	1.0
117	119	4.0	217	219	4.0	317	319	4.0
118	120	4.0	218	220	4.0	318	320	4.0
119	120	1.5	219	220	1.5	319	320	1.0
109	121	10.0	209	221	10.0	309	321	10.0
113	122	10.0	213	222	10.0	313	322	10.0
120	123	10.0	220	223	10.0	320	323	10.0
116	124	10.0	216	224	10.0	316	324	10.0

Table A 3.5. cont'd

Residence Type 4			Residence Type 5		
q	j	a_{qj}	q	j	a_{qj}
401	402	6.0	501	502	6.0
401	403	1.0	501	503	1.0
401	405	0.5	501	505	0.5
401	406	2.0	501	506	2.0
401	425	1.5	505	509	2.0
405	409	2.0	506	509	0.5
406	409	0.5	502	503	5.0
402	403	5.0	502	511	0.5
402	411	0.5	502	512	2.0
402	412	2.0	511	513	2.0
411	413	2.0	512	513	0.5
412	413	0.5	503	514	0.5
403	414	0.5	503	515	2.0
403	415	2.0	503	525	7.0
414	416	2.0	514	516	2.0
415	416	0.5	515	516	0.5
417	402	4.0	517	502	4.0
417	403	0.5	517	503	0.5
417	418	0.5	517	518	0.5
417	419	2.0	517	519	2.0
418	420	2.0	518	520	2.0
419	420	0.5	519	520	0.5
409	421	6.0	509	521	6.0
413	422	6.0	513	522	6.0
420	423	6.0	520	523	6.0
416	424	6.0	516	524	6.0

Table A 3.5. cont'd

Residence Type 6			Residence Type 7			Residence Type 8		
q	j	a_{qj}	q	j	a_{qj}	q	j	a_{qj}
600	601	10.0	700	701	10.0	800	801	5.0
600	602	6.0	700	702	5.0	800	802	4.5
600	603	5.0	700	703	6.0	800	803	2.5
600	604	9.0	700	704	9.0	800	804	3.0
600	605	9.0	700	705	9.0	800	805	2.5
600	606	11.3	700	706	11.0	800	806	6.0
600	607	12.0	700	707	12.0	800	807	6.0
600	608	13.3	700	708	13.0	800	808	7.0
600	609	7.3	700	709	6.0	800	809	5.5
600	610	8.0	700	710	7.0	800	810	5.5
600	611	9.3	700	711	8.0	800	811	6.5
600	612	6.3	700	712	7.0	800	812	3.5
600	613	7.0	700	713	8.0	800	813	3.5
600	614	8.3	700	714	9.0	800	814	4.5
600	615	10.3	700	715	10.0	800	815	4.0
600	616	11.0	700	716	11.0	800	816	4.0
600	617	12.3	700	717	12.0	800	817	5.0
600	618	10.3	700	718	10.0	800	818	3.5
600	619	11.0	700	719	11.0	800	819	3.5
600	620	12.3	700	720	12.0	800	820	4.5
600	621	18.0	700	721	10.0	800	821	5.0
600	622	18.0	700	722	10.0	800	822	5.0
600	623	18.0	700	723	10.0	800	823	5.0
600	624	18.0	700	724	10.0	800	824	5.0
600	625	10.0	700	725	10.0	800	825	7.0

Table A 3.6. Initial number of different heating technologies (thousands)

Heating technology	Description	Quantity
101	Individual heating with oil	687
102	Direct electric heating	0
103	District heating	8
117	Electric boilers	50
201	Individual heating with oil	284
202	Direct electric heating	55
203	District heating	12
217	Electric boilers	54
301	Individual heating with oil	92
302	Direct electric heating	102
303	District heating	20
317	Electric boilers	102
401	Individual heating with oil	659
402	Direct heating	22
403	District heating	54
417	Electric boilers	0
501	Individual heating with oil	677
502	Direct heating	44
503	District heating	442
517	Electric boilers	0
	Total	3 364

Table A 3.7. Estimated number of different types of residences during different time periods

Period / Residens Type S	1976-80	1981-85	1986-90	1991-95	1996-2000
1	708	634	576	525	467
2	402	401	397	391	387
3	316	316	315	313	309
4	702	644	587	519	459
5	1 136	1 102	1 073	1 053	1 027
6	98	146	237	328	416
7	94	151	260	357	463
8	130	198	332	463	594
Total	3 586	3 592	3 777	3 949	4 122

Table A 3.8. Estimated number of different types of residences lokated in communities with district heating systems during different time periods

Period / Residens Type S	1976-80	1981-85	1986-90	1991-95	1996-2000
1	148	164	166	168	162
2	82	101	118	125	136
3	59	67	77	89	104
4	334	314	294	255	220
5	251	226	204	190	178
6	25	38	74	114	150
7	24	43	81	120	165
8	80	118	196	282	367
Total	1 003	1 071	1 210	1 343	1 482

P A R T I I I

T H E R E S U L T S

8. THE POLICY ALTERNATIVES AND THEIR IMPLICATIONS FOR THE PRODUCTION OF ELECTRICITY AND HEAT

The system of models presented in Part II of this study can be used to analyze different energy policy strategies and other changes in the exogenous conditions for energy supply and demand in Sweden. Our attention is focused on nuclear power policy. Although the scope of the empirical part of this study is fairly narrow, the issues selected are studied thoroughly.

The results of the model simulations are presented in terms of a comparison between the impact of four different strategies for nuclear power policy on the power and heat sector and on the rest of the economy. Obviously the relevance of these results depends on the relevance of the policy alternatives studied. What, then, is a relevant policy alternative?

The most reasonable basis for formulating policy alternatives should be proposals by political parties and other important pressure groups. In this particular case we can use a resolution adopted by the Swedish Parliament in the spring of 1975 as the point of departure. According to this resoulution thirteen nuclear plants, corresponding to an installed capacity of 10,400 MW, are projected to be on line by 1985, but no additional plants will be allowed. All thirteen plants will be constructed in such a way that they cannot deliver hot water to district heating systems.[1/] This program, decided on by Parliament, should obviously constitute one of our policy alternatives.

On the other hand, this parliamentary decision has by no means silenced the debate. Some groups, such as the power industry, favor a more liberal nuclear power policy, while other groups want a more restrictive policy. Given these circumstances we have formulated the following stylized electricity and heat supply policy alternatives:

1/ The cooling water required in all nuclear plants is heated to such a high temperature that it can be used in district heating systems.

I. The power industry is allowed to choose freely among all existing types of plants.[1/]

II. The power industry is allowed to choose freely among all existing types of plants, but nuclear plants have to be located far from densely-populated areas. Thus, within resonable relative price variations, the cooling water from nuclear power plants cannot be used for space heating purposes.

III. The nuclear power program adopted by the Swedish Parliament in 1975 is fulfilled

IV. No nuclear power at all is allowed after 1980.

Of course the policy finally adopted will be much more ecomplex than each of alternatives I-IV. Moreover, it is quite likely that the adopted policy will be revised on several occasions. Nevertheless results of model simulations, constrained by the policy alternatives described above, should be useful to energy policy decision-makers.

The empirical part of this study consists to a large extent of comparisons, in several dimensions, of the four strategies for nuclear power policy described above. The analysis in this chapter is confined to the impact on the electricity and heat production sector.[2/] The demands for electricity and heat are therefore treated as exogenously determined magnitudes.

Subsequent chapters deal with the impact of the selected strategies on other sectors of the economy. Accordingly the demands for electricity and heat are endogenous magnitudes in those chapters.

1/ If nuclear plants are to be used for the combined production of electricity and heat for district heating systems, they have to be located fairly close to densely-populated areas (generally less than 60 km.). Thus, policy alternative I implies that there are no particular stipulations, in terms of distance from densely-populated areas, about the location of power plants.

2/ Note that "heat production" refers to the production of heat for district heating systems and industries. Heat production in oil furnaces in individual houses is excluded.

We begin by comparing the different policy strategies on the basis of the model presented in Chapter 6. The assumptions underlying the simulations are presented in Section 8.1. Using these assumptions, a cost minimizing investment and operations plan for the electricity and heat production sector is calculated for each of the policy alternatives. The results are presented in Section 8.2. Then, in Section 8.3, the four plans are compared in terms of electricity and heat prices, investment costs, oil consumption and various environmental effects. Section 8.4 contains a few remarks about load management. Some conclusions are presented in Section 8.5.

8.1 The Underlying Assumptions

The results presented in this and subsequent chapters are conditioned, of course, by the structure of the model and by the numerical values of the model's parameters and exogenous variables. The properties of the electricity and heat production model were discussed in Chapter 6. We now turn to the additional assumptions which underlie the results obtained.

Obviously, the assumed numerical values of the model's parameters and exogenous variables should be realistic. This applies in particular to the cost parameters which to a large extent determine the choice between different kinds of plants in the model. But due to the linearity of the model, the demand assumptions are - fortunately - not as strategic as the cost assumptions; the level of demand determines the size of the production sector but has a limited influence on the plant structure. Thus, for our purposes, we do not have to make very sophisticated electricity and heat demand predictions.

Two issues related to the electricity and heat sector are of particular interest in this study. First we want to determine an optimal capacity expansion and utilization plan for each of the four policy alternatives. We also want to investigate the consequences of these plans in terms of investment costs, consumption of oil and environmental effects. Second, for each nuclear policy alternative, we want to investigate the development of electricity and heat prices.

The simulations cover the period 1975 - 1995 which is divided into four five-year subperiods. All price and cost estimates are expressed in terms of the general level of prices prevailing in 1976.

8.1.1 Demand

The results in this chapter are all based on the assumption that the annual[1)] demand figures listed in Table 8:1 are used in the simulations.

Table 8:1 The demand assumptions

<table>
<tr><td colspan="2"></td><td colspan="2">75-80</td><td colspan="2">80-85</td><td colspan="2">85-90</td><td colspan="2">90-95</td></tr>
<tr><td rowspan="2">Electricity</td><td>TWh</td><td colspan="2">95</td><td colspan="2">120</td><td colspan="2">152</td><td colspan="2">192.6</td></tr>
<tr><td>Annual rate of growth, %</td><td></td><td colspan="2">4.9</td><td colspan="2">4.9</td><td colspan="2">4.9</td><td></td></tr>
<tr><td rowspan="2">Heat</td><td>TWh</td><td colspan="2">21.3</td><td colspan="2">29.9</td><td colspan="2">34.7</td><td colspan="2">38.3</td></tr>
<tr><td>Annual rate of growth, %</td><td></td><td colspan="2">6.8</td><td colspan="2">3.0</td><td colspan="2">2.0</td><td></td></tr>
</table>

It is assumed throughout that 5 TWh will be produced annually in industrial back pressure plants outside the model sector.

The most recent electricity demand prediction for the entire period was published by the Energy Forecasting Commission.[2)] The Commission made

---

1) The figures in the table refer to the average annual demand during each five-year period.

2) See SOU, (62).

four conditional forecasts, differing with respect to the assumptions about the rate of economic growth and the nuclear power policy. However, the comparison between our four policy alternatives is more easily interpreted if the same demand assumptions are applied in all simulations. Moreover, since the demand for energy is treated as an endegenous magnitude in the following chapters, the simplified demand assumptions is resonable at this stage of the analysis.

In 1970 the demand for electricity was 57,3 TWh.[1] According to the Energy Forecasting Commission the demand growth rate between 1970 - 1985 can be expected to lie in the interval 5.2 - 7.8 % per annum. The demand assumption applied here implies an annual growth by 6.5 % per annum between 1970 - 1978, the middle year of period 1 and then an even rate of growth by 4.9 % per annum. For the period 1985 - 2000 the Energy Forecasting Commission expected the growth rate of electricity demand to be between 2.5 % and 4.5 % per annum. Thus, the level of electricity demand in 1993, the year in the middle of period 4, is expected to be somewhere between 150 TWh and 253 TWh. This means that our demand assumption implies a more even growth of electricity demand than the Energy Forecasting Commission expected, and that the level of electricity demand at the end of the prediction period lies in the middle of the interval expected by the Commission.

According to a recent report by the Ministry of Finance[2] the heat deliveries to district heating systems was 16.9 TWh in 1975. The demand is expected to increase by 8 % per annum between 1975 and 1980, which means that the level of demand is 21.3 TWh in 1978. The high rate of increase in the demand for heat during the first period reflects the fact that many individual oil furnaces are expected to be replaced by district heating systems in the near future. After this, the rate of increase in the demand for heat is expected to be close to the rate of increase in the number of residential dwellings.

---

1) See Energihushållning, (61].

2) SOU, (65]. See p. 40.

The time segmentation adopted in this study and the assumed allocation of thermal power capacity between time segments were given in the Appendix to Chapter 6. Table 8:2 shows the approximate allocation of electricity and heat demand between the time segments. This table also reveals the "demand intensities"[1] implied by the approximate shape of the load curve.

Table 8:2 The approximate load curves

	1	2	3	4
	$\frac{E_i(t)}{E(t)}$	$\frac{E_i(t)}{E(t)} \Big/ \frac{H_i}{H}$	$\frac{W_i(t)}{W(t)}$	$\frac{W_i(t)}{W(t)} \Big/ \frac{H_i}{H}$
0	0.046	1.54	0.025	1.62
1	0.188	1.45	0.095	1.55
2	0.132	0.88	0.115	1.50
3	0.204	1.36	0.245	1.41
4	0.116	0.78	0.220	1.27
5	0.199	1.05	0.160	0.64
6	0.114	0.60	0.140	0.56
Σ	1.000		1.000	

$E_i(t)$ = Demand for electricity in time segment i

$W_i(t)$ = Demand for heat in time segment i

H_i = Number of hours in time segment i

$E(t) = \sum_{i=0}^{6} E_i(t)$; $W(t) = \sum_{i=0}^{6} W_i(t)$; $H = \sum_{i=0}^{6} H_i$.

Sources: Column 1 was compiled on the basis of load statistics by G. Saros of the National Industrial Board.
Column 4 is based on Hedbom & Rundström (22].

---

1) The concept "demand intensity" is discussed on p. 151.

8.1.2 Fuel Price Assumptions

The prices of fuel oil and coal are both set equal to 30 Sw.Cr./Gcal[1)] for the initial period. The cost of enriched uranium, including waste disposal costs, is derived from the operating costs at nuclear power plants, which are assumed to be about 2.2 s öre/kWh. These price assumptions are obtained from a recent report by the Ministry of Industry.[2)]

In accordance with the discussion in Chapter 3 we should expect fuel prices to increase in real terms over time. However, at the present time nobody seems to be willing to make long term forecasts about the development of oil, coal and nuclear fuel prices. In this study we have, arbitrality assumed that all fuel prices increase by 3 % per annum in real terms over the entire prediction period.

8.1.3 Assumptions regarding Power Plant Availability and Investment Costs

The figures adopted for maximum operating times (τ_s), plant availability (a_{ws}) and investment costs (K_s) are listed in Table 8:3. These figures are discussed in some detail in Bergman et al. (8).

Table 8:3 Maximum operation times (τ_s hours), availability (a_{ws}) and investment costs (K_s Sw. Cr./KW) for different thermal power plants[x)]

Type of plant	s	τ_s	a_{ws}	K_s
Conventional nuclear power	1	7584	0.60	3000
Combined nuclear power	2	7584	0.60	3800
Base load, oil fired	3	7752	0.89	1900
Base load, coal fired	4	7752	0.83	2200
Peak load, oil fired	5	7752	0.85	1300
Back pressure	6,7	7752	0.85	2200
Gas turbines	8	8088	0.85	1000
Hot water generating	9	8600	-[3)]	-
Hydro power	10	-	-	2800[4)]

x) These concepts are discussed in Chapter 6

Notes 1, 2, 3, and 4, see p. 205.

The investment cost figures are compiled by H. Hedbom and T. Rundström[5] and revised on the basis of a recent report by the Ministry of Industry.[6]

In section 4.5 a particular behaviour assumption adopted in this study was discussed. The assumption was that historical costs are taken into consideration when electricity and heat prices are determined. Technically this was carried out by assuming that there is a capital cost associated with the utilization of existing capacity. The "cost" of using capacity of different types can be calculated on the basis of the figures in Table 8:3.

The following symbols are needed for these calculations:

r = The rate of interest

S_E = The rate of depreciation of existing capacity

K_s = Investment cost (Sw.Cr.) per unit of installed capacity (KW) of type s.

τ_s = Maximum operation time per year for capacity of type s

a_{ws} = Average availability of capacity of type s

$1-\eta_m$ = Average distribution losses

Thermal capacity is expressed in GWh "potential production of energy"[7] and hydro capacity in MW installed capacity. The parameter ρ_s is defined as

---

1) This corresponds to 300 Sw.Cr./m^3 for (heavy) fuel oil and 200 Sw.Cr./ton for coal.

2) See Industridepartementet, (58].

3) No published figures available. The figure 0.90 have been used in the calculations.

4) The figure represents an estimated replacement value. See Hedbom & Rundström, (22].

5) See Hedbom & Rundström, (22].

6) See Industridepartementet, (58].

7) See p. 148 where the concept "potential production of energy" is defined.

$$\rho_s = \frac{(r + \delta_E)K_s}{\tau_s \cdot \eta_m \cdot a_{ws}} \quad \frac{\text{Millions Sw.Cr.}}{\text{GWh}} \; ; \quad s = 1, 2, \ldots, 9$$

$$\rho_{10} = (r + \delta_E)K_{10} \cdot 10^{-3} \quad \frac{\text{Millions Sw.Cr.}}{\text{MW}}$$

On the basis of these formulas and the figures in Table 8:3 and on the assumption that the rate of interest is 8 % and the rate of depreciation 1,4 % per annum[1], the parameter ζ_s can be computed for each type of plant. The results of such calculations can be seen in Table 8:4.

Table 8:4 The calculated cost of using capacity of type s

s	Type of plant	ρ_s
1	Nuclear power	0.0696
2	Combined nuclear power	0.0882
3	Base load, oil fired	0.0291
4	Base load, coal fired	0.0361
5	Peak load, oil fired	0.0208
6,7	Combined oil fired	0.0353
8	Gas turbines	0.0154
9	Hot water generating	0.0021
10	Hydro power	0.0263

The availability figure for nucelar power plants adopted in this study represents a fairly pessimistic assumption. The figure implies that a nuclear plant can be in operation on an average of only 27 weeks each year. This is less than the first-year performance experienced so far for Swedish nuclear power plants in operation ;[2] see Table 8:5.

1) In accordance with the National Accounts.

2) The reasons for the pessimistic assumption adopted in this study will become clear later on in this chapter.

Table 8:5 The performance of Swedish nuclear power plants.

Year after installation	Expected number of weeks in operation	Actual number of weeks in operation
1	26	29
2	31	31
3	36	34
4	39	36

Source: Norrby (41).

8.1.4 The Rate of Interest

All the results presented later on in this chapter are obtained from model-simulations carried out on the assumption that there is no inflation and no uncertainty. Thus, we should use an interest rate corresponding to the rate of return on invested capital that would be required by the power producers under such circumstances. This is a quite obvious principle which, however, is rather difficult to apply in practice.

The Swedish State Power Board, which is the dominating power producer in Sweden, currently use the interest rate 10% in its investment calculation. Since the demand for electricity has been rapidly growing for a long time and power deliveries on the basis of long term agreements are subject to price index clauses, there has not been very much risk connected with production and distribution of electric power. Accordingly, this interest rate should be fairly close to a risk-free interest rate. Thus, the most difficult problem is to take account of the expected rate of inflation.

The existence of price index clauses in the tariffs implies that the interest rate used in investment calculations does not have to reflect the expected future input price increases. However, to the extent that the power producers are dependent on external funds their return requirements must be high enough to cover both the real return requirements and the rate of inflation expected by the bondholders. Thus, we should reduce the figure 10%, but we do not know by how much. However, in this study we have, somewhat arbitrarily, used the interest rate 8% in the simulations.

8.2 Nuclear Power Policy, Capacity Expansion and Utilization in the Electricity and Heat Sector

We now investigate how the four nuclear power policy strategies are likely to affect the electricity and heat sector in two respects: 1) the optimum choice of plant structure and 2) the rates of capacity utilization.

The following simulation procedure was used. For each policy alternative, the model has been solved under the assumptions presented in the preceding section. Then, in order to test the sensitivity of the solutions, parametric variations of a number of assumptions were carried out.

One important point should be noted in this context. The formulation of the model implies a distinction between the owners of plants in existence at the initial point in time and the producers of electricity and heat. The producers can rent plants from the owners at prices which reflect the relevant rates of profit and depreciation. Accordingly, to the extent that there is some overcapacity in the system, the producers can choose not to rent one or more of a particular type of plants. This can be interpreted to imply that on the basis of present prices and technological alternatives, past investment in certain types of plants should not have been carried out.

8.2.1 Capacity Expansion

The cost minimizing plant structures determined by the model for the periods 1976 - 1980 and 1986 - 1990 are presented in Table 8:6. The figures for the first period form a basis for discussing the "optimality" of the existing plant structures in the Swedish power system. The figures for the period 1986 - 1990 are a starting point for comparing the four policy strategies. This comparison is confined to the period 1986 - 1990 for three reasons.

First, we are interested in the long-run effects of the different policy alternatives. Second, it takes about ten years, two periods in the model, to build a nuclear power plant. Thus, the full effect of a nuclear power policy decision taken in 1978 cannot be evaluated until the end of the 1980s. Third, at the beginning of the period 1986 - 1990, the model power system has adjusted itself to prevailing exogenous conditions and later periods are not significantly different from that period.

The period 1976 - 1980 exhibited a substantial overcapacity in the Swedish power system. However, the model is likely to exaggerate this overcapacity to some extent. First, only "normal" years in terms of water supply are included in the model. Thus, no additional thermal capacity is needed as a reserve for dry years. Second, the load curve approximation in this study tends to reduce the need for capacity at a given level of demand (see p. 166). Third, the figures in the column "exogenous" represent estimated magnitudes.

These objections, however, are not significant enough to discard the conclusion that there is some overcapacity in the present Swedish power system. One reason for this overcapacity can be that the demand forecasts published by the power industry in the late 1960s overestimated the growth of electricity demand.[1)] This is mainly due to the decline in energy (and electricity) demand that took place between 1973 and 1974 in connection with the oil crisis. Since the construction times in the power sector are very long (5 - 10 years) the capacity expansion plans to a large extent have to rest on demand forecasts. Thus, if the future demand is overestimated some overcapacity will appear.

An additional explanatory factor could be that the principles of electricity pricing were changed at the beginning of the 1970s.[2)] The previous power tariffs were based on a system with quantity discounts, whereas the new system is based on the long-run marginal cost of electricity generation.

---

1) See SOU, (65).

2) See Lundberg, (35).

Table 8:6 Optimum plant structures[x)] in the electric power system, 1976 - 1980 and 1986 - 1990, given certain assumptions about nuclear power policy.

		1976 - 1980				1986 - 1990							
		Exogenous[1)]		Utilized		I		II		III		IV	
Type of plant	s	MW	%	MW	%	MW	%	MW	%	MW	%	MW	%
Conventional nuclear	1	5560	20	5560	30	15010	42	17150	50	10400	32	-	-
Combined, nuclear	2	-	-	-	-	5240	15	-	-	-	-	-	-
Base load, oil	3	2100	8	0	0	0	0	0	0	2100	6	8760	30
Base load, coal	4	-	-	-	-	0	0	0	0	0	0	0	0
Peak load, oil	5	1070	4	30	0	0	0	260	1	1070	3	1070	4
Combined, oil	6,7	1950	7	600	3	580	2	1950	6	4880	15	4650	16
Gas turbines	8	1600	6	1240	7	1100	3	1600	5	1490	5	1600	5
Hydro	10	15000	55	11080	60	14090	39	13650	39	12880	39	13330	45
		27280	100	18510	100	36020	100	34610	100	32820	100	29410	100

x) The figures for 1986 - 1990 represent the sum of rented (utilized) exogenous capacity and endogenously installed capacity.

1) The amount of capacity of different kinds expected to be installed by 1978.

According to Table 8:6, oil-fired plants represent the capacity surplus in the Swedish power system. As can be seen in the table, all existing nuclear power is utilized, while no base load oil-fired plants are used at all. The figures for the period 1986 - 1990 clearly reveal the impact of different nuclear power policy strategies on the development of the Swedish power system; in policy alternatives I and II where nuclear power is allowed, vast investments are made in nuclear power plants.

The nuclear power availability assumption adopted here was fairly pessimistic. If the availability of these plants turns out to be higher, their profitability is increased and the amount of installed capacity required per unit of "potential production of energy" is reduced. An increase in the prices of fossil fuels will also improve the relative profitability of nuclear power plants, as will a reduction of the rate of interest.

If the price of oil is reduced to one-third, the plant structure is not significantly affected. This is also the case if the rate of interest is increased from 8 % to 12 % or if the price of nuclear fuel is doubled. However, if all three (the price of oil reduced to one third, the price of nuclear fuel doubled and the rate of interest increased from 8 % to 12 %) of these changes occur simultaneously, no endogenous investments in nuclear power are made in an optimal solution.

It should be empasized these results are obtained on the basis of a very pessimistic assumption about the availability of nuclear power plants (the parameter a_{ws}). An availability figure based on the actual experiences with Swedish nuclear power plants had been adopted, would have made the position of nuclear power even stronger from a cost minimization point of view.[1)]

Not surprisingly, the profitability of combined plants, nuclear as well as non-nuclear, is highly dependent on the level of heat demand.

---

1) In order to keep the total cost of the simulations as low as possible, no simulations with a higher nuclear power availability figure were carried out.

As can be seen in Table 8:6, investments in combined oil-fired plants are large in policy alternative III where no more nuclear power plants are allowed than the 13 decided on initially. Further, the stock of oil-fired base load plants is maintained. The choice between oil and coal-fired base load plants turned out to be very sensitive to the assumed price relation between oil and coal. However, heavy fuel oil and the kind of coal used in power plants have very few alternative uses. Since both oil and coal fired power plants are used in many countries, a possible interpretation of our result is that world market prices for heavy fuel oil and coal are determined by electricity prices in these countries.

The alternatives III and IV differ mainly with respect to the total amount of installed capacity and the composition of base-load capacity. In alternative IV a smaller amount of capacity is needed than in alternative III simply because of our pessimistic assumption about nuclear power availability. Table 8:6 shows that the nuclear capacity that has to be scrapped in alternative IV is replaced by base load oil fired plants. As was mentioned above, the choice between oil- and coal-fired base load plants was very sensitive to variations in the fuel- and capacity-cost assumptions.

An unexpected result which applies to all periods and simulations, is that the total exogenous hydro capacity is not utilized.[1] This is surprising since there are plans in Sweden to install additional capacity in existing hydro power plants in order to reduce the cost of peak production, that is, reduce the need for production in gas turbines.

There are three explanations for the model result. First, our estimated cost of using hydro capacity reflects the cost of entirely new hydro capacity. According to the Energy Forecasting Commission the cost of additional capacity in existing hydro power plants only amounts to about 30 - 40 % of the cost of an entirely new plant.[2] Second, as mentioned above, the load curve approximation tends to underestimate capacity requirements in

---

1) However, all available water is used for electricity production.

2) See SOU, (62), p. 234.

the power system. Third, in the model, gas turbines are fuelled with conventional heavy fuel oil. In the real world, these plants are fuelled with a more expensive special fuel. This means that the model tends to overestimate the profitability of gas turbines.

8.2.2 The Production of Electricity and Heat

Next we turn to the contributions of different types of plants to the total production of electricity and heat. The figures obtained from model simulations are presented in Table 8:7, along with actual figures for 1975.[1)]

Table 8:7 The percentage shares of the total production of electricity and heat delivered from different types of plants, 1975 and 1986 - 1990[x)]

Time period			1975	1986 - 1990			
Kind of energy	Type of plant	s	Actual figures	Model prediction			
				I	II	III	IV
	Conventional nuclear	1	10	44	50	30	
	Combined, nuclear	2		11			
	Base load, oil	4	7			9	39
Electricity	Peak load, oil	5				1	1
	Combined, oil	6,7	5	0	5	15	16
	Gas turbines	8	0	0	0	0	0
	Hydro	10	78	44	44	44	44
		Σ	100	100	100	100	100
	Combined, nuclear	2		94			
Heat	Combined, oil	6,7		3	38	94	97
	Heat generating plants	9		3	62	6	3
		Σ		100	100	100	100

x) Zero written out in the table means that the plant in question has been utilized, but that it has contributed less than 1 % to total production.

1) See SOU, (65) p. 47.

In all the policy alternatives the Swedish power system gradually changes; the dependence on thermal power increases over time. The differences between the policy alternatives for 1986 - 1990 are very straightforward. In I, conventional and combined nuclear plants are used for base load electricity and heat production while hydro power and heat generating plants are used for peak load production. In II, combined nuclear plants are replaced by combined oil fired plants and in III and IV, some or all conventional nuclear power is replaced by base load oil fired plants, and combined oil fired plants.

The results concerning the production of heat for district heating systems should be interpreted with care. This is because the formulation of the model implies the existence of an integrated distribution system for hot water. This is not the case in the real world. There are several local district heating systems which could be connected to a combined nuclear or oil fired plant only at substantial costs. Since investments in distribution systems are not endogenously determined in the model, we have in fact overestimated the profitability of heat production in combined plants.

8.3 Effects on the Rest of the Economy

In the preceding section we confirmed that the choice of nuclear power policy strategies has a significant impact on the structure of the power sector. This, as such, is interesting, although the choice of nuclear power policy becomes crucial when we recognize that the different alternatives have markedly different implications for the rest of the economy.

If the Swedish economy were a "perfect economy" in the text-book sense, an analysis of the effects of the policy alternatives on the rest of the economy could be confined to a comparison of differences in the resulting electricity and heat prices. However, since electricity and heat production has important external effects, these aspects should also be incorporated. Further, it is interesting to compare the alternatives in terms of investment costs and oil consumption. All of these aspects are compared in this section.

8.3.1 Electricity and Heat Prices

Electricity tariffs in Sweden have been based on the long-run marginal cost of electricity production since the beginning of the 1970s.[1] Thus, as a rough approximation, the model's estimate of the marginal cost resulting from shift of the level of the load curve, given its shape, can be used as a measure of the price of high voltage electricity.[2] The electricity prices calculated in this way, which result from the different policy strategies, are listed in Table 8:8. The corresponding figures for heat are shown in Table 8:9, although the relation between our calculated prices and real world prices is less straightforward in this case.[3] To begin with we discuss the caluclated electricity prices presented in Table 8:8 and then we turn to the calculated heat prices.

Table 8:8 Calculated high voltage electricity prices for different policy alternatives (expressed in 1976 Sw. öre/kWh)

Time period / Policy alternative	76-80	81-85	86-90	91-95	Average rate of change, % per annum
I	6.8x)	7.3x)	8.5x)	9.6x)	1.7
II	6.8x)	7.3x)	8.5x)	9.4x)	1.6
III	6.8	7.3	14.0	16.3	4.3
IV	6.8	13.1	14.5	16.3	4.3

x) If nuclear power plants are assumed to be available during 36 instead of 27 weeks per year these figures should be reduced by about 2 Sw.öre/kWh.

---

1) See Lundberg (35) and State Power Board (68).

2) The roughness of this approximation is discussed in Section 10.3.

3) This is because the majority of heat producers have not adopted a uniform tariff policy, such as marginal cost pricing. Moreover, heat producers are not connected to each other by a nationwide network of grids (as are electricity producers).

Two points should be noted in Table 8:8. First, in all the alternatives there is a gradual increase of the calculated price of electricity. Second, in the later periods there are substantial differences between the nuclear and the non-nuclear alternatives.

The gradual increase of electricity prices is the combined effect of the diminishing share of hydro power in the total production of electricity, and our assumption about a 3 % yearly increase in all fuel prices. When the latter assumption was removed and the policy alternatives I and III was simulated under the assumption of constant fuel prices, the average rate of change of the calculated price of electricity between 1976 and 1995 was 0.8 % and 3.0 % per annum in alternative I and III respectively.[1)] Since the average rates of change initially were 1.7 % and 4.3 % (see Table 8:8), about 0.9 % and 1.3 % per annum can be attributed to the assumed fuel price increases. Thus, in the nuclear alternative the price of electricity is less sensitive to fuel price variations than in the non-nuclear alternative. This is because nuclear power plants are more capital-intensive than fossil-fuelled plants.

Table 8:8 also shows that in terms of the level of the calculated price of electricity there are substantial differences between the nuclear and the non-nuclear alternatives. On the other hand both the nuclear alternatives yield approximately the same long run price of electricity and that also applies to the non-nuclear alternatives. A few remarks should be made about the latter result.

In terms of the calculated price of high voltage electricity as shown in Table 8:8, the difference between the alternatives III and IV is confined to the period immediately after the nuclear power plants are scrapped. This of course, is not very surprising; the optimum choice of additional capacity should be independent of the maximum amount of nuclear capacity once that capacity is less than the required capacity.

1/ The price of electricity increases faster in alternative III than in alternative I, since the cheap hydro power is replaced, by oil fired plants which, on the basis of our assumptions, are less economical than nuclear plants.

The immediate price increase due to the scrapping of nuclear plants is, however, relatively low. This result should be interpreted with some care. This is mainly because we have assumed that base load fossil fuelled plants can be constructed within five years,[1/] that is, one model period. This is not the case in the real world; the actual construction period is about 7-8 years. On the other hand, gas turbines and small back pressure plants can be constructed within less than five years. However, if several plants are to be constructed on short notice, the actual investment costs may exced our estimates due to bottle-neck problems. In any case, if such plants, designed for peak and medium load production, are installed to replace nuclear base load plants, the calculated price of high voltage electricity would increase dramatically.[2/] In other words, due to the definition of the unit time period and the high level of aggregation, the model is likely to underestimate the problems connected with a total scrapping of all existing nuclear power plants by 1980.

Next we turn to the calculated price of heat.

Table 8:9 Calculated heat prices for different policy alternatives (expressed in 1976 Sw.öre/kWh)

Time period / Policy alternative	76-80	81-85	86-90	91-95
I	4.3	6.0	2.7	2.6
II	4.3	5.3	5.9	6.9
III	4.3	5.9	3.3	3.2
IV	4.3	2.7	2.9	3.1

1/ See p. 152.

2/ However, a dramatic rise in electricity prices would reduce the demand for electricity.

Since investments in heat distribution systems are not taken into consideration in the present formulation of the model, the figures in Table 8:9 only apply to rather large urban areas where a local network for distribution of heat already exist.

In terms of heat prices the policy alternatives where combined plants are used for heat production differ markedly from the alternative where heat mainly is produced in heat generating plants. Tables 8:8 and 8:9 also indicate that the relation between electricity and heat prices is very sensitive to the choice of nuclear power policy strategy. In relation to the price of heat, the price of electricity is highest in alternatives III and IV and lowest in alternative II. In other words, when combined plants predominate in the power sector (alternatives I, III and IV), the fuel efficiency gains have a greater impact on heat prices than on electricity prices.

These results indicate that the choice of strategy for nuclear power policy is likely to have an important impact not only on the size but also on the structure of the Swedish energy market. A policy which allows nuclear plants, provided they are located far from densely-populated areas, will tend to stimulate the demand for electricity through low electricity prices. A policy which does not allow additional nuclear power plants will of course induce a switch from electricity to other kinds of energy. However, the most "liberal" nuclear power policy (alternative I) is also likely to have that effect.

8.3.2 Investments in Electricity and Heat Production Equipment

The production of electricity and heat is very capital intensive. Thus, power plant investments always have a significant impact on the capital market. This makes it interesting to ascertain the size of the amount of resources used for power plant investments in the different policy alternatives.

The total amount of expenditures, measured in 1976 prices, on power and heat plant investments in the different alternatives are shown in Table 8:10. Observe that the figures only include investments in production equipment. Thus, the costs of transmission lines etc. are excluded.

Table 8:10 Yearly investment expenditures on power and heat production plants for different policy alternatives (1976 M Sw.Cr.)

Policy alternative \ Time period	76-80	81-85	86-90	91-95
I	2,640	4,580	3,940	3,930
II	2,640	3,820	3,530	3,740
III	2,640	2,670	1,730	3,160
IV	2,640	2,720	2,620	3,330

Investment activity during the first period is dominated by exogenously determined investments in nuclear and hydro power plants. This also applies to the second period to some extent. However, the large investments in nuclear power plants[1)] in alternatives I and II affect the demand for investment resources as early as the second period. From that period and onwards, the nuclear alternatives lead to larger annual investment expenditures than the non-nuclear alternative.

The figures in Table 8:10 are based on the assumption that no investment resources are wasted on nuclear plants which are not completed or never taken into operation. Otherwise the figures for 1981 - 1985, policy alternative IV, should be increased by the amount of wasted resources.[2)]

The reason why the scrapping of nuclear power does not lead to a greater increase in power plant investments is that there is some overcapacity in the power sector. The 5500 MW of nuclear power is replaced by 4000 MW[3)] from fossil plants and a higher rate of utilization of existing plants.

---

1) If a new nuclear power plant is to be on line in period t, it is assumed that half of the necessary investment resources are bought during period t-1 and the rest during period t.

2) This would correspond to a total investment expenditure of 8,240 M Sw.Cr.

3) 2300 MW in base load oil fired plants and 1700 MW in combined oil fired plants.

To the extent that the 4000 MW of additional capacity cannot be implemented before 1983, the representative year in the second model period, electricity has to be rationed if the existing nuclear plants are scrapped. This rationing can be carried out either by means of quotas, etc. or by electricity price increases higher than the marginal cost of production.

8.3.3 Oil Consumption

If constraint are imposed on the expansion of nuclear capacity and the demand for electricity continues to grow, additional fossil fuelled power plants will have to be added to the Swedish power system. As indicated above, the relative profitability of coal and oil fired plants for base load production is very sensitive to the fuel price assumptions. A choice in favor of oil will have a great impact on the consumption of oil by the power sector; see Table 8:11.

Table 8:11 Oil consumption for electricity and heat production for different policy alternatives (1000 m^3)

Time period / Policy alternative	76-80	81-85	86-90	91-95	Average rate of change, % per annum 1976-1995
I	2,550	3,890	360	990	-4.7
II	2,550	3,890	4,920	4,770	3.1
III	2,550	3,890	10,490	20,670	10.5
IV	2,550	12,790	20,850	31,100	12.5

In policy alternative I oil fired plants are only used for peak and near peak production of electricity and heat, whereas oil fired plants are used for peak electricity production and all heat production in policy alternative II. The difference between III and IV essentially is the result of the replacement of 10400 MW nuclear capacity by oil fired plants.

In 1975 the total consumption of oil in Sweden was approximately $29 \cdot 10^6$ m^3. Of this about 8 % was used for power production. On the basis of Table 8:11 it is obvious that policy alternatives III and IV both would have a significant impact on Sweden's total consumption of oil. Moreover, with the crisis of 1973 - 1974 as a background, Table 8:11 indicates that policy alternatives III and IV has to be supported by guarantees of continuous supply of oil.

8.3.4 Environmental Effects

A complete analysis of the environmental effects resulting from the choice of nuclear power policy should involve the following three steps:

I Determination of the amounts of different pollutants emitted

II Determination of the effects of the emitted pollutants on the environment

III Determination of how people evaluate the changes in the environment

One way of expressing the environmental effects of power and heat production would be to include "processes" for desulphurization of fossil fuels and reprocessing and storage of used nuclear fuel.[1/] However, this has not been possible within the scope of this study. We make only a modest attempt to deal with the first step. Also, we limit ourselves to three pollutants: emissions of sulphur dioxide and cooling water and the accumulation of radio-active waste. The last variable is measured by the yearly input of uranium in nuclear power plants.

The results of the application of this limited measure of environmental effects with respect to the different policy alternatives are shown in Table 8:12.

Although our measure of environmental effects is very superficial, the results in Table 8:12 lead to a very clear conclusion. The power sector has substantial environmental effects, but the nature of these effects differs significantly between the various policy alternatives.

1/ In the supply submodel for refined petroleum products (one of the submodels of the EFM) desulpurization processes are included.

Table 8:12 Environmental effects of different nuclear power policy alternatives

Kind of emission	Time period / Policy alternative	76-80	81-85	86-90	91-95
Sulphur dioxide, 1000 tons	I	48·s	74·s	7·s	19·s
	II	48·s	74·s	93·s	90·s
	III	48·s	74·s	199·s	392·s
	IV	48·s	243·s	396·s	591·s
Cooling water, GWh	I	50	95	152	236
	II	50	95	157	258
	III	50	95	118	170
	IV				
Consumption of uranium, tons	I	105	197	381	557
	II	105	197	325	536
	III	105	197	197	197
	IV	105	0	0	0

s = percentage share of sulphur in fuel oil.

8.4 Electricity Prices and the Shape of the Load Curve

The shape of the load curves was kept constant in all of the simulations that generated the results reported in this chapter. However, the shape of the load curve is an economic variable that can be affected by means of various load management measures, of which so-called "peak load pricing" is perhaps the most well-known.

The purpose of load management is to flatten out the load curve in order to incrase the load factor of installed capacity and reduce the need for peak capacity. Load management results in lower total costs for producers. But changes in the time distribution of energy consumption usually lead to higher costs and reduced convenience for consumers. Thus, there is an optimum shape of the load curve, and it is not likely that the optimal load curve is completely flat.

This means that a good deal of information is needed in order to evaluate the "optimality" of an observed load curve. Although this could not be analyzed fully within the framework of our study, we will discuss how the calculated prices of electricity differ between various time segments and study the extent to which these differences appear in the prices charged by Swedish power producers. This implies investigating whether Swedish consumers of electricity should and do have incentives for taking the time pattern of their electricity consumption into consideration.

The calculated electricity prices for all time segments and policy alternatives for the period 1986 - 1990 are shown in Table 8:13.

Table 8:13 Calculated prices of high voltage electricity in different time segments. 1986 - 1990. for different nuclear power policy alternatives, Sw.öre/kWh

i^x / Alt.	0	1	2	3	4	5	6	Total
I	45.2	10.4	5.8	5.8	5.8	5.8	5.8	8.5
II	46.8	10.0	5.8	5.8	5.8	5.8	5.8	8.5
III	45.2	17.2	11.3	11.3	11.3	11.3	11.3	14.0
IV	45.2	17.8	11.8	11.8	11.8	11.8	11.8	14.5

x i = time segment; see p. 151.

According to the results in Table 8:13, the calculated price of electricity delivered during the day in winter differs significantly from the prices of deliveries at other times. This pattern appeared in all the other periods as well. The table also shows a marked difference between the policy alternatives in terms of the relation between peak and off-peak prices.

Our calculations are based on the assumption[1/] that there is a cost for using exogenously determined capacity, i.e. all initial capacity, nuclear capacity added in the second period and all additional hydro capacity. When this assumption was dropped so that all hydro (and some other) capacity was treated as a free resource, it turned out that at electricity demand levels lower than about 150 TWh per annum.[2/] there were no differences between the time segments in terms of calculated electricity prices.

This result is easily explained. When the available hydro capacity and water supply is large enough in relation to annual demand, the use of hydro capacity can be varied over time in such a way that the load met by production in thermal plants becomes constant over the year. Thus, the calculated price of electricity will be determined by the marginal cost of production in thermal plants and a peak charge, corresponding to the cost of hydro capacity, will be added during peak hours. Accordingly we can conclude that the time differentiation of the calculated electricity prices shown in Table 8:13 to a large extent reflects differences in capital costs, while the marginal operating costs are more or less constant over the year.[3/]

Prior to 1973, Swedish electricity tariffs included a quantity discount component. The general principles of high voltage electricity pricing

---

1/ See p. 106.

2/ For our simulations we assumed that the demand for electricity was 152 TWh per annum for the period 1986 - 1990.

3/ The high calculated price in time segment 0 reflects the cost of gas turbines.

in Sweden were entirely revised in 1973 and a new system was designed. The basic idea of the new tariff system is that the price of each delivery should reflect the long-run marginal production and distribution costs of that delivery. However, the tariff system is subject to the constraint that total revenues should cover total costs including a "normal" rate of profit on invested capital.[1)] To some extent these tariff principles also apply to low voltage deliveries.

According to the new tariff system the price of high voltage electricity has four components, each reflecting a particular cost item:

I A fixed charge which reflects the costs of metering, billing and a proportion of overhead costs. This charge is governed mainly by the supply voltage.

II A contractual demand charge which reflects the costs of local system components utilized, by and large, exclusively by the consumer. This charge is based on the average demand per hour and the average of the two highest monthly values of this demand during the year.

III A peak load charge which reflects the costs of transmitting the consumers' share of the cumulated load and the extra costs of peak load generation required in excess of off peak costs. This charge is based on the average demand per six-hour period and the average of the four highest monthly values of this demand during the year.

IV An operating charge which reflects variable production costs during the off peak period, including the costs of transmission losses. This charge is based on the measured amount of electricity consumed during the year.

Thus, for a high voltage electricity consumer the time pattern of consumtion has a definite impact on the total cost of electricity purchases.

---

1) See The State Power Board (68).

Yet the tariffs applied by Swedish power producers do not represent an application of the principles of "peak load pricing". If this was the case, the price of each kind of electricity delivery should be equal to the short-run marginal cost of that delivery, including scarcity premiums necessary to keep the demand within capacity limits.

In general the tariff principles applied by Swedish power producers are not consistent with these rules. Actual electricity prices basically reflect long-run marginal costs which coincide with short-run marginal costs only when the plant structure is optimally adjusted to prevailing demand and cost conditions. Further, since demand elasticities are not explicitly taken into account when the prices are determined, both the level and time structure of demand are implicityly assumed to be independent of the prices of various kinds of deliveries.

Swedish low voltage electricity tariffs are somewhat simpler than high voltage tariffs. In particular, the low voltage tariffs do not contain any peak load charge.[1/] Low voltage tariffs generally consist of a fixed charge, related to the capacity of the main fuse, and an operating charge, related to the measured amount of electricity consumed during the year.

This means that households, including thoseusing electricity for residential heating purposes, do not generally have any incentives for worrying about the time pattern of their electricity consumption; up to the limit set by the capacity of the main fuse the marginal cost of electricity is constant and this applies to all seasons of the year. This means that at times electricity is delivered at a price which is lower than the marginal cost of production and distribution. More important, however, is that it cannot be ruled out that an application of the rules of "peak load pricing" or the same tariffs as for high voltage deliveries to low voltage deliveries would severly undermine the competitiveness of

---

1/ However, the operating charge for certain areas and tariffs differs between daytime and nighttime or between summertime and the rest of the year.

electric heating, which has been one of the most dynamic factors behind the growth of electricity demand during the last ten years.

Unfortunately we cannot deal further with these problems within the scope of this study. The discussion above does indicate, however, that an analysis of the relation between electricity demand and electricity prices cannot be confined to the elasticity of demand with respect to the average price of electrícity.

8.5 Some Conclusions

The model simulations discussed in this chapter clearly demonstrate that, on narrow economic grounds, nuclear power constitutes a very competitive technology for electricity and heat production. This conclusion is well in line with the expectations about nuclear power which were common during the 1960s. Since then, however, the costs for nuclear plants have increased dramatically and the expected availability figures have been reduced. These factors have given rise to doubts as to the profitability of nuclear power plants.

Other changes, in addition to those affecting the profitability of nuclear power, have also occured since the 1960s. Power plant equipment in general has become more expensive and, of course, the price of oil has more or less exploded. These factors have restored nuclear power to a position of profitability. It seems as if those who had high hopes about nuclear power were right, but for the wrong reasons. Nuclear technology has encountered more problems than expected, but the increase in oil prices has more than offset the cost effects of these problems.

According to our results the choice of nuclear power policy will have a considerable impact both on the level and structure of energy prices (see Tables 8:8 and 8:9). In the long run the calculated high voltage electricity prices were about 100% higher in the non-nuclear natives (III and IV) than in the nuclear alternatives (I and II).

These results should be interpreted with some care. We noted above that the costs for nuclear power plants have increased dramatically. It is natural to interpret this development, as we did above, as a sign of unexpected problems for nuclear technology. Another quite reasonable interpretation is that the oil price increase gave the producers of nuclear power equipment an opportunity to reap extra profits on their products. If this interpretation is valid the development of future electricity prices will only partly be determined by the nuclear power policy adopted in Sweden. Electricity prices will also depend on the relation between the prices of oil and other fuels on one hand and the cost for nuclear and other kinds of power plants on the other.

The policy alternatives are compared in this study on the basis of a simple cost minimization criterion. But the choice of technology has many aspects other than (private) economic profitability.
This became clear when the three policy alternatives were compared in several dimensions. Each policy strategy has environmental effects as well as effects on preparendness and national security, although the nature of these effects differs among the policy alternatives. All of these effects are subject to substantial uncertainties. Thus, the choice of nuclear power strategy should be based on an analysis of the social costs and benefits associated with the different alternatives. This conclusion, as such, does not give much guidance to energy policy decision-makers. However, since the Swedish energy policy debate is to a large extent concentrated on the external effects of nuclear power, it should be emphasized that such effects are associated with all of our policy alternatives.

On the basis of the analysis in this chapter we cannot reach any firm conclusions about the social desirability of one particular policy alternative in relation to another. But we have reached some partial conclusion and with all the reservations in mind, we now turn to an analysis of the impact of the four nuclear power policy alternatives on some other sectors of the Swedish economy.

9. THE RESIDENTIAL HEATING SECTOR

After the preceding analysis of the electricity and heat production sector, we turn to an important oncumer sector of these energy forms, i.e. the residential sector. The purpose of this chapter is to investigate the potential responsiveness in the demand for energy by this sector when the prices of energy increase.

The energy used for residential heating purposes is low temperature heat, which can be regarded as low quality energy. This means that all kinds of energy sources can be used to generate energy for residential heating purposes. Accordingly, there is a high degree of substitutability among different fuels on the residential heating market. Thus, the residential heating sector is potentially very sensitive to variations in the supply conditions for different kinds of energy.

The amount of produced energy required to sustain a given indoor temperature depends on the ability of a building to maintain a temperature differential between the building and the outside environment. This ability can be influenced in many ways. Improved insulation and different kinds of control systems reduce the transmission of heat from the building to the outside environment. Solar collectors and heat pumps improve utilization of the natural flows of energy in the outside environment. In the following, all measures taken to change a building in this respect are denoted "energy conservation" measures. The existence of various conservation options implies that there is a potential substitutability between energy and capital in the residential heating sector.

The efficiency of a given "energy conservation" measure depends on the size, age, location and quality of the building in which the measure is undertaken. The allocation of resources for energy conservation purposes between different measures and kinds of buildings is therefore a rather complicated matter. Further, it is not obvious whether resources should be allocated to expanding the production of energy or to activities that reduce the consumption of energy.

Our empirical analysis of the Swedish residential heating sector focuses on the following four resource allocation problems:

I The choice between different fuels.

II The allocation of resources among purchases of produced energy and energy conservation equipment, that is, the trade-off between energy and capital in this sector.

III The allocation of resources for energy conservation purposes among different kinds of dwellings.

IV The allocation of resources between energy conservation in the residential heating sector and energy production.

The first three issues can be analyzed by means of the model of the Swedish residential heating system developed in Chapter 7. The fourth issue can be dealt with by linking this model to that of the Swedish electricity and heat production sector underlying the results discussed in the previous chapter.

The optimum choice of fuel and capital intensity in the Swedish residential heating sector is discussed in Section 9.1. A partial analysis of this sector and the energy production sector is made in 9.1.1 and 9.1.2, respectively. Section 9.2 deals with the impact of rising energy prices on the residential demand for energy. Then, in Section 9.3, the sensitivity of the solutions with respect to the interest rate is discussed. Section 9.4 contains an analysis of the optimum allocation of investments between energy production and energy conservaton, and some conclusions are drawn in Section 9.5.

9.1 The Optimum Choice of Fuel and Capital Intensity in the Swedish Residential Heating Sector

This analysis is performed using the present - 1976 - level of prices. This means that the data base of the residential heating system model presented in Chapter 7 has to be adjusted somewhat. All of the cost estimates[1)] presented in the Appendix 3 have been adjusted in accordance

---

1) Expressed in the 1971 prices.

with the relative change in construction cost index between 1971 and 1976. These adjusted cost figures are then kept constant throughout the simulations.

The rate of interest is set equal to 8 % per annum in all of the simulations in this section. Thus, the rate of interest we apply in the residential heating sector, is the same as that used in our analysis of the electricity and heat production sector.

9.1.1 A Partial Analysis of the Residential Heating Sector

When treating the residential heating system model as a separate model, we have to add some exogenous assumptions about secondary energy prices. In the simulations presented here it is assumed that the price of fuel oil is 500 Sw.Cr./m^3, that the price of electricity is 11 öre/kWh, and that the price of hot water is 7.5 öre/kWh. These assumptions are in line with the actual 1976 prices of these kinds of energy. The model simulation based on these price assumptions will be designated "medium price".

First, we investigate what the optimum level of gross energy consumption in the Swedish residential heating sector would be if energy prices remained at the 1976 level and if the customary indoor temperature were unchanged. This can be accomplished by comparing the results of the "medium price" simulation with a hypothetical situation where no changes in the heating technologies of existing dwellings are made, and where heating technologies are allocated to new dwellings in accordance with historical proportions. In other words, we compare the results of the "medium price" simulation with a trend extrapolation of the energy demand for residential heating purposes.

The results of these comparisons[1] are shown in Tables 9:1 and 9:2. The comparisons are confined to two periods, but in these as well as all other simulations presented here the model was solved for five periods. Thus, the terminal condition should not significantly distort the results.

---

1) See Appendix A.4 for a detailed presentation of the results of the simulations discussed in this chapter.

Table 9:1 A comparison of the extrapolated residential gross demand for energy and the optimum residential gross demand for energy at "medium" energy prices in different periods, TWh

	1976-1980		1981-1985	
	Trend	Medium price	Trend	Medium price
Fuel oil[x]	74.9	67.9	73.3	63.8
Electricity	21.9	20.6	22.4	21.0
Hot water	7.7	8.4	7.7	8.7
Total	104.5	96.6	103.3	93.5

x 1 TWh represents approximately 100 000 m^3 fuel oil.

Table 9:2 Market shares[x] for different kinds of heating technologies in 1975 and in the "medium price" simulation, percentage shares

		"Medium price"	
	1975	1976-80	1981-85
Oil	71.3	66.6	63.1
Electric heating	12.8	16.2	18.7
District heating	15.9	17.2	18.2

x Number of dwellings heated by a technology based on a particular fuel in relation to the total number of dwellings.

As for the market shares of the different fuels, we note that these remain fairly stable with respect to the "medium price" assumptions. However, the share of oil is reduced, while technologies based on electric heating and district heating increase their shares. These changes are brought about entirely by the choice of fuel in new dwellings (that is, dwellings built after 1975). Among these, one-family houses are equipped with electric heating, whereas the multi-family dwellings are connected to district heating systems or equipped with oil furnaces. These results indicate that if the oil price increase of 1973 had been known about in advance, oil-based heating technologies would probably be less widespread in Swedish one-family houses. However, current oil prices are not unfavorable enough to induce extensive scrapping of oil furnaces.

Next we turn to the level of energy consumption. Table 9:1 clearly reveals that an optimal adjustment to energy prices in 1976 would markedly reduce residential consumption of energy. The size of this reduction would be about 8 - 10 TWh per annum, which corresponds to about 2 % of Sweden's total energy consumption in 1975.

In the model simulation this reduction in energy demand is brought about by implementing a number of energy conservation measures. The standard of insulation in old one-family houses is improved; heat pumps are installed in new one-family houses and a high standard of insulation is chosen. Control-systems are installed in new multi-family dwellings and no energy conservation measures at all are carried out in old multi-family dwellings.

The annual investment expenditures implied by the "medium price" simulation were 1 340 million Sw.Cr. (current prices) in the first period and 430 million Sw.Cr. in the second. Thus, at present energy prices, large sums of money can be profitably invested in energy conservation.

9.1.2 Energy Production or Energy Conservation

The preceding discussion concerned the profitability of energy conservation given current (1976) market prices for energy. However, there might be divergencies between these market prices and the marginal costs of energy production. If so, the optimum amount of energy conservation investments at price levels in 1976 should perhaps be smaller or larger than indicated above.

This issue can be analyzed by linking the residential heating system model to the electricity and heat production model. Since it takes about ten years, or two model periods, to complete the construction of a nuclear power plant, this analysis is extended to three periods.

The outcome, however, depends on which kind of nuclear power policy is assumed. Thus, the analysis is carried out for each of three strategies for nuclear power policy among those discussed in Chapter 8.[1] We begin with the assumption that policy alternative I is chosen, that is, all kinds of power plants, including nuclear power plants located close to densely-populated areas, are allowed. This means e.g. that nuclear plants can deliver hot water to district heating systems.

The simulation using the combined electricity, heat and residential heating system model under the assumptions that nuclear power policy I is chosen and that primary energy prices remain at the 1976 level,[2] is denoted "linked I". The energy consumption patterns in the "medium price" and the "linked I" simuations are compared in Table 9:3.

The first point to be noted about these results is that the consumption of oil is substantially lower in the "linked I" than in the "medium price" simulation. This is because old one-family houses switch from oil-based heating technologies to district heating. Further, new one-family houses are equipped with electric heating and new multi-family dwellings with district heating. Since conversion losses are fairly high in heating technologies based on oil, the restructuring of the residential heating market leads to a reduction in gross energy consumption and, simultaneously, an increase in net energy consumption.

The annual investment expenditures in the residential heating sector are somewhat higher in the "linked I" than in the "medium price" simulation. In the latter, however, investments were made in energy conservation equipment. In the "linked I, simulation, most investment expenditures are absorbed by the cost of switches from oil-based to other heating technologies and very little is spent on energy conservation.

---

1) Since the development of electricity and heat prices in policy alternatives III and IV differed only in period 2, we confine the analysis in this chapter to policy alternatives I, II and III.

2) See p. 204.

Table 9:3 Optimum gross energy consumption patterns in residential buildings in the case of strategy I

Period	Simulation	Consumption, TWh				Market shares, % x)		
		Oil	Electricity	Hot water	Total	Oil	Electric Heating	Distric Heating
76-80	"Medium price"	67.9	20.6	8.4	96.9	66.6	16.2	17.2
	Linked I	55.5	22.5	14.1	92.1	57.5	18.7	23.8
	Difference	12.4	-1.9	-5.7	4.8	9.1	-2.5	-6.6
81-85	"Medium price"	63.8	21.0	8.7	93.5	63.1	18.7	18.2
	Linked I	50.4	23.6	14.1	88.1	52.7	23.5	23.8
	Difference	13.4	-2.6	-5.4	5.4	10.4	-4.8	-5.6
86-90	"Medium price"	60.3	22.9	9.5	92.6	57.7	23.0	19.4
	Linked I	38.1	22.6	26.7	87.3	35.0	21.5	43.5
	Difference	22.2	0.3	-17.2	5.3	22.7	1.5	-24.1

x See the explanation to Table 9:2.

As a result, the production of electricity and heat in this case has to be increased. Further, as soon as combined nuclear power plants are available, the market share of district heating increases dramatically.

Thus, when nuclear power policy strategy I is assumed, the total consumption of energy is reduced, but the consumption of electricity and, in particular, hot water is increased. As compared to the corresponding simulation in Chapter 8 (p. 211), the profitability of combined nuclear power plants is increased in the "linked I" simulation. In the residential heating system, large sums of money can again be profitably invested. However, these investments are not used for energy conservation purposes, but for switching from oil to other fuels.

These results can be regarded as an indication that hot water market prices in Sweden are too high. However, the results can to some extent be explained by the properties of the model.

As we noted in Chapter 7, the model formulation implies that the consumer price of energy is independent of the quantity consumed. This is a fairly reasonable assumption with regard to fuel oil and low voltage electricity, but it is more questionable in the case of hot water. This is due to the considerable capital expenditure associated with connecting a house to a district heating system, and accordingly, the fixed part of the tariff is large.

Another property of the model which might have affected the results is the implication of the model formulation that all district heating systems can be supplied with hot water from an optimal combination of hot water generating plants and back pressure plants. This is not the case in the real world. Accordingly, the marginal cost of hot water production in many areas is higher than the figure determined by the model.[1)]

The above analysis is repeated in the simulation "linked II", except that in this case nuclear power policy strategy II is assumed. This means that all kinds of power plants are allowed, but nuclear plants may not be located close to densely-populated areas. Consequently, they cannot (profitably) deliver hot water to district heating systems. Table 9:4 shows the results of the "linked II" simulation.

Tables 9:3 and 9:4 indicate that there is no substantial difference between the "linked I" and the "linked II" simulations until the third period. In this period there is more electric heating and considerably less district heating in the latter than in the former simulation.

---

1) As was mentioned in Chapter 8, combined nuclear plants cannot be expected to deliver heat to district heating systems in small towns. To some extent this also applies to combined oil fired plants.

Table 9:4 Optimum gross energy consumption patterns in residential buildings in the case of strategy II

Period	Simulation	Consumption, TWh				Market shares, % x)		
		Oil	Electricity	Hot water	Total	Oil	Electric Heating	District Heating
76-80	"Medium price"	67.9	20.6	8.4	96.9	66.6	16.2	17.2
	Linked II	55.8	22.5	13.9	92.2	57.7	18.7	23.6
	Difference	12.1	-1.9	-5.5	4.7	8.9	-2.5	-6.4
81-85	"Medium price"	63.8	21.0	8.7	43.5	63.1	18.7	18.2
	Linked II	50.2	23.4	14.5	88.1	52.7	22.4	24.9
	Difference	13.6	-2.4	-5.8	5.4	10.4	-3.7	-6.7
86-90	"Medium price"	60.3	22.9	9.5	92.6	57.7	23.0	19.4
	Linked II	45.7	25.8	15.2	86.7	46.1	28.1	25.7
	Difference	14.6	-2.9	-5.7	5.9	11.6	-5.1	-6.3

x See the explanation to Table 9:2.

Table 9:5 shows the results of the simulation "linked III", where it is assumed that nuclear power policy strategy III is chosen. This means that no nuclear power plants in addition to the 13 plants already decided upon are allowed.

In the "linked III" simulation, the residential heating sector develops in approximately the same way as in the "linked I" simulation. One difference is that the profitability of combined oil fired plants is improved in "linked III". This means that the marginal cost of hot water becomes fairly low in this simulation, which explains the increased market share for district heating. Thus, both the pro-nuclear policy strategy "I" and the conservative strategy "III" tend to favor district heating, while strategy "II", the middle-of-the-road strategy, favors electric heating.

Table 9:5 Optimum gross energy consumption patterns in residential buildings in the case of strategy III

Period	Simulation	Consumption, TWh				Market shares, % x)		
		Oil	Electricity	Hot water	Total	Oil	Electric heating	District Heating
76-80	Isolated "Medium price"	67.9	20.6	8.4	96.9	66.6	16.2	17.2
	Linked III	55.9	22.5	13.9	92.3	57.7	18.7	23.6
	Difference	12.0	-1.9	-5.5	4.6	8.9	-2.5	-6.4
81-85	Isolated "Medium price"	63.8	21.0	8.7	93.5	63.1	18.7	18.2
	Linked III	51.2	23.2	14.4	88.7	53.8	21.6	24.6
	Difference	12.6	-2.2	-5.7	4.8	9.3	-2.9	-4.4
86-90	Isolated "Medium price"	60.3	22.9	9.5	92.6	57.7	23.0	19.4
	Linked III	42.9	20.0	26.1	88.9	39.8	17.3	42.9
	Difference	17.4	2.9	-16.6	3.7	17.9	5.7	-23.5

x See the explanation to Table 9:2.

9.2 The Effect of Rising Energy Prices

We now investigate the optimum residential energy consumption patterns in a situation where all energy prices are increasing at the same rate. This enables us to concentrate on the substitutability between energy and capital in the residential heating sector.

In order to deal with this issue, a "high price, 8 %"[1] simulation is carried out using the residential heating system model. Then the results of this simulation are compared with those of the "medium price"

1) The results of a simulation called "high price, 12 %" are discussed in the next section.

simulation. The assumptions behind these simulations differ in one respect only. In the "medium price" simulation energy prices remain constant over time while energy prices are doubled between the first and the third periods[1)] in the "high price, 8 %" simulation.

The main results of this comparison are shown in Tables 9:6 and 9:7.

Table 9:6 Optimum gross energy consumption (TWh) in residential buildings in the "medium price" and "high price, 8 %" simulations

	1976-80			1981-85			1986-90		
	Medium price	High price, 8 %	Differ-ence	Medium price	High price, 8 %	Differ-ence	Medium price	High price, 8 %	Differ-ence
Fuel oil	67.9	66.9	1.0	63.8	50.1	13.7	60.3	45.7	14.6
Electricity	20.6	21.0	-0.4	21.0	19.3	1.7	22.9	21.6	1.3
Hot water	8.4	8.4	0	8.7	4.5	4.2	9.5	4.7	4.8
Total energy	96.9	96.3	0.6	93.5	73.8	19.7	92.6	71.9	20.7

Table 9:7 Optimum market shares of different kinds of heating technologies in the "medium price" and "high price, 8 %" simulations

	1976-80			1981-85			1986-90		
	Medium price	High price, 8 %	Differ-ence	Medium price	High price, 8 %	Differ-ence	Medium price	High price, 8 %	Differ-ence
Oil	66.6	65.2	1.4	63.1	60.9	2.2	57.7	53.9	3.8
Electric heating	16.2	17.6	-1.4	18.7	20.9	-2.2	23.0	26.7	-3.7
District heating	17.2	17.2	0	18.2	18.2	0	19.4	19.4	0

1) Half of the price increase occurs between the first and second periods.

Thus, higher energy prices induce a substantial reduction in energy consumption in the residential sector. This reduction is brought about by a number of measures. One-family houses built before 1975 are equipped with additional insulation and control systems are installed. Control systems are installed in all kinds of multi-family dwellings, while one-family houses built after 1975 are equipped with a high standard of insulation and heat pumps.

When all energy prices rise, heating technologies based on electricity increase their market share at the expense of technologies based on oil. The reason for this is that control systems and heat pumps can easily be used in combination with electric heating.

Table 9:8 shows that the sum of money which can be profitably invested in energy conservation measures is substantially higher in the "high price, 8 %" simulation than in the "medium price" simulation.

Table 9:8 Annual investment expenditures, in millions of 1976 Sw.Cr., implied by the "medium price" and "high price, 8 %" simulations

	1976-80	1981-85	1986-90
"Medium price"	1339	432	827
"High price, 8 %"	1346	4064	975
Difference	-7	-3632	-148

This indicates that energy and capital are close substitutes in the residential heating sector. Further it seems reasonable to assume that this conclusion can be extended to cover all kinds of low temperature heating; from a heating point of view residential buildings do not significantly differ from other buildings.

9.3 The Sensitivity of the Solutions with Respect to Interest Rate Variations

If the demand for investment funds increases, the rate of interest is also likely to rise. As a result a number of previously profitable investment projects will not be carried out. In the residential heating sector this means that some energy conservation measures will not be implemented and perhaps energy conservation measures will not be carried out in all kinds of buildings.

In order to deal with this issue, we repeat the "high price" simulation for a 12 % per annum rate of interest. The results are then compared with those from the "high price, 8 %" simulation.

It turns out that the total demand for energy is greater in the "high price, 12 %" than in the "high price, 8 %" simulation. Thus, investments in energy conservation equipment seem to be fairly interest elastic, which is well in line with the conclusions in the preceding section. This can be seen in Table 9:9.

Table 9:9 Annual investment expenditures, in millions of 1976 Sw.Cr., implied by the "high price, 8 %" and "high price, 12 %" simulations

	1976-80	1981-85	1986-90
"High price, 8 %"	1346	4064	975
"High price, 12 %"	794	1968	1897
Difference	552	2096	-922

When investment funds for energy conservation purposes become more scarce, they are primarily allocated to one-family houses. Further, investment expenditures are allocated to control systems to a lesser extent than in the case of 8 % interest rate. This implies that investment in additional insulation in one-family houses seems to be the most profitable energy conservation measure in the Swedish residential heating sector given the present structure of energy prices.

9.4 Allocation of Investment Resources between Energy Production and Energy Conservation

The formulation of the combined electricity, heat and residential heating system model implies that the supply of capital goods is completely elastic. It also assumes a perfect capital market, where there is, in relative terms, very little borrowing and lending in the energy production and residential heating sectors.

However, we have shown that investment expenditures in these sectors were substantial in most simulations. This tends to render our assumption of a constant interest rate and capital goods prices highly questionable.

We established in the preceding section that an increase in the rate of interest from 8 % to 12 % had a considerable impact on investment activity in the residential heating sector. Total investments were reduced and investment resources were allocated mainly to the one-family houses. We now investigate whether investment resources should primarily be allocated to investments in energy production or to investments in energy conservation when the rate of interest is increased.

We begin by comparing two versions of the "linked I"[1] simulation which differ only with respect to the interest rate assumption. The rate of interest was set equal to 8 % in one version and 12 % in the other. The prices of energy and other resources were set equal to the 1976 level. The results of this comparison are summarized in Tables 9:10 - 9:12.

These three tables indicate that investments in energy production plants are more profitable than investments in residential heating technologies. The increase in the interest rate reduces investments in the residential heating sector to a much larger extent than in the electricity and heat production sector. To some extent these findings are the results of our treatment of heat production mentioned on p. 236.

---

1) See p. 234.

Table 9:10 Optimum gross energy consumption in residential buildings in the "linked I, 8 %" and "linked I, 12 %" simulations, TWh

	1976-80			1981-85			1986-90		
	8 %	12 %	Diff.	8 %	12 %	Diff.	8 %	12 %	Diff.
Fuel oil	55.5	69.0	-13.5	50.4	64.2	-13.8	38.1	52.2	-14.1
Electricity	22.5	22.5	0	23.6	23.2	0.4	22.6	20.1	2.5
Hot water	14.1	8.6	5.5	14.1	9.0	5.1	26.7	21.3	5.4
Total energy	92.1	100.1	-8.0	88.1	96.5	-8.4	87.3	93.7	-6.4

Table 9:11 Optimum market shares of different kinds of heating technologies in the "linked I, 8 %" and "linked I, 12 %" simulations, %

	1976-80			1981-85			1986-90		
	8 %	12 %	Diff.	8 %	12 %	Diff.	8 %	12 %	Diff.
Oil	57.5	64.1	-6.6	52.7	60.2	-7.5	35.0	50.1	-15.1
Electric heating	18.7	18.7	0	23.5	21.6	1.9	21.5	16.9	4.6
District heating	23.8	17.2	6.6	23.8	18.2	5.6	43.5	32.9	10.6

The main difference between the results of the "linked I, 8 % and "linked I, 12 %" simulations is that a higher proportion of the total stock of dwellings remains heated by oil in the 12 % version. Due to the low thermal efficiency of oil-based heating technologies, an increase in the interest rate will be accompanied by a rise in the gross consumption of energy in the residential heating sector. Further, the market share of district heating systems will not be as large as in the low interest case. Consequently the demand for hot water will be lower, as will the need for (capital intensive) combined power plants. Accordingly, total investments in the electricity and heat production sector will also be reduced.

Table 9:12 Average annual investment expenditures in the electricity and heat and the residential heating sectors in the "linked I, 8 %" and "linked I, 12 %" simulations, millions Sw.Cr. in 1976

Simulation	Row	Sector	1976-80	1981-85	1986-90
Linked I, 8 %	1	Electricity and heat	2640	4470	4080
	2	Residential heating	1500	450	1060
	3	Total	4140	4920	5140
Linked I, 12 %	4	Electricity and heat	2640	4200	3630
	5	Residential heating	770	420	1410
	6	Total	3410	4620	5040
Difference (in per cent)	7	$\frac{\text{Row 1 - Row 4}}{\text{Row 1}} \cdot 100$	0 0	6.0	11.0
	8	$\frac{\text{Row 2 - Row 5}}{\text{Row 2}} \cdot 100$	48.5	6.7	-33.0
	9	$\frac{\text{Row 3 - Row 6}}{\text{Row 3}} \cdot 100$	17.6	6.1	2.0

These results are obtained on the assumption that nuclear power policy strategy I is chosen. When the same analysis is carried out in the case of policy III, the outcome in terms of sectoral investment allocations is the same. That is, the choice of nuclear power policy has a great impact on the market shares of different kinds of energy, but a limited impact on the sectoral allocation of investment resources.

9.5 Some Conclusions

After the presentation of some conclusions can be made. The first concerns the effect of the 1973 - 1974 oil price increase on the residential heating sector in Sweden. The comparison between a trend extrapolation of the energy demand for residential heating purposes and the optimal choice of heating technologies at current prices indicated numerous profitable energy conservation options in the Swedish residential heating sector. In another study based on the same model,[1] it was found that the structure of the Swedish residential heating sector is fairly well adapted to pre-1973 oil prices. Thus, it seems as if the oil price increase has brought the sector out of long run equilibrium, and that there is now a potential demand for investment funds and different kinds of energy conservation equipment from the residential heating sector.

The second conslusion concerns the sectoral allocation of investment resources. The simultaneous analysis of the electricity and heat production sector and the residential heating sector indicated that at the present (1976) oil prices - the size of the energy production sector should not be reduced. Rather, it turned out that more investment resources should be allocated to the electricity and heat production sector at current prices. At higher interest rates, increasingly scarce investment funds should, on the basis of a simple cost minimization criterion, be allocated primarily to producing energy and not to conserving it.

However, our simulations were based on the implicit assumption that combined plants, nuclear as well as oil fired, could deliver hot water to all existing district heating systems. As has been pointed out before this is only true for district heating systems in big cities. Thus, it cannot be ruled out that a segmentation of the heat market of the model-economy would have improved the relative profitability of energy conservation measures.

Moreover, even if it is true that investments in energy production is more profitable than investments in energy conservation in residential buildings, this conclusion may not hold for energy conservation investments in other sectors of the economy. It should also be stressed that energy conservation investments also yield returns in terms of reductions in environmental effects etc.

---

1) See Bergman, (5).

The choice of a strategy for nuclear power policy turned out to be important mainly with regard to the relative market shares of different kinds of energy. The allocation of investment resources among the sectors studied, however, was fairly independent of the chosen strategy.

The third conclusion concerns the energy conservation effects of energy policies primarily affecting the prices of energy. The simulations results showed that a 100% increase in all energy prices over a ten-year period induced a substantial reduction in the consumption of energy for residential heating purposes. Further, energy conservation efforts were mainly directed towards one-family houses.

It is well known that people living in multi-family dwellings have very little control over the energy consumption features of their apartments (the degree of insulation, etc.). Further, there is often a very weak relation between the cost and consumption of energy for the residents of multi-family dwellings. Although these problems to some extent also apply to one-family houses, they are comparatively less important. Thus since the results presented here indicate that energy conservation efforts are most economical in one-family houses higher energy prices are in fact likely to provide incentives to energy conservation efforts without significant changes of the institutional arrangements of the residential heating sector.

Nevertheless, it is quite likely that the model simulations overestimate the actual price elasticity of the demand for residential heating energy. Although the owners of one-family houses experience a direct relation between their cost and consumption of energy, they may not respond as predicted by the model. First, not all owners of one-family houses have sufficient knowledge about existing energy conservation methods. Second, they may be unable to finance an investment in energy conservation equipment; in general the prospect of lower costs for residential heating can not be used as security for a loan. Thus energy policies primarily affecting energy prices are likely to be more efficient from an energy conservation point of views if they are supplemented by information to houseowners about existing alternatives and changes in the functioning of the capital market.[1/]

1/ Beginning in 1975 Swedish home-owners can receive "energy conservation loans" on favorable terms, provided certain specified energy conservation measures are carried out.

APPENDIX 4

This appendix lists the choices of heating technology for the different kinds of dwellings in each simulation. By means of Tables A 4:1 - A 4:8, the exact nature of the different heating technologies can be identified.

Table A.4.1. One-family houses built before 1950

Fuel	Heating technology	1975	Medium price			High price, 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	101	92,2	32,2	26,3	18,9	16,8	9,1		97,0	9,1		29,0	20,7	10,2	27,0	18,5	10,2	29,0	20,7	18,9
	105		64,8	72,4	79,7	80,2				8,0	8,9	41,9	46,8	51,6	43,9	49,1	54,0	41,9	46,8	51,6
	106																			
	109						89,6	98,6		81,5	89,8									
	121																			
	125																			
Subtotal		92,2	97,0	98,7	98,6	97,0	98,7	98,6	97,0	98,7	98,6	70,9	67,5	61,8	70,9	67,5	64,2	70,9	67,5	70,5
Electr.	102																			
	111																			
	112																			
	113																			
	117	6,7	1,8	0	0	1,8	0	0	1,8	0	0	7,1	7,9	8,7	7,1	7,9	8,7	7,1	7,9	0
	118																			
	119																			
	120																			
	122																			
	123																			
Subtotal		6,7	1,8	0	0	1,8	0	0	1,8	0	0	7,1	7,9	8,7	7,1	7,9	8,7	7,1	7,9	0
Distr. heating	103	1,1	1,1	1,3	1,4	1,1			1,1	1,3		22,0	24,6	29,5	22,0	24,6	27,1	22,0	24,6	29,5
	114										1,4									
	115																			
	116						1,3	1,4												
	125																			
Subtotal		1,1	1,1	1,3	1,4	1,1	1,3	1,4	1,1	1,3	1,4	22,0	24,6	29,5	22,0	24,6	27,1	22,0	24,6	29,5
Total		100	100	10	100	1[illegible]	100	100	100	100	100	100	.00	100	100	100	100	100	100	100

Table A.4.2. One-family houses built between 1950 and 1975

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	201	70,1				1,0	1,0		70,6			3,7	3,5		3,7	1,0		4,0	3,7	3,8
	205		70,6	70,8	71,5	69,7	1,5	1,5		70,8	1,0	45,8	45,9	46,3	45,8	45,9	46,3	45,8	45,9	46,3
	206																			
	209						68,3	69,0			70,5									
	221																			
	225																			
Subtotal		70,1	70,6	70,8	71,5	70,6	70,8	70,5	70,6	70,8	71,5	49,5	49,4	46,3	49,5	46,9	46,3	49,8	49,6	50,1
Electr.	202	13,6							13,7			13,7	13,7	13,9	13,7	13,7	13,9	13,7	13,7	
	211		13,7	13,7	13,9	13,7														13,9
	212																			
	213						26,2	26,4		23,7	23,9									
	217	13,3	2,7	2,5	1,5	12,7			12,7	1,0		13,4	13,5	7,1	13,4	13,5	13,6	13,4	13,5	3,3
	218		10,0	10,0	10,1					1,5	1,5									
	219																			
	220																			
	222																			
	223																			
Subtotal		26,9	26,4	26,2	25,4	26,4	26,2	26,4	26,4	26,2	25,4	27,1	27,2	20,9	27,1	27,2	27,5	27,1	27,2	17,1
Distr. heating	203	3,0	3,0	3,0	3,0	3,0			3,0	3,0		23,4	23,4	32,7	23,4	25,9	26,2	23,1	23,2	32,7
	214						3,0				3,0									
	215																			
	216							3,0												
	225																			
Subtotal		3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	23,4	23,4	32,7	23,4	25,9	26,2	23,1	23,2	32,7
Total	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.4.3. One-family row-houses built between 1950 and 1975

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	301	29,1				0,3	0,3		29,1			0,3	0,3		0,3	0,3		1,3	1,3	1,3
	305		29,1	29,1	29,2	28,8	0,6	0,6		29,1	1,3	26,3	26,3	26,3	28,8	28,8	28,9	27,8	27,8	27,9
	306																			
	309						28,2	28,3			27,9									
	321																			
	325																			
Subtotal		29,1	29,1	29,1	29,2	29,1	29,1	28,9	29,1	29,1	29,2	26,6	26,6	26,3	29,1	29,1	28,9	29,1	29,1	29,2
Electr.	302	32,3							32,3			32,3	32,3	32,4	32,3	32,3	32,4	32,3	32,3	
	311		32,3	32,3	32,4	32,3				32,3										32,4
	312																			
	313						64,6	64,8			39,4									
	317	32,3	0,9	0,9	0,6	32,3			32,3	10,4		32,3	32,3	10,5	32,3	32,3	32,4	32,3	32,3	7,6
	318		31,3	31,3	31,4					0,6	0,6									
	319																			
	320																			
	322																			
	323																			
Subtotal		64,6	64,6	64,6	64,4	64,6	64,6	64,8	64,6	43,4	40,0	64,6	64,6	42,9	64,6	64,6	64,8	64,6	64,6	40,0
Distr. heating	303	6,3	6,3	6,3	6,3	6,3			6,3	27,5		8,9	8,9	30,8	6,3	6,3	6,3	6,3	6,3	30,8
	314						6,3				30,8									
	315																			
	316							6,3												
	325																			
Subtotal		6,3	6,3	6,3	6,3	6,3	6,3	6,3	6,3	27,5	30,8	8,9	8,9	30,8	6,3	6,3	6,3	6,3	6,3	30,8
Total		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.4.4. Multi-family dwellings built before 1950

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	401	89,7	89,2	88,2	87,1	89,2	28,7	21,8	89,2	88,2	87,1	89,2	88,2	49,6	89,2	88,2	87,1	89,2	88,2	53,3
	405																			
	406						59,5	65,2												
	409																			
	421																			
	425																			
Subtotal		89,7	89,2	88,2	87,1	89,2	88,2	87,1	89,2	88,2	87,1	89,2	88,2	49,6	89,2	88,2	87,1	89,2	88,2	53,3
Electr.	402	3,0							3,1			3,1	3,4	3,7	3,1	3,4	3,7	3,1	3,4	3,7
	411																			
	412		3,1	3,4	3,7	3,1				3,4										
	413						3,4	3,7			3,7									
	417																			
	418																			
	419																			
	420																			
	422																			
	423																			
Subtotal		3,0	3,1	3,4	3,7	3,1	3,4	3,7	3,1	3,4	3,7	3,1	3,4	3,7	3,1	3,4	3,7	3,1	3,4	3,7
Distr. heating	403	7,3	7,7	8,4	9,2	7,7			7,7	8,4		7,7	8,4	46,7	7,7	8,4	9,2	7,7	8,4	42,9
	414																			
	415						8,4				9,2									
	416							9,2												
	425																			
Subtotal		7,3	7,7	8,4	9,2	7,7	8,4	9,2	7,7	8,4	9,2	7,7	8,4	46,7	7,7	8,4	9,2	7,7	8,4	42,9
Total		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.4.5. Multi-family dwellings built between 1950 and 1975

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	501	58,2	57,2	55,9	54,7	57,2	6,8	4,3	57,2	55,9	54,7	57,2	55,9	38,1	57,2	55,9	54,7	57,2	55,9	38,1
	505																			
	506						49,1	50,4												
	509																			
	521																			
Subtotal		58,2	57,2	55,9	54,7	57,2	55,9	54,7	57,2	55,9	54,7	57,2	55,9	38,1	57,2	55,9	54,7	57,2	55,9	38,1
Electr.	502	3,8							3,9			3,9	4,0	4,1	3,9	4,0	4,1	3,9	4,0	
	511																			
	512		3,9	4,0	4,1	3,9				4,0										4,1
	513						4,0	4,1			4,1									
	517																			
	518																			
	519																			
	520																			
	522																			
	523																			
Subtotal		3,8	3,9	4,0	4,1	3,9	4,0	4,1	3,9	4,0	4,1	3,9	4,0	4,1	3,9	4,0	4,1	3,9	4,0	4,1
Distr. heating	503	38,0	38,9	40,1	41,2	38,9			38,9	40,1		38,9	40,1	57,8	38,9	40,1	41,2	38,9	40,1	57,8
	514																			
	515										41,2									
	516																			
	525						40,1	41,2												
Subtotal		38,0	38,9	40,1	41,2	38,9	40,1	41,2	38,9	40,1	41,2	38,9	40,1	57,8	38,9	40,1	41,2	38,9	40,1	57,8
Total		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.4.6. One-family houses built after 1975

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	601																			
	606																			
	607																			
	608																			
Subtotal			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electr.	602																			
	611																			
	612																			
	613																			
	615																			
	616																			
	617																			
	622																			
	623																			
	625		100	100	100	100	100	100	100	100	100	100	100	68,8	100	100	100	100	100	68,8
Subtotal			100	100	100	100	100	100	100	100	100	100	100	68,8	100	100	100	100	100	68,8
Distr. heating	605											0	0	31,2				0	0	31,2
	618																			
	619																			
	620																			
	624																			
Subtotal			0	0	0	0	0	0	0	0	0	0	0	31,2	0	0	0	0	0	31,2
Total			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.4.7. One-family row-houses built after 1975

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	701																			
	706																			
	707																			
	708																			
	721																			
Subtotal			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electr.	702																			
	711																			
	712																			
	713																			
	715																			
	716																			
	717																			
	722																			
	723																			
	725		100	100	100	100	100	100	100	100	100	100	100	68,8	100	100	100	100	100	68,8
Subtotal			100	100	100	100	100	100	100	100	100	100	100	68,8	100	100	100	100	100	68,8
Distr. heating	705											0	0	31,2						
	718																			
	719																			
	720																			
	724																	0	0	31,2
Subtotal			0	0	0	0	0	0	0	0	0	0	0	31,2	0	0	0	0	0	31,2
Total			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.4.8. Multi-family dwellings built after 1975

Fuel	Heating technology	1975	Medium price			High price 8 %			High price 12 %			Linked I			Linked II			Linked III		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Oil	801																			
	806																			
	807																			
	808																			
	821		38,5	40,4	41,0				38,5	40,4	41,0							0	15,2	25,9
Subtotal			38,5	40,4	41,0	0	0	0	38,5	40,4	41,0	0	0	0	0	0	0	0	15,2	25,9
Electr.	802																			
	810																			
	812																			
	813					38,5	40,4	41,0												
	814																			
	815																			
	816																			
	817																			
	822																			
	823											38,5	59,6	41,0	38,5	40,4	41,0	38,5	25,3	15,1
Subtotal			0	0	0	38,5	40,4	41,0	0	0	0	38,5	59,6	41,0	38,5	40,4	41,0	38,5	25,3	15,1
Distr. heating	805																		19,2	34,9
	818																			
	819		61,5	59,6	59,0	61,5	59,6	59,0	61,5	59,6	59,0	61,5	40,4	24,1	61,5	59,6	59,0	61,5	40,4	24,1
	820																			
	825																			
Subtotal			61,5	59,6	59,0	61,5	59,6	59,0	61,5	59,6	59,0	61,5	40,4	24,1	61,5	59,6	59,0	61,5	59,6	59,0
Total			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

10. OIL PRICES, ENERGY POLICY AND THE DERIVED DEMAND FOR ENERGY

The substitutability between different kinds of primary energy and primary energy and capital was analyzed in Chapter 8. The preceding chapter dealt with the substitutability between different kinds of secondary energy and secondary energy and capital. We now turn our attention to a third important substitution process, that between different final goods and services. These substitutions are important because the composition of final demand affects the structure of the production system and thus, since production sectors are not equally energy intensive, the demand for energy.

The analysis of the postwar growth of Sweden's energy consumption (Chapter 2) showed that a substantial part of the increased energy intensity of Sweden's GNP could be attributed to changes in the composition of the final demand for goods and services. We did not find any evidence that the observed development could be attributed to declining, energy prices (in real terms). Or, in other words, energy prices had been so low that factors other than energy prices determined the composition of final demand.

However, after the oil crisis of 1973 - 1974, the level of oil prices has become much higher than during the period we analyzed.[1)] Consequently, the share of energy costs in total production costs is higher than before the oil crisis. This means that commodity prices now are more sensitive to energy price changes than they were prior to 1973. Thus, it cannot be ruled out that variations around the present energy price level will affect commodity prices and the composition of final demand to the extent that the derived demand for energy will be substantially affected. At least it seems worthwhile to analyse these aspects, which is the purpose of this chapter.

---

1) Owing to the oil price increase in 1973 - 1974, the relation between oil prices and the consumer price index reached the same level as in 19

Thus, the purpose of this chapter is to study the part of the overall elasticity of energy demand that can be attributed to changes of the composition of final demand for goods and services. The methodology that has been applied is briefly presented in Section 10.1. The basic assumptions regarding the development of the Swedish economy are presented in Section 10.2. In Section 10.3 the estimated elasticities of commodity prices with respect to energy prices are presented, while Section 10.4 deals with the changes in non-energy commodity demand resulting from the estimated changes in commodity prices. Then, in Section 10.5, the flexibility of the derived demand for energy is estimated. The relation between, on the one hand, international oil prices and domestic energy taxes, and, on the other hand, domestic energy prices is dealt with in Section 10.6. In Section 10.7 we again discuss the impact of the different nuclear power policy alternatives. This time the analysis is carried out against the background of some simulations with the complete supply model. In Section 10.8, finally, some concluding remarks are made.

10.1 Methodology

When we postulate that all input-output coefficients in the production system are constant, we can derive a fairly simple expression for the elasticity of the economy's demand for energy. In order to simplify the derivation further, we assume that there is no joint production and that there are n commodities and n sectors of production.

Let E be the economy's demand for energy, E_j the demand for energy per period by sector j, C_j the net output per period in sector j and h_j [1/] the energy input per unit of net output in sector j. It then holds that

$$E = \sum_j E_j = \sum_j h_j C_j \qquad [1]$$

1/ See note 1) on next page 258.

Further, let P_E be the price of energy and P_j the price of the output produced by sector j. Using these symbols, we can define the price elasticity of energy demand, η_E, in the following way:

$$\eta_E = \frac{dE}{dP_E} \cdot \frac{P_E}{E} ; \qquad [2]$$

The variables P_E and E can easily be obtained and dP_E is exogenous. On the basis of (1) dE can be written

$$dE = \sum_j h_j \cdot dC_j \qquad [3]$$

We postulate that the demand for commodity j is determined by the prices of all commodities and the level of nominal income.[2] Thus, in equilibrium $C_j = C_j(P_1, \ldots , P_n, m)$ where m is the level of nominal income. Accordingly the change in equilibrium output of commodity j, resulting from a change in the price of energy, becomes:

---

1) By "net output", C_j, is meant that part of gross output, X_j that is delivered to final uses. The difference between gross output and net output, accordingly, is used as input in the production system. Thus, if a_{ij} denote the input of commodity i per produced unit of commodity j, it holds that

$$X_i = \sum_j a_{ij} X_j + C_i \ ; \qquad (1)$$

Further, if we let e_i denote the input of energy per produced unit of commodity i, it holds that

$$E = \sum_i e_i X_i \ ; \qquad (2)$$

Using obvious matrix notations we can define the coefficients h_j by solving (1) and substitute the solution in (2). We then get

$$E = e(1-a)^{-1} C \equiv h \cdot C$$

where h is the vector of energy input coefficients per unit of net output in the production sectors.

2) These are the same assumptions as those underlying the demand model presented in Chapter 4.

$$dC_j = \sum_i \frac{\partial C_j}{\partial P_i} \cdot \frac{\partial P_i}{\partial P_E} \, dP_E \; ; \qquad [4]$$

Next we let the symbol η_{ji} denote the elasticity of the demand for commodity j with respect to the price of commodity i, while the symbol ε_{iE} denotes the elasticity of the price of commodity i with respect to the price of energy. Using these symbols we can rewrite [4] in the following way:

$$dC_j = \sum_i \left[\left(\frac{\partial C_j}{\partial P_i} \cdot \frac{P_i}{C_j} \right) \frac{C_j}{P_i} \right] \cdot \left[\left(\frac{\partial P_i}{\partial P_E} \cdot \frac{P_E}{P_i} \right) \frac{P_i}{P_E} \right] dP_E =$$

$$= \sum_i \frac{C_j}{P_E} \cdot \eta_{ji} \cdot \varepsilon_{iE} \cdot dP_E \; ; \qquad [4']$$

Observe that [4'] can be written

$$\frac{dC_j}{C_j} = \sum_i \eta_{ji} \cdot \varepsilon_{iE} \cdot \frac{dP_E}{P_E} \; ; \qquad [4'']$$

Substitution of [4'] in [3] yields

$$dE = \sum_i \sum_j \frac{h_j C_j}{P_E} \cdot \eta_{ji} \cdot \varepsilon_{iE} \cdot dP_E = \sum_i \sum_j \frac{E_j}{P_E} \cdot \eta_{ji} \cdot \varepsilon_{iE} \cdot dP_E \; ; \qquad [3']$$

and substitution of [3'] in [2] yields

$$\eta_E = \frac{P_E}{dP_E \cdot E} \sum_i \sum_j \frac{E_j}{P_E} \cdot \eta_{ji} \cdot \varepsilon_{iE} \cdot dP_E =$$

$$= \sum_i \sum_j \frac{E_j}{E} \cdot \eta_{ji} \cdot \varepsilon_{iE} \, ^{1)} \; ; \qquad [2']$$

---

1) This formula implies that energy price increases are completely shifted over to households and that the wage rate is independent of the level of commodity prices.

The formula [2'] indicates that in addition to the assumption about fixed input-output coefficients, a number of additional assumptions are required befor η_E can be estimated. To begin with, the quotient E_j/E is a function of the structure of the production system, that is, a function of the composition of final demand. Further, coefficients η_{ji} and ε_{iE} are functions of the price system according to which η_E is calculated. This means that our calculations have to be based on explicit assumptions about the size and structure of the final demand for goods and services and the prevailing price system. Moreover, we want to make the elasticity calculations for a future point in time. This means that the calculations have to be based on a prediction of the development of the Swedish economy. In the following the prediction used in this study is denoted the "reference path".

The empirical version of the household demand model in Chapter 4 and the "non-energy commodity supply model" in Chapter 5 have been used in the application of the expression for η_E derived above. This means that we did not estimate each of the components of [2'] separately. Instead the calculations involve the following steps:

I First a reference development path for non-energy commodity prices and the consumption of energy is calculated on the basis of explicit assumptions about the final demand for non-energy commodities, labor productivity, wages and the prices, including taxes, of different kinds of secondary energy. Except for the assumptions about energy prices, all of these assumptions are based on a recent forecast by the Ministry of Finance. Thus, by using this forecast as a reference path for the development of the Swedish economy, we get estimates of the variables E, E_j, C_j and P_i by means of the non-energy commodity supply model presented in Chapter 5. The assumptions underlying the reference path are presented in Section 10.2.

II Then, by using the same model as in I above and making parametric variations in the prices of energy, the elasticity of non-energy commodity prices with respect to energy prices is calculated. In other words, by making explicit assumptions about dP_E,[1] we cal-

---

1) In the actual calculations substantial changes in energy prices were assumed. Accordingly the symbol "Δ" should have been used instead of "d".

culate the products ε_{iE} dP_E in [4'] above. These calculations are dealt with in Section 10.3.

III Next the change of the private demand for different kinds of consumer goods and services resulting from the estimated changes of the prices of these goods and services is calculated by means of the private demand model presented in Chapter 4. In terms of [4'] we use the estimated products $\varepsilon_{iE} \cdot dP_E$ to calculate dC_j (and $\frac{dC_j}{C_j}$) for each j. In the following the vector of calculated changes of final demand is denoted dC.

IV In the fourth step the vector ΔC is added to the final demand constraints of the non-energy commodity supply model. By solving the model, the estimated change of the final demand for non-energy commodities is transformed into an estimate of the change of the demand for energy. That is, by making a parametric change of the prices of energy, dP_E, and using the system of models, we get an estimate of dE, which can be inserted in [2].

This sequence of calculations enables us to estimate the sensitivity of energy demand, along a reference growth path for the Swedish economy, which is the result of substitutions between different goods and services in the household sector. Since the formulation of the model implies that the wage rate is exogenously determined, it is not suited to deal with employment effects of energy price changes. For this reason, employment effects are not discussed in this study.

10.2 The Reference Path

The reference path used as a basis for the calculations in this chapter was obtained from the long-term projections recently published by the Ministry of Finance; see SOU (67). The time horizon of these projections is the year 2000. The period 1976 - 2000 is divided into three subperiods, 1976 - 1980, 1981 - 1990 and 1991 - 2000. One forecasting methodology is used for the first subperiod and another for the remaining two subperiods. These projections are expressed in terms of annual growth rates which are constant within each subperiod.

The Ministry of Finance has published four conditional predictions denoted I, II, III and IV for the period 1976 - 1980. These conditional predictions differ with respect to assumptions about a) the allocation between the public and private sectors and b) the length of the working week.

Six conditional predictions, A - F, for the period 1981 - 2000 have been published. These predictions differ with respect to the rate of aggregate capital formation, input-output coefficients of the production sectors, terms of trade for the Swedish economy and the implementation of energy rationing. All six projections are based on the assumption that the actual development of the Swedish economy during the period 1976 - 1980 will concur with prediction II.[1] This means that we can choose from among six consistent projections for the entire period 1976 - 2000.

However, among the six alternatives, the one denoted A was considered to be the main alternative. For this reason, alternative A has been chosen as the reference path for the calculations presented later on in this chapter.

In projection A the rate of growth of the economy's stock of capital is assumed to be 3 % per annum during the entire period 1981 - 2000. The input-output coefficients of the production system are assumed to be constant and equal to those predicted for 1980.[2] The composition of exports prevailing in 1980 is assumed to remain unchanged.[3] No long-term improvement or deterioration in Sweden's terms of trade is assumed. Finally, it is assumed that energy rationing will not occur.

---

1) This implies that the length of the working week is assumed to remain at 40 hours and that the volume of total private consumption grows by 2 % per annum.

2) This means that prediction A is based on the same input-output figures as those in the data base of the non-energy commodity supply model. See Appendix 1.

3) In the model used for these projections the import share of the supply of each commodity is assumed to be constant.

A consistent development path for the Swedish economy between 1976 and 2000 has been determined on the basis of these assumptions. The main characteristics of this development path are shown in Table 10:1. The details are included in the main report of the Ministry of Finance, see SOU (63) and SOU (66).

Table 10:1. Main characteristics of the growth of the Swedish economy along the reference path; annual percentage growth rates of real[x] magnitudes

Period	Private consumption	Public consumption	Exports	Imports	Labor productivity
1976-1980	2.0	2.9	6.7[1)]	5.3	3.1
1981-1990	2.3	3.0	3.3	3.3	3.5
1991-2000	2.5	3.0	3.0	2.7	3.3

x Measured in 1968 prices.

In addition to the data base of the non-energy supply model (see Appendix 1) the estimates by the Ministry of Finance is the main data source behind the results presented in this chapter. For each of the five-year periods between 1975 and 2000 the assumptions about the following variables are based on the forecasts made by the Ministry of Finance:

I The sum of privat, public and net foreign demand for the output from each of the domestic production sectors.[2)]

---

1) The high rate of growth of exports between 1976 and 1980 reflects the basic assumption that Sweden's current trade deficit should be eliminated by 1980.

2) Despite the great similarity of assumptions in the projections of the Ministry of Finance and our reference path simulation, both simulations do not yield identical results in terms of production and employment. There are two reasons for this. First, the energy sector is included in the models employed by the Ministry of Finance but not in the non-energy commodity supply model. Second, investments are determined in different ways in the two simulations. In the model used in this study, investments are determined by means of constant capital-output ratios. In the projections of the Ministry of Finance, investments are exogenously determined for the period 1976 - 1980, and determined by means of neoclassical production functions for the period 1981 - 2000.

II The input of energy per unit of gross output in each of the production sectors.

On the basis of these assumptions, the demand for secondary energy along the reference path can be determined by means of the non-energy commodity supply model.[1] The results can be seen in Table 10:2.

Table 10.2. The development of energy demand along the reference path; average annual percentage growth rates

Kind of energy	1978-1983	1983-1988	1988-1993	1993-1998
Electricity	3.2	2.7	3.4	2.7
Gasoline	2.3	2.3	2.2	4.1
Light fuel oil	1.6	1.7	2.0	2.7
Heavy fuel oil	2.7	2.4	3.3	2.4

One remark should be made about Table 10:2. First, all input-output coefficients, including energy input coefficients, are kept constant along the entire reference path, this applies to the energy demanded for residential heating and lighting as well.[1] Thus, the results presented in Table 10:2 should not be interpreted as a long-term prediction of the demand for secondary energy in Sweden. For that purpose the impact of expected technical change would have to be incorporated into the calculations. Nevertheless, the figures in Table 10:2 are used as a reference path for the consumption of energy.

The last feature of the reference path we have to calculate is the development of prices of non-energy commodities. To do this by means of our model, we need assumptions about the wage rate, the rate of interest, the prices of secondary energy and the level of indirect taxes and subsidies.

1/ This part of total energy demand can be determined in the residential heating services supply model.

Starting from the 1975 real wage level, the wage rate grows at the same relative rate as the average productivity of labor along the reference path. The rate of interest is set equal to 8%. The real prices of secondary energy prevailing in 1976 are assumed to remain unchanged. Predictions regarding indirect taxes and subsidies were obtained from the Ministry of Finance.

Even though most assumptions about exogenous variables are based on the above mentioned Ministry of Finance predictions, the commodity prices determined by our model differ from those determined by the model used by the ministry. The main reason for this difference is that in the latter model both profit and wage rates differ between various sectors of the economy.1/

10.3 The Elasticity of Commodity Prices with respect to Energy Prices

10.3.1 A Methodological Note

The non-energy commodity supply model used for the calculations presented in this chapter can be regarded as a multi-period input-output model where energy is a primary input. In a one-period input-output model there is a very simple relation between the prices of primary inputs and the prices of final outputs.2/ When energy is treated as a primary input the elasticity of the price commodity j with respect to the price of energy, ε_{Ej}, is equal to the share of the total cost of energy in the initial price (or production cost) of commodity j. Further, it can easily be shown (and is in fact obvious) that ε_{Ej} is non-linear in the price of energy, P_E, and that

$$\text{I} \qquad \frac{d\,\varepsilon_{Ej}}{d\,P_E} > 0$$

$$\text{II} \qquad \lim_{P_E \to \infty} \varepsilon_{Ej} = 1.$$

This description of the relation between energy prices and commodity prices is also valid for the non-energy commodity supply model in Chapter 5.

1/ See Restad (47), Chapter 4.

2/ See for instance Bergman (6).

The figures presented in the next sub-section are obtained by means of the formula

$$\varepsilon_{Ej} = \frac{\frac{P_j^*}{\overline{P}_j} - 1}{\frac{P_E^*}{\overline{P}_E} - 1}$$

where $\overline{P}_j$ is the reference path price of commodity j and $\overline{P}_E$ the reference path price of energy, whereas P_j^* and P_E^* are the corresponding magnitudes obtained in a simulation where, <u>ceteris paribus</u>, $\overline{P}_E \neq P_E^*$.

10.3.2 The Estimated Elasticities

In order to estimate the elasticity of commodity prices with respect to energy prices, two kinds of simulations with the non-energy commodity supply model have been carried out. First, the level of domestic electricity prices was doubled in relation to the reference path prices. Next, electricity prices were kept at the reference path level but the domestic prices of all kinds of refined petroleum products[1/] were doubled. All the results presented in this chapter refer to the second model period, that is, the period 1981 - 1985.

The prices of imported non-energy commodities were kept constant throughout. Thus, the analysis is confined to the effect of variations in domestic prices of secondary energy. The relation between international and Swedish energy prices and between international energy prices and Swedish non-energy import prices will be discussed later on in this chapter.

1/ Gasoline, light fuel oil and heavy fuel oil.

The results from the simulations are shown in Table 10:3. In spite of the large increase in energy prices, the elasticities are calculated as point elasticities. This tends to bias the estimates upwards. It should also be noted that heating technology in residential dwellings remained unchanged in the calculations performed for Table 10:3.

Table 10:3. The estimated elasticity of consumer goods prices with respect to energy prices 1981 - 1985

Commodity	i	Elasticity with respect to electricity prices	Elasticity with respect to petroleum products prices	Elasticity with respect to petroleum products and electricity prices 1/
Food	1	0.012	0.044	0.056
Beverages and tobacco	2	0.004	0.016	0.020
Clothing	3	0.016	0.046	0.062
Cultural goods and services	4	0.014	0.035	0.049
Hygiene	5	0.032	0.093	0.125
Private transportation	6	0.012	0.294	0.306
Leisure activities	7	0.018	0.096	0.114
Furniture	8	0.032	0.071	0.103
Other goods and services	9	0.012	0.039	0.051
Housing services	10	0.044	0.181	0.225
The general level of prices[x]		0.014	0.045	0.059

x A weighted average based on the composition of the private consumption 1981 - 1985 along the reference path.

We start the analysis of these results by discussing the impact of higher prices of electricity. It is clear from the Table 10:3 that variations in electricity prices are likely to have a non-neglible impact on the prices of only a few commodities.

1/ Since the model is entirely linear, these figures can be obtained by adding the other two columns.

Not surprisingly the most important impact is shown to be on housing services. It may be that this figure represents an underestimate of the impact of electricity price increases on the cost of housing services. This is because the input-output coefficients underlying the calculations were determined by means of a trend extrapolation procedure based on input-output statistics from 1968.[1/] However, the share of one-family houses in total residential construction has increased during the past few years and since nowadays electric heating is installed in most new one-family houses, the trend is likely to underestimate the present electricity input coefficient in the production of housing services.

The high level of aggregation tends to even out the differences between the commodity groups. Two commodities are worth mentioning: hygiene and furniture. The prices of both of these commodities are not quite insensitive to electricity price variations. However, the calculated elasticities for these two commodities are likely to be biased upwards. This is because consumer commodity hygiene is to a large extent based on chemicals which constitute an output from the chemicals and plastics sector. Plastics are energy intensive whereas chemicals are not. Thus, the aggregation of these two kinds of products into one tends to bias out estimate of the sensitivity of hygiene prices with respect to the price of electricity.

A parallell case is that furniture is based on wood, which is produced by the wood and paper sector. In this aggregated sector paper is the energy intensive product whereas wood is not.

In spite of the uncertainties necessarily connected with this kind of estimations, one conclusion is very clear from Table 10:3. Within vast limits, variations in electricity prices will - with one exception, housing - not substantially affect either the level or the structure of Swedish consumer goods prices.

1/ See Åberg (54)

However, the same conclusion cannot be drawn about the impact of petroleum products price increases. This can be seen in the second column in Table 10:3. The estimated elasticities range from 0.016 to 0.294 and most elasticities are higher than 0.035.

As expected, increases in petroleum products prices have the greatest impact on private transports and housing services.[1/] The figure for the latter commodity should be somewhat reduced as a consequence of the remark made above about the increased share of electric heating. Further, for the reason discussed above, the figures for hygiene and furniture should also be reduced somewhat.

The consumer goods discussed so far are all linear combinations of the outputs from a number of production sectors in the model. The elasticity of the output prices of these sectors with respect to energy prices is shown in Table 10:4.[2/]

The estimated elasticities are highest for those sectors where petroleum products are used not only as fuel but also for other purposes (chemicals and plastics, non-metallic minerals). Among the rest of the sectors the impact of higher energy prices is greatest in the main export sectors, that is mining and quarrying, wood and paper, and iron and steel. This indicates that in the short run, Swedish energy prices cannot be raised much more rapidly than foreign energy prices without having consequences for the country's external balance.

The general impression from Table 10:4 is that the output prices of production sectors are not very sensitive (less than 50 - 75 %) to in-

---

1) When interpreting these results it should be noted that no distinction is made between the use of oil as an energy commodity and the use of oil as an "ordinary" input.

2) To avoid confusion in the comparison of Tables 10:3 and 10:4 the relation between the sector "letting of dwellings" and the consumer good "housing services" should be commented on. The "letting of dwellings" sector produces residential dwellings where heat and light are provided only in the areas used jointly by all residents (stairways, etc.). The consumer good "housing services" contains inputs from the "letting of dwellings" sector as well as the energy sector.

Table 10:4. The estimated elasticity of sector output prices with respect to energy prices 1981 - 1985

Sector	i	Elasticity with respect to electricity prices	Elasticity with respect to petroleum products prices	Elasticity with respect to petroleum products and electricity prices
Forestry and logging	11	0.010	0.053	0.063
Mining and quarrying	12	0.052	0.070	0.122
Import-competing foods	13	0.014	0.048	0.062
Beverages and tobacco	14	0.004	0.017	0.021
Textiles and leather	15	0.014	0.047	0.061
Wood and paper	16	0.047	0.083	0.130
Printing and publishing	17	0.015	0.040	0.055
Rubber products	18	0.024	0.062	0.086
Chemicals and plastics	19	0.053	0.158	0.211
Iron and steel	20	0.071	0.069	0.140
Machinery and equipment	21	0.022	0.046	0.068
Shipbuilding	22	0.026	0.044	0.070
Miscellaneous industries	23	0.020	0.031	0.051
Agriculture and fishing	24	0.009	0.042	0.051
Sheltered food	25	0.012	0.045	0.057
Non-metallic minerals	26	0.033	0.119	0.152
Construction	27	0.021	0.060	0.081
Wholesale and retail trade	28	0.012	0.051	0.063
Transport	29	0.013	0.084	0.097
Letting of dwellings	30	0.006	0.029	0.035
Miscellaneous services	31	0.012	0.030	0.042

creases in electricity prices. On the other hand petroleum products price increases of the same order of magnitude are likely to have a noticeable effect on equilibrium prices.

This last conclusion contradicts the results of earlier studies by this author. Table 10:5 contains a comparison of the results of this study and those obtained in a study by Bergman & Bergström (1974). The latter study was carried out using input-output statistics for 1971. The main difference between these two studies is that the impact of oil price increases was estimated in terms of the pre-1973 level in the earlier study, while the effect of increases from the considerably higher oil price level in 1976 is estimated in the present study.

Table 10:5. The estimated elasticity of sector output prices with respect to petroleum products prices before and after the "oil crisis"; selected sectors

This study	Elasticity	Bergman & Bergström[x]	Elasticity
Wood and paper	0.083	Pulp	0.029
		Paper	0.031
Iron and steel	0.069	Iron and steel	0.023
Transport	0.084	Transport	0.061

x Bergman & Bergström, Energipolitik och energianvändning, EFI, Stockholm 1974.

Although the sector definitions do not exactly coincide, it is quite clear that the elasticity of commodity prices with respect to petroleum products prices rose markedly due to the oil price increase of 1973 - 1974.[1)]

1) One methodological difference between the studies, which works in the same direction as the oil price increase, is that the effect brought about through more expensive capital goods is included in this study but not in the Bergman & Bergström study. However, since neither machinery and equipment nor construction (the major capital goods) are very energy intensive, this methodological difference should not affect the main conclusion.

10.4 The Elasticity of Consumer Commodity Demand with respect to Energy Prices

The impact of energy price increases discussed in the preceding section can now be transformed into changes in the demand for various consumer goods. This is accomplished by means of the system of demand equations described in Chapter 4. Some problems related to the application of the demand model are discussed in subsection 10.4.1 and the results are presented in 10.4.2.

10.4.1 The Application of the Demand Model

Some theoretical problems connected with integrating the supply and demand models into a single model were touched upon in Chapter 4. However, in the practical work with the non-energy commodity supply model it turned out that the calculated supply prices of non-energy commodities are largely independent of the composition of the final demand. This result is a consequence of the linearity and lack of substitutability in the non-energy commodity supply model, which means that it can fairly easily be integrated with the household demand model. In this subsection it is described how that integration was carried out.

The Ministry of Finance forecasts, the basis of our reference path, contain predictions of the growth of private consumer demand. However, these predictions are not expressed in terms of consumer goods and services (commodities 1 through 10 in our study[1/]) but in terms of production sector outputs (commodities 11 through 32). Thus, in the first step we have to transform the reference path into a development path for the consumption of commodities 1 through 10.

This can be done in two ways. One is to use the reference path prices of consumer goods determined by the non-energy commodity supply model along with the demand model, and thereby obtain a projection of the future demand for consumer goods and services.

1/ See the commodity list on p. 118.

The other is to transform the reference path projection of household consumption of production sector outputs into a projection of household consumption of consumer goods and services. This can be done by means of the matrix where each column defines a consumer commodity group as a linear combination of various production sector outputs.[1/]

Both approaches were tried and it turned out that there were substantial differences between the two projections. There are three plausible explanations, not mutually exclusive, for this result:

i) The differences between the commodity prices determined by means of the model used in this study and those determined by the model used by the Ministry of Finance.

ii) The matrix that transforms consumer goods into production sector outputs may have important deficiencies.

iii) The demand model used by the Ministry of Finance[2/] may give significantly different results than the demand model used in this study.

On <u>à priori</u> grounds, there is no possibility of determining the relative importance of these explanations. However, due to the simple structure of the non-energy commodity supply model the impact, in terms of energy consumption, of a given change in the final demand is independent of the initial size and structure of final demand. Thus, since our analysis is confined to the changes in the demand for energy we do not have to make any judgement about the relative merits of the two demand forecasts discussed above. In any case, the first of the above described approaches was adopted.

The application of the demand model was carried out in the following way: The prices and demanded quantities of consumer goods and services for 1973 were used as the points of departure.[3/] The calculated prices and total household expenditures (less expenditures on housing) along the reference path served to

---

1/ That is the matrix presented in Table A.1.1 in Appendix nr 1.

2/ The demand model used by the Ministry of Finance for the period 1981-2000 is of the same type as Johansen's growth model for Norway; see Johansen (30). A very simple demand model was used for the period 1976-80.

3/ Since the demand model determines the changes in private consumer demand initial values for prices, total expenditures and the shares of total expenditures spent on the different commodities are needed.

determine a sequence of vectors, C(t), representing the demand for consumer goods and services in different time periods. This procedure was then repeated for each of the three cases where electricity prices, petroleum products prices and both electricity and petroleum products prices, respectively, were doubled. By subtracting each of the last three vectors from the reference path vector, three "difference vectors", $\Delta C(t)$, were determined.

The calculated $\Delta C_i(t)$ were then transformed into an estimate of the elasticity of the demand for consumer goods with respect to energy prices. The calculated $\Delta C_i(t)$ were then added to the demand constraints of the non-energy commodity supply model and were thus transformed into an estimate of the elasticity of energy demand with respect to energy prices. The results of these calculations are presented in subsection 10.4.2 and the estimates in Section 10.5.

The elasticity calculations refer to period 2 in the model (1981 - 1985). But this does not mean that the results should be interpreted as a conditional prediction for that period. Rather, the figures should be interpreted as estimates of the long-run elasticities in an economy with Leontief technology and conventional demand equations. Since our estimates of prices and consumed quantities of consumer goods and services along the reference path are very uncertain, these elasticity calculations are likely to yield biased results. Moreover we do not know the direction of the bias. However, since many different errors are aggregated into one single elasticity measure for the price sensitivity of energy demand, the size of the bias is probably not very important.

10.4.2 The Results

The elasticity of consumer commodity demand with respect to energy prices can be seen in Table 10:6. In accordance with the discussion above, the estimate for the commodity "housing services" is omitted.

Table 10:6 shows that an increase in the price of electricity tends to reduce the demand for all kinds of consumer goods, even though the elasticities have very low numerical values. Considering the results of the preceding section, this is not a very surprising result.

Table 10:6. The estimated elasticity of consumer commodity demand with respect to energy prices 1981 - 1985

Commodity	i	Elasticity with respect to electricity prices	Elasticity with respect to petroleum products prices	Elasticity with respect to electricity and petroleum products prices
Food	1	-0.023	-0.113	-0.132
Beverages and tobacco	2	-0.013	-0.002	-0.014
Clothing	3	-0.037	0.101	0.065
Cultural goods and services	4	-0.007	0.167	0.157
Hygiene	5	-0.015	-0.055	-0.068
Private transport	6	-0.027	-0.275	-0.292
Leisure activities	7	-0.020	0.074	0.053
Furniture	8	-0.028	-0.285	-0.301
Other goods and services	9	-0.015	-0.141	-0.152

As shown in the second column of Table 10:6, the impact of petroleum products price increases is much more substantial than the corresponding impact of electricity prices. There are both positive and negative elasticities and some have considerable absolute values. These results should be interpreted with some care, however.

The very high negative elasticity of the demand for private transport (that is, the demand for cars and gasoline) with respect to petroleum products prices seems reasonable. But this does not apply to the still higher (in absolute value) elasticity of furniture. This result is unreasonable simply because our estimate of the impact of energy prices on the price of furniture is biased upwards.[1)]

Since two of the nine commodities in the demand model have high negative elasticities, some commodities are likely to have positive elasticities.

1) See the discussion on p. 268.

In our model these are clothing, cultural goods and services and leisure activities. In the case of clothing the positive elasticity is of course to a large extent the result of the positive own-price elasticity discussed above.[1] It follows that this result should not be taken too seriously.

Despite the various peculiarities, some interesting results have been obtained from application of the demand model. According to our results further increases in oil prices, notably gasoline prices, are likely to curb the demand for private transport. Instead, an increasing share of the purchasing power of households will be directed towards cultural goods and services and leisure activities. In other words, the market mechanism seems to yield results which are well in line with the suggestions of many critics of mass-consumption society. It is also interesting to note that a doubling of the price of electricity has a very small impact on the size and composition of the private demand for non-energy consumer goods and services.

10.5 The Flexibility of the Derived Demand for Energy

The next step involves transforming the changes in the demand for consumer goods and services into changes in the demand for energy. This can easily be done (cf. p. 261) by means of the non-energy commodity supply model. The results of these calculations can be seen in Table 10:7. Before discussing these results, a few remarks should be made about the biases inherent in our method of calculation.

The most important point, of course, is that we have confined the analysis to one kind of substitution, that is between different final non-energy goods and services, following an increase in energy prices. Thus, we neglect the impact of substitutions between different factors of production, including substitutions between different kinds of energy. Accordingly the estimated elasticities should be lower than the "true" long-run elasticities.

1/ See p. 100.

Incorporation of the demand model and the residential heating services supply model into the same model-system necessitated very strong assumptions about the demand for housing services. It is assumed that the demand for housing services is completely inelastic with respect to prices and level of income. In addition, when the non-energy commodity supply model is used as a single model, the energy input coefficients of the residential sector are kept constant. It follows that the estimated elasticities are further biased downwards. This holds in particular for electricity since direct purchases are a predominant part of total household electricity consumption.[1)]

Another important factor in this connection is that the analysis is confined to aggregated consumer commodity groups. Aggregation always tends to even out the differences, in terms of input structure, between commodity groups. The consumer commodities have also been aggregated so that the substitutability between commodity groups is minimized.[2)] Consequently, as compared to a completely disaggregated model, our aggregated model tends to underestimate a) the changes in relative commodity prices resulting from energy price changes, b) the substitution between commodities resulting from the changes in relative prices and c) the changes in energy consumption resulting from the changed composition of final demand.

After having established all these qualifications, we now turn to Table 10:7.

To begin with, there is a substantial difference between the impacts of increases in electricity prices and petroleum products prices. This, of course, is a fairly obvious consequence of the results presented in Table 10:6. Likewise, it is not surprising that gasoline demand turns

---

1) Direct electricity consumption in the household sector applies to heating and lighting. Electricity is used to fuel various kinds of electrical equipment. The remaining household electricity consumption is the result of consumption of non-energy goods and services for which electricity has been used as a factor of production.

2) Commodities that are close substitutes or complementary are allocated to the same aggregated commodity group.

out to have the highest estimated elasticity. The general impression, however, is that the derived demand for energy seems to be fairly price inelastic.

Table 10:7. The estimated elasticity of energy demand with respect to energy prices 1981 - 1985

Commodity	i	$\frac{d X_i}{d P_{46}} \cdot \frac{P_{46}}{X_i}$	$\frac{d X_i}{d P_{Petr}} \cdot \frac{P_{Petr}}{X_i}$ [1]	$\frac{d X_i}{d P_E} \cdot \frac{P_E}{X_i}$ [2]
Electricity	46	-0.007	-0.041	-0.049
Gasoline	51	-0.026	-0.277	-0.303
Light fuel oil	52	-0.006	-0.042	-0.049
Heavy fuel oil	53	-0.016	-0.088	-0.104
Oil products	51+52+53	-0.015	-0.109	-0.125

The results of our calculations can also be presented in terms of differences in annual energy demand growth rates. The annual energy demand growth rates between the middle years of model period 1 and model period 2 at different energy price levels can be seen in Table 10:8. In accordance with the above line of reasoning (p. 8) we consider the model solutions for period 1 and period 2, respectively, as long-run equilibrium situations. Thus, Table 10:8 shows the energy demand consequences of an adjustment to a new equilibrium structure of final demand.

Although the estimated price elasticities of energy demand were fairly low, a doubling of energy prices brings about a restructuring of final demand that has a non-neglible impact on energy demand growth rates. This holds in particular for gasoline.

---

1) P_{Petr} denotes the price index of the aggregated commodity "petroleum products".

2) P_E denotes the price index for the aggregated commodity "electricity and petroleum products".

Table 10:8. Estimated annual energy demand percentage growth rates at different energy prices 1978 - 1983

Kind of energy	Reference path growth rate	Electricity prices doubled between per. 1 and per. 2	Petroleum products prices doubled between per. 1 and per. 2	Electricity and petroleum products prices doubled between per. 1 and per. 2
Electricity	3.2	3.0	3.0	3.0
Gasoline	2.3	1.6	-3.5	-4.1
Light fuel oil	1.6	1.5	1.3	1.2
Heavy fuel oil	2.7	2.6	1.5	1.3

10.6 Energy Policy, Crude Oil Prices and Secondary Energy Prices.

So far in this chapter we have dealt with the impact on energy consumption by a 100% increase in the prices of secondary energy. To make the picture more complete we should also briefly discuss the exogenous changes that are likely to bring about a doubling of secondary energy prices. Two factors will be touched upon in this section: nuclear power policy and crude oil prices.

The analysis of the four nuclear power policy alternatives carried out in Chapter 8 indicated that the long run price of high voltage electricity would be about 70-100% higher in the non-nuclear alternatives (III and IV) than in the nuclear alternatives (I and II).[1/]

1/ See p. 199 where the policy alternatives are defined and p. 215 where those results are discussed.

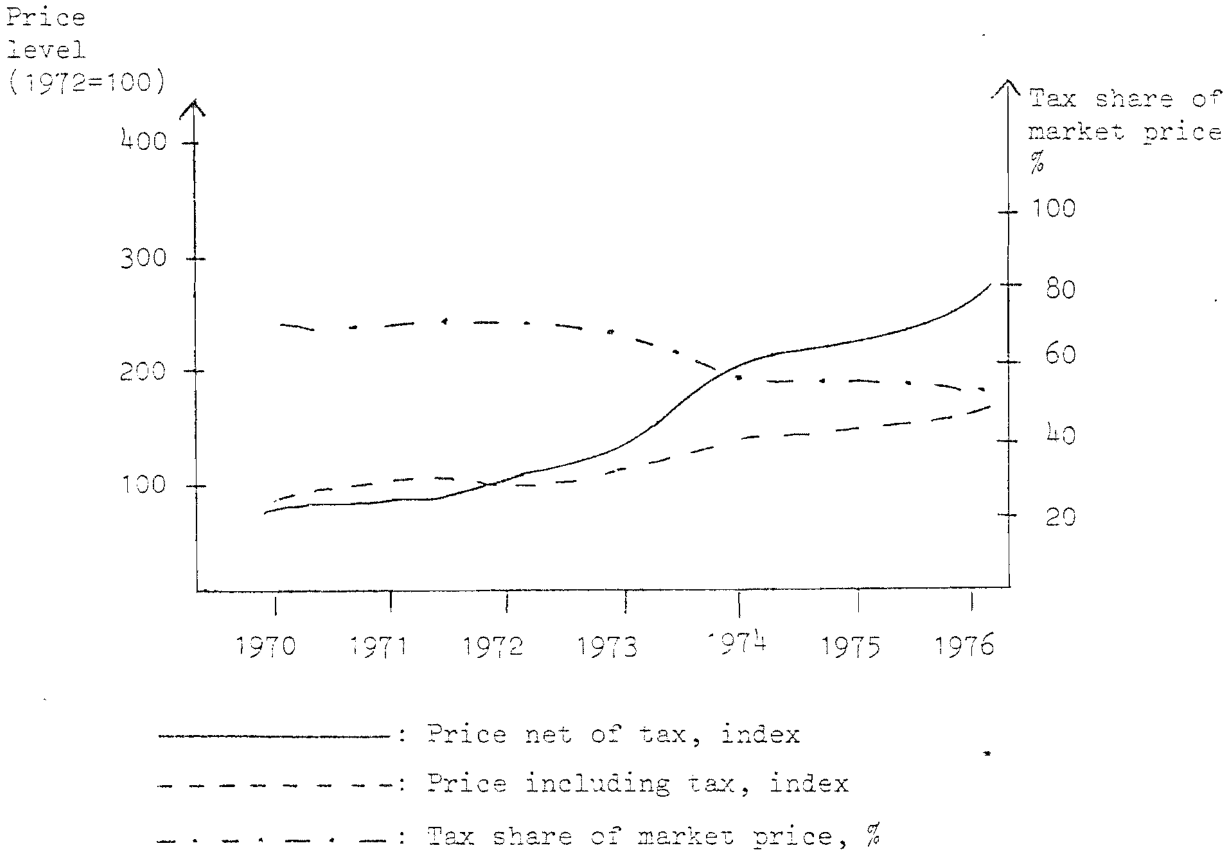
This means that the estimates presented in Tables 10:3 and 10:4 roughly indicates the difference between the nuclear power policy alternatives in terms of non-energy commodity prices. According to Table 8:8 on p. the policy alternatives I, II and III will not differ until the third period (1986 - 1990) while the electricity price rise occurs in the second period (1981 - 1985) in policy alternative IV.

The development of petroleum products prices on the Swedish market during the 1970s is outlined in Diagrams 10.1 - 10.3. The share of taxes in the (average annual) market price of these products is also shown. The year prior to the oil-crisis, 1972, is taken as the base year. The diagrams indicate how the prices of petroleum products on the Swedish market responded to the increase in posted prices of crude oil from about $ 1.50 barrel to $ 9.00 barrel during a few months in 1973 - 1974. According to these diagrams, Swedish market prices of petroleum products increased substantially in response to the crude oil price increase, but Swedish market prices did not rise nearly as much as crude oil prices. A rough estimate is that the elasticity of petroleum products prices before tax with respect to crude oil prices was about 0.3 for fuel oils and 0.2 for gasoline.[1/] This means that transportation, refining and various distribution costs account for some 70-80% of Swedish petroleum products prices before tax.

In the case of gasoline, the elasticity of the market price with respect to the price of crude oil was considerably lower than the corresponding figure for the price before tax. Thus, the high share of taxes in the price of gasoline acts as an additional buffer between crude oil prices and the market price of gasoline. On the other hand the market price of gasoline is fairly sensitive to changes in the gasoline tax.

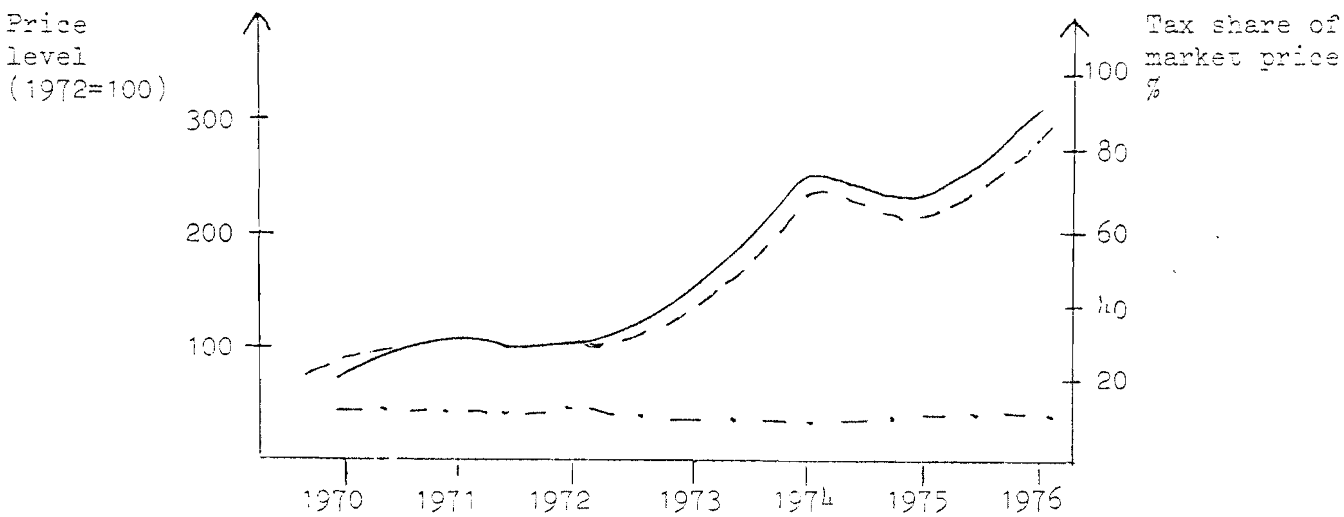
1/ The crude oil price increased by 500% (from $ 1.50 to $ 9.00 per barrel), the fuel oil price by about 150% and the gasoline price by 100%.

Diagram 10.1. The development of gasoline prices and taxes, 1970-1976



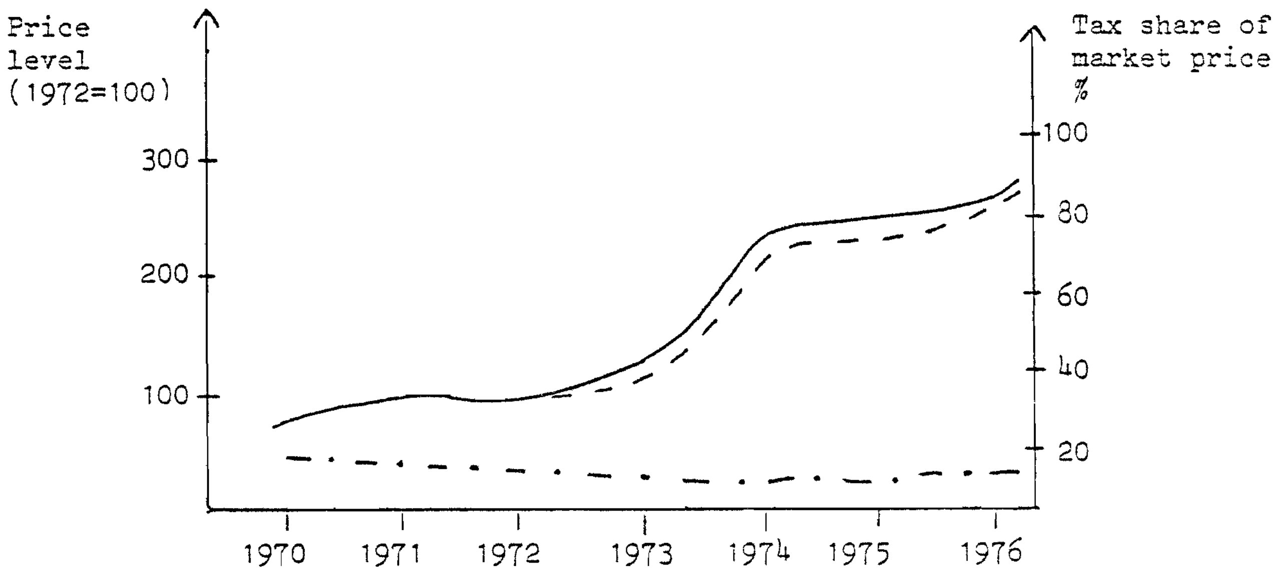
Source: Svenska Petroleum Institutet.

Diagram 10.2. The development of light fuel oil prices and taxes, 1970-1976



Source: See Diagram 10.1.

Diagram 10.3. The development of heavy fuel oil prices and taxes, 1970 - 1976



Source: Svenska Petroleum Institutet.

We noted above that non-energy product prices become more elastic with respect to secondary energy prices as these prices rise (see p.). In the same way, ceteris paribus, the elasticity of petroleum products prices with respect to crude oil prices is positively related to the level of these prices. Thus, further increases in crude oil prices are likely to have a relatively greater effect on petroleum products prices than the 1973 - 1974 increase.

10.7 The Nuclear Power Policy Alternatives and the Demand for Energy

The analysis in the preceding sections of this chapter has led to two conclusions of particular interest in connection with a discussion of the impact of the nuclear power policy alternatives. First, according to Table 10:4, it seems as if an electricity price increase mainly affects the prices of the main exporting sectors. Second, according to Table 10:9, it seems as if a doubling of the price of electricity does not induce such changes in the composition of final demand that the demand for electricity, derived from the demand for final non-energy commodities, is significantly affected on the level of aggregation of this study.

The latter result indicates that an analysis of the impact of the choice between the four nuclear power policy alternatives can be carried out without substantial bias even though possible changes of the composition of the final demand for non-energy commodities is neglected. The former conclusion indicates that an analysis of the choice between the policy alternatives indeed should include the foreign trade sector.

In this study the so called "complete supply model" of the EFM[1] was utilized for a comparison of policy alternatives I (no constraints on nuclear power) and III (no more than 13 nuclear plants). The simulations were based on the assumptions underlying the reference path simulation. However, for several reasons exports and non-energy imports were determined exogenously. The main reason was that the trade pattern of the model is very sensitive to the assumptions made about world market prices. Since no long term prediction of the development of these prices was available, there was no reasonable basis for an endogenous treatment of the foreign trade.

This means that there are two substitution mechanisms left in the model. The first is the substitution between different kinds of primary energy in the electricity and heat production sector. The second is the substitution between different kinds of secondary energy and of energy and capital in the residential heating sector. This means that at given trade and domestic final demand patterns, the growth rates of the consumption of uranium, heavy fuel oil, light fuel oil, electricity and heat can still differ. The estimated growth rates for these kinds of energy in policy alternatives I and III can be seen in Table 10:9 The comparison is confined to the annual growth rates between the middle years of the first three periods.

---

1) That is, the model which is obtained when all the supply models are linked to each other. See p. 62.

Table 10:9. - Estimated annual percentage growth rates of energy consumption in the case of nuclear power policy I and the case of nuclear power policy III. 1978 - 1988.

	Policy alternative I		Policy alternative III	
	1978-1983	1983-1988	1978-1983	1983-1988
Uranium	2.2	7.5	2.2	1.6
Heavy fuel oil	1.1	-1.2	1.3	4.1
Light fuel oil	-0.1	1.3	-0.1	1.4
Electricity	4.3	2.7	4.2	2.6
Heat	1.4	2.6	2.1	2.1

In both alternatives the consumption of light fuel oil decreases while the consumption of uranium and electricity increases between 1978 and 1983. The reason for this is that nuclear capacity can still grow at the same rate in both alternatives. As a result the consumption of light fuel oil in the residential heating sector is significantly reduced and replaced by electric heating.

During the period 1983 - 1988 the consumption of uranium grows rapidly while the consumption of heavy fuel oil is reduced in policy alternative I. In policy alternative III the maximum level of nuclear capacity is reached. The additional demand for electricity and heat is met by production in oil fired plants, and consequently the consumption of heavy fuel oil increases. Due to the higher prices, the growth of electricity and heat consumption is somewhat lower in alternative III than in alternative I.

These results indicate that in spite of the rigidity of the model, the development of the calculated energy balance is quite dependent on the nuclear power policy assumption.

10.8. <u>Some Conclusions</u>

The analysis in this chapter focused on two kinds of energy, electricity and petroleum products. We discussed:

I Energy policy strategies and changes in crude oil prices which are compatible with, at most, a 100 % increase in the market prices of electricity and petroleum products, respectively.

II The reduction in demand that is likely to occur through changes in the composition of the private demand for goods and services resulting from a 100 % increase in the prices of electricity and petroleum products, respectively.

We begin with the results from changes in electricity prices. It turned out that when the prices of electricity were doubled, there was an almost negligible impact on the composition of the final demand for consumer goods and services, and thus on the derived demand for electricity. This was not because all (the aggregated) consumer commodities were equally electricity intensive, i.e. the increase in electricity prices could not lead to changes in relative consumer commodity prices. Nor was it due to the very limited substitutability of the different consumer commodities. Instead, the reason was that the impact of doubled electricity prices on consumer commodity prices was very small; it ranged in fact between 0.004 and 0.044.

Thus, since the impact of a 100 % increase in electricity prices on the average prices of major commodity groups is very limited at the current level of electricity prices, the allocation of private expenditures among these commodity groups is fairly independent of variations in electricity prices. Another aspect of this outcome is that the <u>ceteris paribus</u> increase in labor productivity required to counterbalance doubled electricity prices is quite insignificant.

However, this does not mean the economic consequences of electricity price increases are neglible. The figures presented in Table 10:4 show that the impact of a 100 % increase in electricity prices is quite significant in some of Sweden's main exporting sectors. The calculated elasticity of the price of the output with respect to the price of electricity was 0.07 in the iron and steel industry 0.05 in the mining and quarrying industry as well as in the wood and paper industry. These fairly high elasticities simply reflect the fact that the electricity intensiveness of the technology used in these sectors is relatively high. Thus, unless the Swedish exporting sectors are compensated in one way or another, a significant increase in electricity prices in Sweden in relation to electricity prices in other countries, is likely to negatively affect the international competitiveness of Sweden's export industry. On the other hand, a reduction of the production in the three sectors mentioned above would, indeed, reduce the consumption of energy in Sweden.

In this chapter we simply assumed that the prices of electricity were doubled. However, according to the results presented in Chapter 8, a switch from nuclear power policy alternative I[1)] or II[2)] to alternative III[1)] or IV[2)] would lead to about 70 - 100 % higher prices of high voltage electricity in the long run. Thus, one can say that the high electricity intensiveness of important export sectors, represents a constraint on the choice of nuclear power policy in Sweden; the choice cannot be made without consideration of the corresponding choice in other countries.

Doubled petroleum products prices turned out to have a significant impact on both the level and structure of commodity prices. This sensitivity of commodity prices with respect to oil prices is to a large extent the result of the 1973 - 1974 oil price increase; similar calculations based on pre-1973 oil prices indicated considerably lower elasticities of commodity prices with respect to oil prices.

Owing to the changes in commodity prices resulting from the assumed increase in petroleum products prices, the composition of final demand was changed. It was also reduced in real terms. Consequently the derived demand for petroleum products decreased. This applied in particular to gasoline. Along with the results presented in Chapter 9, these findings indicate that the demand for petroleum products can be expected to be fairly price elastic.

The market prices of petroleum products can rise either as a result of higher world market prices of crude oil and refined petroleum products or as a result of changes in domestic energy taxation. The discussion in Section 10.7 indicated that Swedish fuel oil prices are fairly elastic with respect to crude oil prices while the opposite holds for gasoline.

From an energy policy point of view the factors behind a given petroleum products price increase do matter. In the case of a world market determined increase of petroleum products prices the competitiveness of the Swedish export sectors is not likely to be significantly affected, but as a result of the terms of trade deterioration more resources have to be allocated to the export sectors or the import competing sectors. The oil price increase can be expected to indece a reduction in the consumption of oil through switches to less oil intesive methods of production and patterns of consumption in the economy. However, the total impact on the consumption of oil by the oil price increae might be significantly reduced by the expansion of export sectors using oil intensive methods of production.

In the case of a tax-induced increase of petroleum products prices the competitiveness of the exporting sectors will, ceteris paribus, be negatively affected. This can be seen in Table 10:4. Thus, in terms of the international competitiveness of the economy this case is connected with the same kind of problem as the choice between nuclear power policy, alternatives discussed above.

The main impression of the results presented in this chapter may, after all, be that for the economy as a whole there is not very much flexibility in the energy consumption patterns. In other words, the results may seem to support the view that once the growth of the GNP is determined, the growth of the consumption of energy is determined as well.

However, it should be stressed that the analysis carried out in this chapter has been very partial in at least two respects. First, the only kind of energy demand-affecting substitutions that has been taken into account is substitutions between presently known products or technologies. Second, the analysis of substitutions between different products was carried out on a very aggregated level, and the analysis of substitutions between different production methods was confined to the residential heating sector, and the electricity and heat production sector.

The second point has been mentioned before. Moreover it is obvious that the estimated overall elasticity of energy demand had been higher, perhaps much higher, if the analysis had been extended to cover more sectors and if it had been carried out on a less aggregated level. The first point, however, has not been touched upon before in this study, and it should therefore be somewhat elaborated.

If energy prices are expected to increase in relation to other prices, producers and households are likely to take that into account when they plan new investments in production equipment and durable consumer goods. Thus, they are likely to seek for less energy-intensive production methods (including methods for production within the households) than those presently in use. This will, in the first instance, increase the demand for equipment which is available on the market and which has the desired properties. The adjustments in the residential heating sector discussed in Chapter 9, represent examples of this kind of substitutions.

The main effect of the expected energy price increase, however, is that the demand for less energy-intensive production methods creates a market for methods with this property.[1)] This means that if the substitutability of energy and other factors of production is studied on the basis of knowledge about currently marketed production methods the estimate is likely to be biased downwards. Moreover, an analysis confined to currently existing methods of production may not only underestimate the potential energy conservation options. It may also give wrong information about the most efficient, in economic or energy terms, allocation of energy conservation efforts.[2)]

Thus, if new products and technologies were taken into account, it is reasonable to believe that the long run flexibility of energy demand would be significantly higher than the figures presented in this chapter suggest. However, this is not a conclusion following from the discussion in this and the preceding chapters, but rather a surmise about the results from a more sophisticated study.

1/ S.H. Olson (42) describes how the expected shortage of timber in the American economy induced development of new types of bridges and other kinds of equipment used by the railways. The new equipment required much less timber than the equipment in use. The new types of equipment, however, were not used until the timber prices actually tended to rise.

2/ In addition, it is not obvious that the energy input coefficients should be the primary goal for energy conservation efforts. For instance the reduction of energy consumption can be greater if resources are used to reduce the input of steel in a certain activity, than if the same amount of resources are used to reduce the input of energy in the steel industry. See Jungenfelt (32).

11. SUMMARY AND CONCLUSIONS

The point of departure for this study was the change in Sweden's energy situation between 1950 and the beginning of the 1970s, and the concomitant reorientation of Swedish energy policy. One main feature of the change in the energy situation was a dramatic increase in Sweden's dependence on imported oil. Another was the increasing difficulty of basing further expansion of the power sector on hydro power. This development was considered acceptable, or perhaps desirable, for two reasons. First, access to low-cost energy was considered a means of promoting rapid economic growth. Second, nuclear power plants, fuelled with domestic uranium, were expected to be available at the time when water power resources had been fully exploited. Moreover, heat generated in nuclear plants was expected to replace oil. In other words, nuclear technology was expected to solve both of the basic problems emerging from the gradual post-war change in the Swedish energy balance.

But the basic expectations underlying Sweden's energy policy turned out to be too optimistic. In the beginning of the 1970s doubts about nuclear technology became widespread. The oil crisis occurred in 1973. With such a large share of imported oil in her energy balance and vast nuclear power investment plans, the basic preconditions for Swedish energy policy were changed. As a result a reorientation of that policy was initiated.

The idea of "freedom of action" is important to the "new" Swedish energy policy proposed by the former Swedish government. This means that the energy policy decisions made today should put as few constraints as possible on the future choice among various energy supply options. Another aspect of the "new" energy policy is the increased emphasis on the environmental and safety effects of energy production and consumption. In order to attain a certain degree of "freedom of action" and to reduce the environmental effects of the material flows in society, a plan for energy conservation was proposed. The proposed goal of energy conservation efforts is that annual energy growth should be reduced immediately and come to an end during the 1990s.

The energy conservation program is subject to economic and social constraints; it is clearly stated that the efforts to increase the material and social welfare of the Swedish people should not be discontinued[1/]. It is therefore unlikely that an energy policy leading to marked reductions in the growth of the material standard of living in Sweden will be feasible as long as there are other policy alternatives which do not have such effects, even though they are less attractive from environmental and safety points of view.

This study represents a first step towards an analysis of the economic consequences of different strategies for future energy policy in Sweden. It constitutes only a first step because the analysis is confined to a limited number of policy alternatives. Moreover it does not result in estimates about the relation between the energy policy chosen and GNP growth or some other measure of the material standard of living. Instead the analysis is focused on the medium-term (10-15 years) flexibility of energy supply and demand patterns. The study deals in particular with the substitutability of different kinds of energy and of energy and other factors of production. We also investigate the extent to which such substitutions can be induced by energy price variations and the implementation of well-defined strategies for energy policy.

Generally speking, the number of alternatives, compatible with continued increases in the material standard of living, for medium-term energy policy in Sweden depends on two factors, namely

i) the cost differences between various existing energy supply options;

ii) the flexibility of energy consumption patterns. That is, the substitutions between different kinds of energy, between energy and other factors of production, and between energy-intensive and less energy-intensive products that can be induced by rather small variations in relative prices.

1/ See Energihushållning, (61), p. 4-11.

The study is confined to a comparison of a few nuclear and non-nuclear electricity and heat supply alternatives and the flexibility of energy consumption patterns in the residential heating sector and, to some extent, the household sector. The main results of the study are summarized in this chapter and the implications for energy demand forecasting and policy-making in Sweden are discussed. We begin by reviewing our methodological approach.

11.1 Methodology

One of the features of the methodology adopted in this study is that the figures presented are obtained from simulations using a numerically formulated mathematical model. Another feature is that the analysis of the policy alternatives is entirely descriptive, and is not aimed at appraising the relative desirability of the policy alternatives investigated. Moreover, the description of the consequences of the policy alternatives is confined to a few dimensions. Some remarks about the approach adopted are appropriate before we proceed with a summary of the main results.

The outcome of implementing a particular set of energy policy measures depends on the initial structural relationships and the adjustment mechanisms of the economic system. The properties of the adjustment mechanisms depend on the nature of available technology, the behavior of the economic agents, the institutional framework, etc. Thus, a study such as this cannot be carried out unless the relevant structural relationships and adjustment mechanisms in the economy are specified. However, this condition cannot possibly be absolute; there are many potential approaches with different advantages and drawbacks and a unique ranking of these approaches cannot be made on à priori grounds. The choice of approach has to be related to the issues under study, the availability of data, etc. Any framework for analyzing a given issue has to be based on assumptions about the real world. Although these assumptions may be more or less well-founded and more or less explicit, they always have to be made. For this reason the analyst should always have a very clear picture of the relation between his results and the assumptions underlying these results.

The mathematical model approach adopted in this study is superior to other approaches in several respects. The basic feature of a mathematical model is that it represents a set of explicit assumptions about the relationships between a number of variables in the system under study. This feature enables us to investigate how the results obtained are conditioned by each of the underlying assumptions. Moreover, in a mathematical model the interdependencies between various sectors of the economy can easily be taken into account. Obviously a mathematical model is well-suited to a study aimed at comparing energy policy alternatives.

But it is very important to note that two kinds of assumptions underlie the results obtained from a mathematical model and thus the results presented in this study. The first kind of assumption is represented by the mathematical specification of the model, while the second is represented by the assumptions about the numerical values of the model's parameters and exogenous variables. In this study the latter set of assumptions is varied in order to test the sensitivity of the solutions. However, the mathematical structure of the model is kept unchanged in all simulations.

When interpreting the results of this study one model property in particular should be kept in mind. This is the implicit assumption that there is no uncertainty about the future; at the initial point in time the economic agents of the model economy are perfectly informed about all future cost and demand conditions.

The supply part of the model used in this study is formulated as an optimization model. This means that, in principle, the numerical values of the criterion function obtained in different simulations could be compared so as to determine the "best" strategy for future energy policy in Sweden. However, energy policy is likely to affect society in many ways, i.e. through energy prices, environmental effects, dependence on foreign supplies, etc. A given energy policy alternative cannot be evaluated unless all the different kinds of effects can be expressed in a common unit of measurement. Even though this is feasible in theory under certain conditions, it is not very easy in practice.

This is why we have not endeavored to rank the energy policy alternatives in terms of relative desirability. This study is entirely descriptive. Moreover the description is not made in terms of the values of the objective function, but in terms of several variables which are endogenous in the model.

However, our description of the consequences of various alternatives for Swedish energy policy is made almost entirely in terms of economic variables. The approach chosen for this study is motivated by the belief that the economic consequences of different energy policy alternatives contemplated in Sweden will be quite significant in the political process leading to a choice among them.

11.2 A Summary of the Main Results and Conclusions

We now turn to a brief summary of the main results of the model simulations. Some conclusions about the medium-term flexibility of the energy consumption patterns are drawn at the end of this section. So as not to make the exposition too tedious, the discussion about the assumptions underlying the results is kept to a minimum. Readers interested in these assumptions are referred to Chapters 8-10.

The empirical part of this study is based on an analysis of four strategies for future nuclear power policy in Sweden. All policy alternatives are entirely directed towards the supply side of the energy system. The strategies are:

I. The power industry is allowed to choose freely among all existing types of plants.[1/]

II. The power industry is allowed to choose freely among all existing types of plants, but nuclear plants have to be located far from densely-populated areas. Thus, within reasonable relative price variations, the cooling water from nuclear power plants cannot be used for space heating purposes.

III. The nuclear power program adopted by Parliament in 1975 is fulfilled.

IV. No nuclear power at all is allowed after 1980.

1/ If nuclear plants are to be used for combined production of electricity and heat for district heating systems, they have to be located fairly close to densely-populated areas (generally less than 60 km.). Thus, policy alternative I implies that there are no particular rules, in terms of distance from densely-populated areas, governing the location of power plants.

It is obvious that the policy finally adopted will be much more complex than each of the above alternatives. It is also quite likely that the policy adopted will be revised on several occasions.

Nevertheless results from model simulations, constrained by these four policy alternatives, should be useful to energy policy decision-makers. Our analysis of these alternatives will also indicate the extent to which energy consumption patterns are dependent on the energy policy adopted.

The first step in comparing the policy alternatives deals with their impact on the power and heat[1/] production sector. The assumptions about fuel prices, investment costs, interest rate and demand are all discussed in Section 8.1. These assumptions are based on a recent report by the Ministry of Industry in cooperation with the State Power Board. In our analysis it is assumed that power plant investment costs remain at the 1976 level, that all fuel prices increase by 3% per annum and that the rate of interest is 8%.

On the basis of these assumptions, we arrive at estimates of future prices of electricity and heat in each of the policy alternatives. The figures were presented in Tables 8:8 and 8:9 and are reproduced in Tables 11:1 and 11:2. As can be seen in the tables, the policy alternatives differ with respect to both the level and the structure of energy prices.

1/ Observe that "heat production" refers to production of heat for district heating systems and industries. Heat production in oil furnaces in individual houses is thus excluded.

Table 11:1 Calculated high voltage electricity prices for different policy alternatives (expressed in 1976 Sw. öre/kWh)

Policy alternative \ Time period	76-80	81-85	86-90	91-95	Average rate of change, % per annum
I	6.8*)	7.3*)	8.5*)	9.6*)	1.7
II	6.8*)	7.3*)	8.5*)	9.4*)	1.6
III	6.8	7.3	14.0	16.3	4.3
IV	6.8	13.1	14.5	16.3	4.3

*) If nuclear power plants are assumed to be available during 36 instead of 27 weeks per year these figures should be reduced by about 2 Sw. öre/kWh.

Table 11:2 Calculated heat prices for different policy alternatives (expressed in 1976 Sw.öre/kWh)

Policy alternative \ Time period	76-80	81-85	86-90	91-95
I	4.3	6.0	2.7	2.6
II	4.3	5.3	5.9	6.9
III	4.3	5.9	3.3	3.2
IV	4.3	2.7	2.9	3.1

Since all of the assumptions about demand, input prices, etc. are the same for the policy alternatives the differences in terms of output prices are determined entirely by the choice of technology. In policy alternative I nuclear plants are used for both electricity and heat production.[1/]

1/ The treatment of heat production posed particular problems in the analysis. See p. 214.

In spite of our fairly pessimistic assumptions about the profitability of nuclear power, nuclear technology turned out to be very competitive on narrow economic grounds.[1/] Accordingly both electricity and heat prices were low in alternative I.

In alternative II nuclear plants were not allowed to be located close enough to densely-populated areas to make the use of waste heat from nuclear plants for space heating purposes profitable. Consequently the production of heat had to be based on fossil fuels, and heat prices became relatively high. However, nuclear power plants were still used for electricity production, which led to low electricity prices.

Alternative III contained an upper limit on the amount of nuclear capacity allowed. Thus, once the level of electricity demand had reached a certain level, capacity additions had to be based on non-nuclear plants. In this particular case, oil fired plants for combined production of electricity and heat became highly important. The transition from nuclear to oil fired plants led to a significant increase of the calculated prices of electricity. On the other hand, as a result of the efficient utilization of fuel in combined plants, the calculated heat prices were fairly low in this policy alternative. Accordingly, the price of electricity in relation to the price of heat was relatively high in this case.

Policy alternative IV implied eliminating nuclear capacity from the Swedish energy sector after 1980. In the long run there were only slight differences in terms of energy prices between policy alternatives III and IV. However, the problems connected with an immediate scrapping of all existing nuclear power plants are underestimated in the model. This means that the calculated electricity and heat prices for the period 1981-85 in policy alternative IV represent underestimations.[2/]

1/ No attempt was made to evalute the environmental effect and the safety problems connected with various policy alternatives.

2/ See p. 217.

The figures presented above indicate that the development of electricity and heat prices is highly dependent on the choice between the nuclear power policy alternatives. In fact, the calculated long-run price of electricity turned out to be about 100% higher in the non-nuclear alternatives III and IV than in the nuclear alternatives I and II. However, this conclusion may not be quite valid. Nuclear power plants and conventional fossil fuelled power plants compete on the same markets. This means that the market prices of nuclear fuels, fossil fuels and power plant equipment are interdependent. One possibility is that the price of oil determines the prices of nuclear fuel and power plant equipment, but the reverse causality is also possible. In any case, it cannot be ruled out that future electricity and heat production costs in Sweden will in fact be independent of the Swedish nuclear power policy. However, we neglect this possibility in the following and turn to an analysis of how our calculated energy prices affect energy consumption patterns in the residential heating sector.

The consumption of various fuels for residential heating purposes in each of policy alternatives I, II and III are shown in Table 11:3. Since the comparison is confined to the situation some 10-15 years hence, the results obtained for policy alternative III should also be valid for policy alternative IV. Table 11:3 represents a summary of Tables 9:3, 9:4 and 9:5. It shows optimum[1/] gross energy consumption for the case of energy and energy conservation equipment prices in 1976 as well as for nuclear power policies I, II and III.

1/ Optimum refers to minimum cost energy consumption by the residential heating sector for a given number of dwellings with a given indoor temperature.

Table 11:3 Optimum gross energy consumption in residential buildings (1986-90) under various assumptions about nuclear power policy

	Consumption, TWh				Market shares *, %		
	Total	Oil	Electricity	Hot water	Oil	Electric heating	District heating
1976 prices	92.6	60.3	22.9	9.5	57.7	23.0	19.4
Policy alternative I	87.3	38.1	22.6	26.7	35.0	21.5	43.5
Policy alternative II	86.7	45.7	25.8	15.2	46.1	28.1	25.7
Policy alternative III	88.9	42.9	20.0	26.1	39.8	17.3	42.9

*) Number of dwellings heated by a technology based on a particular fuel in relation to the total number of dwellings.

All policy alternatives lead to reductions in the gross energy consumption of the residential heating sector. This is primarily a result of the transition from oil furnaces with low thermal efficiency to electric heating and district heating with high thermal efficiency.[1/] Thus, the four cases represented in Table 11:3 do not differ significantly in terms of net energy consumption.

But there are significant differences between the alternatives. In policy alternative I the transition from individual oil heating is most pronounced, and the increase in the market share of district heating is quite remarkable. Policy alternative III does not differ significantly from alternative I in the sense that in both cases the market share of electric heating is reduced as compared to the figures obtained under the assumption of 1976 prices. The reduction in the consumption of electricity for residential heating purposes, however, is more significant in alternative III than in alternative I.

1/ Note that in the case of electric heating or district heating the energy transformation losses appear in the power and heat production sector.

Policy alternative II leads to energy consumption patterns that are quite different from those obtained in the other policy alternatives. The market share of electric heating rises, while that of district heating only increases to a small extent. All of these results, however, are quite consistent with the calculated electricity and heat prices presented in Tables 11:1 and 11:2. They indicate that energy consumption patterns are highly dependent on the energy policy which is ultimately adopted.

We noted above that net energy consumption was approximately the same in all of the policy alternatives. But the simulations indicated that not only gross energy consumption but also the energy consumption by the residential heating sector was fairly sensitive to price variations. This can be seen in Table 11:4, which is based on Table 9:6. Since the gross consumption of all kinds of energy is reduced in response to a doubling of all energy prices, net energy consumption should have been reduced as well. On the basis of the figures in Table 11:4, we can conclude that in the long run the energy consumption patterns of the Swedish residential heating sector are quite flexible.

Table 11:4 Optimum gross energy consumption (TWh) in residential buildnings (1986-90) at different energy price levels

	1976 energy prices	1976 energy prices doubled
Fuel oil	60.3	45.7
Electricity	22.9	21.6
Hot water	9.5	4.7
Total energy	92.6	71.9

The choices among various energy production technologies as well as among various residential heating technologies represent substitution mechanisms in the economy. Energy production and consumption patterns are adapted in response to changing prices and institutional conditions. As a result the size and composition of the economy's energy balance is changed.

Obviously there are substitution mechanisms in all sectors of the economy. So far, however, only certain sectors have been dealt with in detail in the model used in this study. The input-output relations in all other sectors of the production system are assumed fixed. Thus our model of the economy's production system gives a partial picture of the adjustment process induced by a specified set of energy policy measures. Nevertheless it is interesting to study the flexibility of this "partially flexible" system.

The calculated annual growth rates for the consumption of five kinds of energy in each of two nuclear power policy alternatives are shown in Table 11:5.[1/] The figures are calculated on the assumption of given trade and final demand patterns, as well as given labor productivity increases. It should be noted that uranium and heavy fuel represent primary energy forms; both of these kinds of energy can be used as inputs in the production of electricity.

Table 11:5. Estimated annual percentage growth rates of energy consumption for nuclear power policies I and III, 1978 - 1988

	Policy alternative I		Policy alternative III	
	1978-1983	1983-1988	1978-1983	1983-1988
Uranium	2.2	7.5	2.2	1.6
Heavy fuel oil	1.1	-1.2	1.3	4.1
Light fuel oil	-0.1	1.3	-0.1	1.4
Electricity	4.3	2.7	4.2	2.6
Heat	1.4	2.6	2.1	2.1

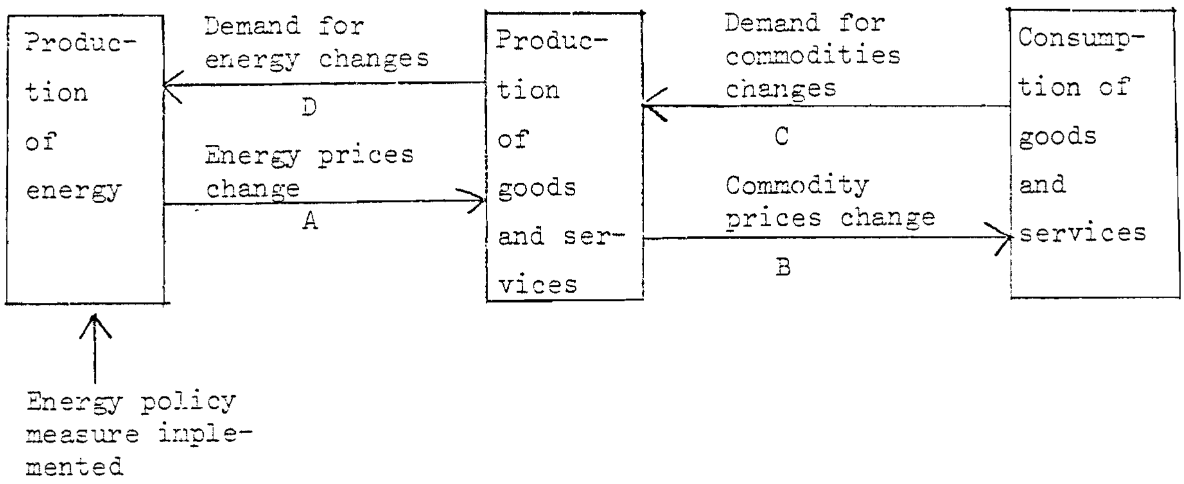
The two policy alternatives yield approximately the same consumption growth rates for light fuel oil and electricity, whereas there are significant differences in terms of the other kinds of energy. Since light fuel oil and electricity are quantitatively more important than the three other kinds of energy, we are tempted to conclude that the development of the Swedish energy balance is fairly independent of the choice of nuclear

1/ Table 11:5 is identical to Table 10:9.

power policy. But the technology used for residential heating purposes is also used to heat other spaces such as the premises occupied by the public and trade sectors. This means that our conclusions about the flexibility of the energy consumption patterns of the residential heating sector are likely to be valid for other sectors as well. It also means that the overall flexibility of the economy's energy consumption pattern can be expected to be higher than indicated by Table 11:5.

It is quite obvious that if alternative methods of production in all energy consuming sectors are identified and incorporated into the model, the calculated flexibility of the economy's energy consumption patterns would be increased. Such developments of the model seem to be worthwhile, although the long-run flexibility of the economy's energy consumption patterns would probably be underestimated. This is because all kinds of capital goods currently on the market were designed during a time when energy prices were generally expected to remain very low. This means that the pre-1973 energy prices are "built into" present technologies. It also means that very little R&D resources have been allocated to designing energy efficient technologies for industrial and household production. However, if it is generally believed that prices will rise in the future, substantial efforts will be allocated to the design of energy efficient methods of production. The properties of these technologies will determine the long-run flexibility of the economy's energy consumption patterns.

So far we have implicitly assumed that a predetermined bundle of final, non-energy, goods and services is to be produced in each period. Our discussion has concerned the flexilibity of the demand for energy, derived from the demand for the predetermined bundles of goods and services. However, changes in energy supply conditions may affect the prices of final goods and services. As a result expenditures will be reallocated, which leads to a restructuring of the production system. When the relative size of the production sectors changes, the consumption of energy is likely to change as well. This adjustment process can be visualized in the following way:



The sequence ABCD was calculated on the basis of the system of models presented in Part II of this study. To simplify the analysis, the change in energy prices was not explicitly related to the implementation of some energy policy measure; it was simply assumed that the prices of electricity and petroleum products were doubled. (However, as was shown in Table 11:1, a doubling of the price of electricity can be interpreted as a transition from a nuclear to a non-nuclear power production technology.) The elasticity of the derived demand for electricity and petroleum products was estimated. Our estimates are subject to an important limitation, i.e. it is assumed that the technology for producing goods and services remains unaffected by increases in energy prices. In accordance with the discussion above, changing relative factor prices are likely to induce changes in the methods of production.

As shown in the figure above, the calculations involved several steps. We confine our discussion in this summary to the first and last steps. We begin by presenting the calculated elasticities of commodity prices with respect to energy prices. The impact of energy prices on consumer goods prices is shown in Table 11:6. It should be noted that the heating technology in residential dwellings remained unchanged in the calculations.

Table 11:6. Estimated elasticities of consumer goods prices with respect to energy prices, 1981 - 1985

Commodity	i	Elasticity with respect to electricity prices	Elasticity with respect to petroleum products prices	Elasticity with respect to petroleum products and electricity prices
Food	1	0.012	0.044	0.056
Beverages and tobacco	2	0.004	0.016	0.020
Clothing	3	0.016	0.046	0.062
Cultural goods and services	4	0.014	0.035	0.049
Hygiene	5	0.032	0.093	0.125
Private transportation	6	0.012	0.294	0.306
Leisure activities	7	0.018	0.096	0.114
Furniture	8	0.032	0.071	0.103
Other goods and services	9	0.012	0.039	0.051
Housing services	10	0.044	0.181	0.225
The general level of consumer prices *)		0.014	0.045	0.059

*) A weighted average based on the estimated composition of private consumption, 1981 - 1985.

Starting with the general level of prices we note that the impact of doubled petroleum products prices is about three times as large as the corresponding figure for electricity. We also note that the general price level is not very sensitive to energy price rises; a doubling of both electricity and petroleum products prices would reduce the real purchasing power of the household sector by about 6%. However, this is the result of a once and for all increase in energy prices.

A continuous increase at a higher rate than the increase in wages and other cost items would gradually make commodity prices very sensitive to energy price variations.

Table 11:6 also shows that a doubling of petroleum products prices affects relative commodity prices to a much larger extent than a doubling of electricity prices. Thus, a doubling of petroleum products prices can be expected to induce more significant reallocations of household expenditures than a doubling of electricity prices. This is confirmed by Table 11:7, where the figures were obtained by carrying out all of the steps in sequence ABCD shown in the figure above. The figures in Table 11:7 can be said to represent estimates of that part of the overall elasticity of energy demand which can be attributed the changes in the composition of final consumer demand. It should be noted that the consumption of housing services was kept constant in the calculations.

Table 11:7. The estimated elasticity of energy demand with respect to energy prices, 1981 - 1985

Commodity	i	$\frac{d X_i}{d P_{46}} \frac{P_{4L}}{X_i}$	$\frac{d X_i}{d P_{Petr}} \frac{P_{Petr}}{X_i}$ 1)	$\frac{d X_i}{d P_E} \frac{P_E}{X_i}$ 2)
Electricity	46	-0.007	-0.041	-0.049
Gasoline	51	-0.026	-0.277	-0.303
Light fuel oil	52	-0.006	-0.042	-0.049
Heavy fuel oil	53	-0.016	-0.088	-0.104
Oil products	51+52+53	-0.015	-0.109	-0.125

1) P_{Petr} denotes the price index of the aggregated commodity "petroleum products"

2) P_E denotes the price index for the aggregated commodity "electricity and petroleum products".

These results indicate that on the level of aggregation in this study the elasticity of electricity demand resulting from reallocations of household expenditures (other than housing) is very low. This conclusion holds for petroleum products as well, with the exception of gasoline. The fairly high elasticity of the demand for gasoline is the result of a reduction in the demand for private transportation services induced by the marked impact of the petroleum products price increase on the price of these services (see Table 11:6).

The results shown in Table 11:8 point to a problem concerning Swedish energy policy, at least in the short run. Even though the general impact of energy price increases on production sector outputs is not very significant, rather high figures are obtained for important exporting sectors (sectors 12, 16, 20). This problem will be discussed further in Section 11.3.

We noted above that if energy prices increase, technologies in the production system will be made less energy intensive. If it had been possible to take this substitution mechanism into account, the estimated figures presented in Tables 11:7 and 11:8 would generally have been lower. It is also reasonable to believe that the change in relative commodity prices would be lower in a more elaborated model. Thus, in a model which incorporates possibilities of adjusting the methods of production in response to changing relative factor prices, the estimated impact of energy price increases on the composition of final demand would be lower than in the model used in this study. On the other hand, the calculated elasticity of energy demand would be higher.

Table 11:8. Estimated elasticities of sector output prices with respect to energy prices, 1981 - 1985

Sector	i	Elasticity with respect to electricity prices	Elasticity with respect to petroleum products prices	Elasticity with respect to petroleum products and electricity prices
Forestry and logging	11	0.010	0.053	0.063
Mining and quarrying	12	0.052	0.070	0.122
Import-competing foods	13	0.014	0.048	0.062
Beverages and tobacco	14	0.004	0.017	0.021
Textiles and leather	15	0.014	0.047	0.061
Wood and paper	16	0.047	0.083	0.130
Printing and publishing	17	0.015	0.040	0.055
Rubber products	18	0.024	0.062	0.086
Chemicals and plastics	19	0.053	0.158	0.211
Iron and steel	20	0.071	0.069	0.140
Machinery and equipment	21	0.022	0.046	0.068
Shipbuilding	22	0.026	0.044	0.070
Miscellaneous industries	23	0.020	0.031	0.051
Agriculture and fishing	24	0.009	0.042	0.051
Sheltered food	25	0.012	0.045	0.057
Non-metallic minerals	26	0.033	0.119	0.152
Construction	27	0.021	0.060	0.081
Wholesale and retail trade	28	0.012	0.051	0.063
Transport	29	0.013	0.084	0.097
Housing rentals	30	0.006	0.029	0.035
Miscellaneous services	31	0.012	0.030	0.042

This study is partial in the sense that many substitution mechanisms which can be expected to be important are not incorporated into our model. Accordingly we cannot draw definite conclusions about the flexibility of the economy's energy consumption patterns on the basis of our results. However, several alternative heating technologies were taken into account in our analysis of the residential heating sector. Our model simulations indicated that the choice among these technologies was sensitive to energy price variations. The sensitivity was high enough to make energy consumption patterns in the residential heating sector highly dependent on the choice of nuclear power policy. It is hard to believe that the substitutability of various kinds of energy and of energy and other factors of production which we found in the residential heating sector is specific to that sector. It therefore seems worthwhile to elaborate on the treatment of other energy consuming sectors in our model, and it is reasonable to expect that such studies will reveal long-run substantial flexibility in Sweden's energy consumption patterns; it will turn out that there is no simple relation between the growth of the final demand for goods and services and the growth of energy consumption.

On the basis of the results obtained in this study, it seems reasonable to regard all four of the alternatives for nuclear power policy as compatible with a continued increase in the material standard of living in Sweden. However, in our discussion about nuclear power policy we focused on the choice between various policy alternatives, while the problems connected with the implementation of the chosen policy alternative was neglected. By recognizing the way in which our results were obtained, we can identify some of the problems encountered by energy-policy makers.

In each of our model simulations future energy policy was determined once and for all at the initial point in time. It was assumed that the economic agents were perfectly informed about all future cost and demand conditions, including the effects of implementating the chosen energy policy alternative. It was also assumed that all economic agents were perfectly rational cost minimizers and that no institutional barriers complicated the adjustment to the expected cost and demand conditions. Further, attention was focused on the impact of the chosen energy policy some 10-15 years hence.

However, these conditions are not very likely to be satisfied in the real world. Economic agents are not perfectly rational and several institutional factors tend to complicate the adjustment to actual and expected cost and demand conditions. For these reasons it is useful to distinguish between the "potential flexibility" of energy consumption patterns and the actual flexibility of these patterns. The concept of "potential flexibility" in this context refers to an ideal situation in terms of rationality of behavior and institutional arrangements. This distinction is of course quite important from an energy forecasting point of view. It is also important from an energy policy point of view; the difference between potential and actual flexibility indicates the need for and potential effect of various energy policy measures. Obviously the results obtained from our model should be regarded as estimates of the potential long-run flexibility of energy consumption patterns.

More important from the policy point of view is the assumption about perfect foresight. This is because the distinction between the short term and the long term is quite vital when energy consumption patterns are studied.

Capital equipment cannot be utilized without some input of energy, and energy consumption is always connected with utilization of capital equipment. This applies to both industrial and household production processes. The relative proportions of energy and capital in many production processes tend to be more or less rigid once the capital equipment is installed. This means that physical lack of energy or dramatic, unexpected energy price increases can force existing production units to close down, or at least scrap existing capital equipment, thereby creating capital losses and perhaps unemployment and other structural problems.[1/]

In other words, whatever the substitutability of energy and other factors of production may be in the minds of the designers of new

1/ See for instance SIND (59) where the employment effects of a sudden reduction in the supply of oil is analyzed by means of an input-output model. See also Industridepartementet (58) for a similar study of the effect of a sudden scrapping of all existing nuclear power plants in Sweden.

machines and other kinds of energy consuming equipment, it is very limited in existing plants. That is, at a given level of economic activity, the short-run flexibility of energy consumption patterns is very low.

This fact makes the role of expectations very important. In the case of a well-anticipated energy price rise, resulting for instance from the implementation of a set of energy policy measures, the flexibility of energy consumption patterns is determined by the ex ante substitutability of energy and other factors of production. In the case of an unexpected energy price rise, on the other hand, the flexibility is determined by the ex post substitutability in existing plants. Thus, in terms of energy consumption patterns as well as in other respects, the consequences of a given set of energy policy measures depend not only on the implemented energy policy as such. They also depend on how well this particular energy policy and the resulting energy prices coincide with those expected by firms and households.

This leads to the conclusion that one of the most important tasks of energy policy-makers is to create consistent expectations about future energy prices and supply conditions among firms and households. This can be achieved if policy makers have access to accurate predictions about the costs and availability of various long-run energy supply options. Given this access, a number of long-run energy policy alternatives can be formulated and their consequences in various respects can be assessed with a reasonable degree of accuracy. Even though the choice among alternatives might be controversial, a choice can be made in one way or another, thus providing a basis for smooth adjustment to the adopted energy policy. When the adjustment process can be extended over several years, the differences - in terms of the resulting long-run energy prices - between policy alternatives compatible with a continued increase in the material standard of living, will obviously be at a maximum.

11.3 Some Topics for Future Research in the Field of Energy Policy

Energy policy is a broad field containing many more issues than those analyzed in this study. Many problems related to energy policy cannot be analyzed be means of models of the kind used here. However, many issues in this field can be classified by means of such models. In this final section we will identify two problem areas where a refined version of our model would be useful.

In response to the uncertainties and diversity of opinions in the energy field, the principle of "freedom of action" in the choice among long-run energy supply options has been adopted as a basis for Swedish energy policy during the next few years. The fundamental idea is that the energy policy decisions made today should put as few constraints as possible on the future set of feasible energy supply options. Combined with environmental concerns the principle of "freedom of action" manifests itself in the ambition to reduce the rate of energy consumption growth, which means that the need to expand the power sector can be kept at a minimum. The idea behind this policy is that it would be difficult not to be committed to a few specific energy supply options in the case of rapidly growing energy consumption.

In order to achieve a reduction in the growth of energy consumption the authorities pay subsidies and grant loans on favorable terms for energy conservation efforts in industries and residential buildings. The potential use of energy taxation as a means of inducing energy conservations efforts is also under study.

However, reduction in the growth of energy consumption may not necessarily increase freedom of action in the choice among various long-run energy supply options. This point can be clarified by defining the concept of "freedom of action". In order to have any meaning, "freedom of action" has to refer to the time period required for a transition from one energy supply option to another, under specified constraints about the structural problems (unemployment, capital losses, etc.) connected with the transition. These structural problems are determined mainly by the limited short-run flexibility of energy consumption patterns at a given level of economic activity. The limited short-run flexibility applies to the energy production sector as well.

An energy policy aimed at a certain degree of freedom of action in the choice among various long-run energy supply options can, in principle, be designed in two ways. One possible strategy is to aim at increasing the short-run flexibility of energy consumption patterns. The larger the short-run flexibility of energy consumption patterns, the greater the possibility of making significant changes in energy supply conditions on short notice without causing structural problems.

The second possible strategy is to focus on the kind and amount of capacity in the energy sector. The construction of energy production and distribution facilities requires a considerable amount of time. The utilization of each particular energy supply option requires know-how and a set of institutional arrangements. This means that the transition from one energy supply option to another is very time-consuming. Thus a fairly high degree of "freedom of action" can be achieved if several energy supply options are developed simultaneously and if there is overcapacity in the energy sector. Some "freedom of action" is attained if know-how about many different energy supply options is accumulated.

The degree of freedom of action in the choice among various energy supply options obviously cannot be increased without cost. In the same way as various energy conservation efforts can be compared in terms of economic efficiency, various ways of attaining a certain degree of freedom of action in the choice among energy supply options can be compared by means of an economic efficiency criterion. On *a priori* grounds we cannot, of course, ascertain the extent to which a policy aimed at "freedom of action" should be directed towards the energy consumption sectors. A preference for the former kind of measure was revealed in the energy policy proposal submitted to Parliament by the former Swedish government.

A conscious energy conservation policy is likely to stimulate the development of less energy intensive production methods and consumption patterns. But even when the energy input coefficients in the production system are lower than they would otherwise be without the energy conservation policy, they are still more or less fixed in the short run. The short-run rigidity of the economy's energy consumption patterns is therefore likely to be the same at any level of energy consumption. Hence the short-run problems created by an unexpected reduction in the supply of energy seem to be fairly independent of the level of energy consumption. This means that energy conservation efforts do not necessarily increase the degree of freedom of action in the choice among energy supply options.

An energy policy that aims at reducing the growth, or even the level, of energy consumption can be motivated in several ways. One is of course that energy production and consumption have negative environmental effects. Another is that there are risks connected with utilizating various energy production technologies. A third reason is that if an economy is dependent on imported fuels, the need for fuel inventories is related to the level of energy consumption.

The possibilities of carrying out a rapid and smooth transition from one energy supply option to another, however, is related to the composition of the energy supply, the time it takes to start utilizing a new energy supply option and the short-run flexibility of energy demand at a given level of economic activity.[1/] Indeed the composition of energy supply is likely to change if the level of energy con-

1/ For instance, assume that the authorities want to scrap all existing nuclear plants as soon as possible under certain employment constraints. If the total annual electricity production is 25 TWh and entirely generated in nuclear power plants, either 100 % of the electricity generating capacity has to be replaced or 100 % of the demand cut off. The larger the percentage reduction in electricity demand can be induced, the smaller the amount of new capacity required. If, on the other hand, total annual production is 100 TWh, of which 15 TWh is generated in nuclear plants, the maximum demand reduction that has to be induced is 15 %. Obviously, in spite of the lower level of consumption, the structural problems connected with the former situation can be expected to be more significant than those related to the latter situation.

sumption changes. Such a development may reduce the future freedom of action in the choice among energy supply options, but the critical factor is the changed composition of energy supply, not the changed level of energy consumption.

Thus, it seems as if the "new" Swedish energy policy has two - quite different - sets of goals. One is to reduce the growth of energy consumption; the other is to attain a certain degree of freedom of action in the future choice among energy supply options. In order to analyze policies for attaining these goals, our model has to be developed, but quite different developments are required in the two cases.

If policies aiming at reducing the growth of energy consumption are to be studied, the development of the model should focus on identifying alternative new technologies for producing goods and services. In particular we should try to identify technologies where the energy input coefficients are small. Then the choice among these technologies and the resulting energy consumption patterns could be studied under various assumptions about the energy policy. The policy alternatives could either manifest themselves as alternative energy price developments or as quantitative restrictions on the total supply of energy in general or of certain kinds of energy.

If, on the other hand, policies aiming at attaining "freedom of action" in the sense discussed above are to be studied, a different development of the model is required. In this case the possibility to change the factor proportions in existing plants, now and in the future, is at focus. That is, we should try to identify flexible energy consuming technologies and not necessarily technologies where the energy input coefficients are small. Presumably a "flexible" technology is, *ceteris paribus*, less profitable than a less "flexible" technology. Given a policy alternative, the allocation between investments in, on the one hand, excess capacity in the energy sector and, on the other hand, the degree of flexibility of energy consuming capital equipment. In this case total scrapping of nuclear power at some future date could be one policy alternative, while rationing of oil could be another. However, unless the model is changed to contain different future "states of the world", each sudden change of the energy supply conditions will be prefectly anticipated by the agents in the model-economy.

The main features of Sweden's future energy policy will be determined during the next few years. It seems as if those responsible for this work will have the important task of clarifying the priorities in the goal of Sweden's energy policy. If the environmental and safety effects of energy production and consumption are regarded as the main problems in the energy field, then policy should perhaps be directed towards reducing the growth, or even the level, of energy consumption. If, on the other hand, the uncertainty about various energy supply options is considered the main problem, then policy should be directed towards e.g. increasing the short-run flexibility of energy consumption patterns. Once the goals of Sweden's future energy policy are properly defined, the discussion about the suitability of various energy policy means can begin.

REFERENCES

1. Books and articles

1. Anderson, D., "Models for Determining Least-cost Investments in Electricity Supply", The Bell Journal of Economics and Management Science, Vol. 3, No 1, Spring 1972., pp 267-299.

2. Anderson, K.P., Residential Demand for Electricity: Econometric Estimates for California and the United States, Rand, R-905-NSF, January 1972.

3. Bergendahl, G., "Investment and Operation of Electricity I: A Multiperiod Cost Minimization Model for Sweden", European Institute for Advanced Studies in Management, Bruxelles 1974.

4. Bergendahl, G., "Investment and Operation of Electricity II: Price Discrimination and Nuclear Postponement", European Institute for Advanced Studies in Management, Bruxelles 1974.

5. Bergman, L., An Energy Demand Model for the Swedish Residential Heating Sector, Swedish Council for Building Research, D:4 1976, Stockholm 1976.

6. Bergman, L., Oil, Energy and the Price Mechanism: An Input-output Study of the Swedish Economy, in Energy and Environment, OECD, Paris 1974.

7. Bergman, L. - Bergström, C., Energipolitik och energianvändning, EFI, Stockholm 1974.

8. Bergman, L. - Bergström, C. - Björklund, A., An energy forecasting model for Sweden, EFI and the National Swedish Industrial Board, SIND 1976:6, Stockholm 1976.

9. Bergström, V., Industriell utveckling, industrins kapitalbildning och finanspolitiken, in E. Lundberg et al., Svensk finanspolitik i teori och praktik, Lund 1971.

10. Bergman, L. - Flam, H., Energi och ekonomisk tillväxt, Sekretariatet för framtidsstudier, R-404-76, Stockholm 1976.

11. Björklund, A., Den privata konsumtionen i EPM, EFI, mimeographed, Stockholm 1975

12. Björklund, A., Forecasting the Industrial Demand for Energy, EFI, Working Paper 6009, Stockholm 1974.

13. Christensen, L.R. - Jorgenson, D.W. - Lau, L.J., "Transcendental Logaritmic Utility Functions", American Economic Review, June 1975.

14. Dahlman, C.J. - Klevmarken, A., Den privata konsumtionen 1931-1973, IUI, Stockholm 1971.

15. Darmstadter, J., Energy in the World Economy, RfF, Baltimore and London 1971.

16. Diczfalusy, B., Energi och inkomstfördelning, Sekretariatet för framtidsstudier, R 408-76, Stockholm 1976.

17. Edblad, P.G., "Reserveffekt i ett kraftsystem", Elteknik, 1965.

18. Finon, D., "Optimization Model for the Franch Energy Sector", Energy Policy, June 1974.

19. Finon, D., Un Modele Energetique Pour la France, Centre National de la Recherche Scientifique, Paris 1976.

20. Hagman, F., Energi för vad?, Örebro 1973.

21. Halvarson, R., "Residential Demand for Electric Energy", The Review of Economics and Statistics, 57 (February 1975), pp. 12-18.

22. Hedbom, H. - Rundström, R., Tekniskt grundmaterial för energiprognosmodell, KTH, mimeographed, Stockholm 1974.

23. Herfindahl, O.C., Depletion and Economic Theory, in Geffney , M., Extractive Resources and Taxation, Madison 1967.

24. Herfindahl, O.C. - Kneese, A.V., Economic Theory of Natural Resources, RfF, Columbus 1974.

25. Hoffman, C.K., A Unified Framework for Energy System Planning, in Searl, M.F., Energy Modeling, RfF, Working Paper EN-1, Washington D.C. 1973.

26. Hotelling, H., "The Economics of Exhaustible Resources", Journal of Political Economy, 39 (April 1931), pp. 137-175.

27. Houthakker, H., "Additive Preferences" Econometrica, Vol. 28, (April 1960), 244-257.

28. Hudson, E.A. - Jorgenson, D.W., "U.S. Energy Policy and economic growth, 1975-2000", The Bell Journal of Economics and Management Science, Vol 5, No 2, Autumn 1974, pp. 461-514.

29. Höglund, B., Modell och observationer, IUI, Lund 1966.

30. Johansen, L., A Multisectoral Study of Economic Growth, Amsterdam 1959.

31. Johansson, T.B. - Lönnroth, M., Energianalys, Sekretariatet för framtidsstudier, R 403-76, Stockholm 1976.

32. Jungenfelt, K.G., Substitutionsproceserna, lecture delivered at XXII Nordiske Nationalökonomiske Möde, Reykjavik 1975, published by the Central Bank of Iceland.

33. Lancaster, K., Mathematical Economics, New York 1972.

34. Lindqvist, J., Driften av ett elektriskt produktionssystem - en flerstegs beslutsprocess", in Elkraftsamarbete i Norden, State Power Board 1961.

35. Lundberg, L., Förslag till Vattenfalls nya högspänningstaxor, Svenska Elverksföreningens förhandlingar 1972, Nr 9.

36. Lundgren, L., Energipolitik i Sverige 1890-1970, unpublished report to the Secretariat for future studies.

37. Lybeck, J., "The Allocation of Consumer Expenditures in a Swedish Macroeconomic Model, EFI, Working Paper 6033, Stockholm 1975.

38. Manne, A.S. - de la Garza, G.F. ENERGETICOS, a process analysis of the energy sectors, in Goreux, L.M. - Manne. A.S., Multi-level Planning: Case Studies in Mexico, Amsterdam 1973.

39. Nelson, J.P., "The Demand for Space Heating Energy", The Review of Economics and Statistics, 57 (November 1975), pp. 508-512.

40. Nordhaus, W.D., "The Allocation of Energy Resources", Brookings Papers on Economic Activity, 4:1974, pp. 529-577.

41. Norrby, J., "Kraftprisernas utveckling", mimeographed lecture delivered at the Federation of Swedish industries.

42. Olson, S.H., The Depletion Myth - A History of Railroad Use of Timber, Cambridge 1971.

43. Parent, J.D., Some Comments on Energy Consumption and GNP, Institute of Gas Technology, Chicago 1974.

44. Parks, R.W., "Systems of Demand Equations: An Emprical Comparison of Alternative Functional Forms", Econometrica 37, No 4 (October 1969), pp. 629-650.

45. Powell, A.A., Emprical Analytics of Demand Systems, Toronto and London 1974.

46. Reardon, W.A., Input-output Analysis of U.S. Energy Consumption, in Searl, M.F., Energy Modeling, FfF, Working Paper EN-1, Washington D.C. 1973.

47. Restad, T., Modeller för samhällsekonomisk perspektivplanering, Stockholm 1976.

48. Stone, R., "Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of Brittish Demand", Economic Journal 64, No 255 (September 1954) pp. 511-527.

49. Solow, R.M., "The Economics of Resources or the Resources of Economics", Richard T Ely Lecture at the Eigty-sixth Annual Meeting of the American Economic Association, American Economic Review, May 1974.

50. Theil, H., Principles of Econometrics, Amsterdam 1971.

51. Thoss, R. - Dölleckes, H.P., Energy and Environmental Planning, in Energy and Environment, OECD, Paris 1974.

52. Werin, L., A Study of Production, Trade and Allocation of Resources, Uppsala 1965.

53. Wickman, K., "Energipolitikens mål och medel", Svenska Kraftverksföreningen, Annual meeting 1969.

54. Åberg, C.J., Plan och prognos, Stockholm 1971.

2. Official reports and similar publications

55. CDL, Kraftutbyggnaderna 1975-1990, Stockholm 1972.

56. Finansdepartementet, Sveriges energiförsörjning 1955-1985, Ds Fi 1967:8.

57. Industridepartementet, Lägesrapport från Energiprognosutredningen, Ds I 1973:2.

58. Industridepartementet, Konsekvenser vid minskad elproduktion i kärnkraftverk, Ds I 1976:1.

59. SIND, Energiransonering i industrin, SIND PM 1:1974.

60. KTH, Institutionen för ångteknik, "Värmekraftstationers ekonomi, mimeographed, Stockholm 1972.

61. Energihushålling m.m. Regeringens proposition 1975:30.

62. SOU 1974:64, Energi 1985 2000.

63. SOU 1974:65, Energi 1985 2000, bilaga.

64. SOU 1975:85 Långtidsutredningen 1975.

65. SOU 1975:96 Energiförsörjningen 1975-1980.

66. SOU 1976:42, Långtidsutredningens modellsystem.

67. SOU 1976:51, Modeller för samhällsekonomisk perspektivplanering.

68. State Power Board, High voltage tariffs as from 1975, Stockholm 1975.