THE IMPACT OF NUCLEAR POWER DISCONTINUATION IN SWEDEN: A GENERAL EQUILIBRIUM ANALYSIS

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FOREWORD

Policy makers everywhere are increasingly being faced with problems requiring decisions with long-term consequences that are difficult to assess. With this in mind, the International Institute for Applied Systems Analysis (IIASA) has been developing models for analyzing applied policy issues, with particular emphasis on general equilibrium modeling related to the problems of small open economies.

One such small open economy is Sweden, a country that has recently been debating whether to continue its nuclear power program in view of the possible risks associated with this form of electricity generation. Prior to a national referendum on this issue, Lars Bergman was asked by a government committee to analyze the long-term economic consequences (at full employment) of discontinuing the Swedish nuclear program – his results then provided the electorate with a basis for a decision in this referendum.

The analysis was carried out using a static general equilibrium model developed at IIASA; this report presents the methodology and results of the analysis.

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THE IMPACT OF NUCLEAR POWER DISCONTINUATION IN SWEDEN

A General Equilibrium Analysis

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This study reports on methodology and results of a study of the economic consequences of a discontinuation of the Swedish nuclear program. The analysis is carried out by means of a computable general equilibrium model and is focused on the impact on real income as well as on the sectoral allocation of production and employment. The main result is that provided factor markets function smoothly enough to ensure full employment of the economy's resources, a proposed nuclear discontinuation strategy does not significantly affect the investigated macroeconomic indicators.

1. Introduction

As a result of a long and heated debate about the safety aspects of nuclear power, culminating after the accident at Three Mile Island, a referendum was held in Sweden in March, 1980, on the future use of nuclear power in the country. Two of the three alternatives in the referendum implied that all the nuclear reactors in operation or under construction should be used over their full lifetime, but no new nuclear plants should be constructed. This was the so-called 'yes' side. The 'no' side implied that the nuclear program should be stopped, and that the six nuclear reactors in operation should be closed down before 1990. In the referendum 58 % of the electorate supported the 'yes' side, while the corresponding figure for the 'no' side was 38 %.

In order to elucidate the possible economic and social consequences of a nuclear power discontinuation, and thus provide the electorate with a basis for its judgements, a government committee was set up in June, 1979. The committee should not make any recommendation or ranking of the alternatives, but highlight the differences between them in, primarily, quantitative terms.

The author was asked by the committee to carry out an analysis of the long-term economic consequences at full employment of a discontinuation of the Swedish nuclear program. A full report of the work made for the committee is given in Bergman (1980). The purpose of this paper is to present the methodology and results of that analysis. The exposition is focused on the calculated impact on real income, measured by real

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household consumption, and the sectoral allocation of production and employment.

In 1978 approximately 25% of total electricity supply in Sweden was generated by the six nuclear power reactors in operation at that time. The nuclear power program implied that six additional reactors would be taken into operation between 1978 and 1985, but after that no investments in new nuclear plants would be made. This meant that the share of electricity generated in nuclear plants would peak around the middle of the 1980s, and then gradually decline as demand grew and the twelve reactors phased out. On the basis of a recent electricity demand prediction, the maximum share of electricity from nuclear plants would be 45–50%. Thus, a discontinuation of all nuclear reactors before 1990, as was proposed by the so-called 'no-side', would indeed represent a significant change in electricity supply conditions in Sweden.

The question then is whether such a change in electricity supply conditions is likely to induce significant structural changes in the economy as a whole. In the following, three inter-related aspects of this issue are dealt with. The first is whether the nuclear power discontinuation is likely to change the aggregated rate of growth of the economy at given rates of aggregate capital formation and full employment. That could be the result of losses in allocative efficiency in various parts of the economy due to increasing scarcity of electricity.

The second aspect is whether the nuclear power discontinuation is likely to bring about a major change in the main uses of the economy resources, i.e., consumption, investment and net export. That could be the result of heavy investment in new electricity supply capacity, but also of substitution of imported fossil fuels for domestic resources in the form of nuclear capacity, leading to a deterioration of the terms of trade.

The third aspect is whether a nuclear power discontinuation is likely to lead to a significant change in the sectoral allocation of production and employment. That could be the result of higher electricity prices, deteriorating the international competitiveness of electricity intensive export and import competing sectors.

The analysis is carried out with a computable general equilibrium model of the Swedish economy. This means that the costs associated with the process of adjustment is left out from the analysis, and thus the impact analysis is confined to comparisons between different equilibrium allocations.

2. The model

The model utilized in this study is a static general equilibrium model of an open economy. This section gives a brief description of the model, which, except for some modifications in the treatment of electricity supply, is the same as the static model fully described in Bergman–Por (1981). Here, only a few remarks about the model's data-base are made, but a comprehensive description of the empirical basis of the study can be found in Bergman (1980). In order not to overburden the exposition, some aspects of the model, for instance the treatment of tariffs and indirect taxes, are left out.

In the model the growth of the labor force as well as net capital formation for the economy as a whole are exogenously determined variables. That also applies to technical change, world market conditions, and public consumption. Except for the electricity sector, where the development of production capacity is exogenously determined, the model endogenously determines a sectoral allocation of capital and labor, compatible with equilibrium on all product and factor markets as well as in foreign trade. Thus, a solution for the model establishes a system of equilibrium product and factor prices as well as a specific pattern of production, consumption, foreign trade, employment and capital use. By connecting solution for different points in time, a development path of the economy can be generated.

In each production sector capital, labour, fuels and electricity are substitutable factors of production, while the use of produced non-energy inputs is proportional to output. The production technology exhibits constant returns to scale in all sectors. However, in the electricity sector the capital stock is fixed at each point in time; consequently there are decreasing returns to scale in the electricity sector at any specific point in time.

The model describes an open economy which is 'small' in the sense that it faces an elastic supply of imports at parametric prices, and that it cannot influence the export prices of competing countries. However, in general products with a given classification supplied by domestic producers are treated as imperfect substitutes for products with the same classification supplied by producers in other countries. This approach, which is due to Armington (1969), implies that users of products with a given classification, in the 'home country' and elsewhere, actually use a composite of imported and domestically produced goods with that particular classification. The composition of the composite good is determined on the basis of some preference function. In this model the preference function is assumed to be homothetic, and to apply to all domestic users. Moreover, domestic users are all assumed to minimize the unit cost of each type of composite goods.

The adoption of this so called 'Armington assumption' has several implications. One is that there will not be complete specialization in the trade-exposed part of the economy in spite of the fact that the number of tradable goods exceeds the number of factors, and the technology exhibits constant returns to scale [Samuelson (1953)]. Another is that there will be intra-industry trade. A third implication is that the 'home' country will have some influence on its own export prices.

The model describes an economy with $n+3$ production sectors producing $n+3$ goods of which n are tradables. There is no joint production, and each good is produced in one sector only. The production sectors are numbered from 0 to $n+2$, 0 being the electricity sector and 1 the fuels production sector, while $n+1$ is the housing sector and $n+2$ the public sector. There is also a 'book-keeping' sector, $n+3$, in which different goods are aggregated into one single capital good. In this particular application, the number of production sectors was 26, i.e., $n=23$.

To begin with we disregard the electricity sector and simply assume that there is an elastic supply of electricity at the price P_0^{D} (which is endogenously determined in the model), and that there are some exogenously determined input requirements for the electricity sector. Assuming competitive conditions the prices of domestically produced goods, P_j, are equal to the unit production costs of these goods. Thus, it holds that

$$P_j=\kappa_j(P_0^{\mathrm{D}},\ldots,P_i^{\mathrm{D}},\ldots,P_n^{\mathrm{D}},W_j,R_j), \qquad j=1,2,\ldots,n+2, \tag{1}$$

where $\kappa_j(\cdot)$ is the unit cost function, and P_i^{D} the price of composite good i, W_j the wage rate in sector j and R_j the user cost of capital in sector j. The heterogeneity of labor is roughly accounted for by an exogenous wage structure, i.e.,

$$W_j=\omega_j W, \qquad j=1,2,\ldots,n+2, \tag{2}$$

where W is a general wage index and ω_j are constants. The user cost of capital is defined by

$$R_j=P_{n+3}(\delta_j+R), \qquad j=1,2,\ldots,n+2, \tag{3}$$

where P_{n+3} is the price of the aggregated capital good, δ_j the rate of depreciation in sector j and R the real rate of interest. The price index of capital goods, P_{n+3}, is defined by

$$P_{n+3}=\sum_{i=1}^{n} P_i^{\mathrm{D}} a_{i,n+3}. \tag{4}$$

As a consequence of the assumptions about technology, the unit cost function $\kappa_j(\cdot)$ can be written

$$\kappa_j(\cdot)=\kappa_j^*(P_0^{\mathrm{D}},P_1^{\mathrm{D}},W_j,R_j)+\sum_{i=2}^{n} P_i^{\mathrm{D}} a_{ij}+Q_j\bar{b}_j, \qquad j=1,2,\ldots,n+2, \tag{5}$$

where the first part reflects the minimum cost of electricity, fuels, labor and capital per unit of output, while the last two parts reflect the cost of non-substitutable inputs per unit of output. Thus, the constants a_{ij} represent the input of composite good i per unit of output in sector j, and $\bar{b}_j$ is the corresponding parameter for complementary imports. The world market price of complementary imports, expressed in the domestic currency unit, is Q_j.

The 'net unit cost' function $\kappa_j^*(\cdot)$ is derived from a nested Cobb–Douglas–CES production function, where electricity, fuels, labor and capital are variable inputs. Thus, there is a constant elasticity of substitution between a composite capital–labor input, defined by a Cobb–Douglas function, and a composite fuels–electricity input, defined by a CES function.

The equilibrium prices of the composite goods are given by the unit cost functions of the composites, i.e., by

$$P_i^{\mathrm{D}} = \phi_i(P_i, P_i^{\mathrm{M}}), \qquad i=1,2,\ldots,n, \tag{6}$$

where P_i^{M} is the exogenously given world market price, in the domestic currency unit, of import good i.

Having defined all prices in the model and the unit cost functions $\kappa_j^*(\cdot)$ and $\phi_i(\cdot)$, the derivation of the model is straightforward. Thus, there are two types of demand for composite goods, intermediate demand and final demand by the household sector. In addition there is export demand for production sector outputs.

By Shephard's lemma and the assumptions about technology, intermediate demand is given by

$$\begin{aligned} X_{ij} &= \frac{\partial \kappa_j^*}{\partial P_i^{\mathrm{D}}} X_j \quad \text{when} \quad i=0,1, \\ & \qquad\qquad\qquad\qquad\qquad\qquad j=1,2,\ldots,n+3. \\ &= a_{ij} X_j \qquad \text{when} \quad i=2,3,\ldots,n, \end{aligned} \tag{7}$$

Household demand is given by

$$C_i = C_i(P_1^{\mathrm{D}},\ldots,P_n^{\mathrm{D}}, P_{n+1}, E), \qquad i=1,2,\ldots,n+1, \tag{8}$$

where E is total household expenditures. The functions $C_i(\cdot)$ are derived from a linear expenditure system estimated on ten consumer commodity groups and a matrix defining each of the consumer commodity groups as a convex combination of composite goods. Observe that household demand for electricity is derived from the demand for housing services, i.e., C_{n+1}.

As a consequence of the 'Armington assumption' foreign demand for domestically produced goods can be written

$$Z_i = Z_i(P_i, P_i^{\mathrm{W}}; t), \qquad i = 1, 2, \dots, n, \tag{9}$$

where P_i^{W} is the exogenously given world market price, in the domestic currency unit, of goods with the classification i. In the model it is assumed that the trade-off between goods with different origins is represented by a CES function. Consequently the function $Z_i(\cdot)$ becomes

$$Z_i = A_i \left(\frac{P_i}{P_i^{\mathrm{W}}} \right)^{\varepsilon_i} \mathrm{e}^{\sigma_i t}, \qquad i = 1, 2, \dots, n, \tag{9'}$$

where A_i is a constant and σ_i the annual rate of change of production of good i in 'the rest of the world', while ε_i is an elasticity of substitution.

On the basis of Shephard's lemma the equilibrium conditions for the product markets can be written

$$X_i = \frac{\partial \phi_i}{\partial P_i} \left\{ \sum_{j=1}^{n+3} X_{ij} + C_i + X_{0i} \right\} + Z_i, \qquad i = 1, 2, \dots, n, \tag{10}$$

$$X_i = C_i, \qquad i = n+1, n+2, \tag{11}$$

$$X_{n+3} = I + \sum_{j=1}^{n+2} \delta_j \frac{\partial \kappa_i^*}{\partial R_j} X_j, \tag{12}$$

where X_{0i} are the input requirements of the electricity sector, C_{n+2} is exogenously given public consumption and I exogenously given net investments.

The demand for competitive imports is given by

$$M_i = \frac{\partial \phi_i}{\partial P_i^{\mathrm{M}}} \left\{ \sum_{j=1}^{n+3} X_{ij} + C_i + X_{0i} \right\}, \qquad i = 1, 2, \dots, n. \tag{13}$$

As $\phi_i(\cdot)$ is derived from a CES function, eqs. (10) and (13) yield the following expression for competitive imports:

$$M_i = B_i \left(\frac{P_i}{P_i^{\mathrm{M}}} \right)^{\mu^i} \{X_i - Z_i\}, \qquad i = 1, 2, \dots, n, \tag{13'}$$

where B_i is a constant and μ_i the elasticity of substitution between imports and domestically produced goods with the classification i. With this formulation the symmetry between the export and import functions becomes obvious. It also shows that the 'small country' assumption is here taken to imply that in 'the rest of the world', $X_i - Z_i \approx X_i$, i.e., that the small country's imports are negligible in relation to production in the rest of the world.

Current account equilibrium implies

$$\sum_{i=1}^{n} P_i Z_i = \sum_{i=1}^{n} P_i^{\mathrm{M}} M_i + Q_1 \bar{b}_1 X_1 + D, \tag{14}$$

where D is an exogenous variable representing imports to the electricity sector, net transfers and net interest payments. Observe that complementary imports are used in the fuels producing sector only, the main item being crude oil.

As capital and labor are inelastically supplied, the equilibrium conditions for the factor markets become

$$K = \sum_{j=1}^{n+2} \frac{\partial \kappa_j^*}{\partial R_j} X_j + K_0, \tag{15}$$

$$L = \sum_{j=1}^{n+2} \frac{\partial \kappa_j^*}{\partial W_j} X_j + L_0, \tag{16}$$

where K is capital and L is labor.

Altogether these expressions yield, after some appropriate substitutions, $6n+10$ equations in the $6n+11$ unknowns $X_1, \ldots, X_{n+3}$, $C_1, \ldots, C_{n+1}$, $Z_1, \ldots, Z_n$, $M_1, \ldots, M_n$, $P_1, \ldots, P_{n+3}$, $P_0^{\mathrm{D}}, \ldots, P_n^{\mathrm{D}}$, E, W, and R. Thus, in order to make the model complete one more equation is needed; it remains to determine the price of electricity.

All the alternatives investigated by the committee were defined in terms of production capacity and input requirements in the electricity sector. Adding the assumption that available capacity is always fully utilized, the price of electricity, P_0^{D}, has to be adjusted in a suitable way. Thus, the equilibrium value of P_0^{D} is given by

$$\bar{X}_0 = \sum_{j=1}^{n+2} \frac{\partial \kappa_j^* (P_0^{\mathrm{D}}, P_1^{\mathrm{D}}, W_j, R_j)}{\partial P_0^{\mathrm{D}}} X_j + X_{00}, \tag{17}$$

where $\bar{X}_0$ is the exogenously given maximum output in the electricity sector. This means that for each point in time and investigated alternative a set of values $\bar{X}_0, X_{00}, \ldots, X_{n0}, L_0$ and K_0 were given, while the equilibrium price of electricity was determined in accordance with eq. (17).

In order to implement the model a complete input–output table for one year as well as estimates of the parameters of the cost and household demand equations are needed. In addition, projections of the development of exogenous variables are needed. The Central Bureau of Statistics made a special revision of the 1975 input–output data, resulting in a 26×26 input–output table where the most electricity intensive parts of the industry were treated as separate sectors. Most of the remaining data was compiled and evaluated within the committee in cooperation with representatives of the Ministry of Economic Affairs and the Swedish National Industrial Board.

As the uncertainty of the substitutability of electricity and other factors of production was significant and available econometric results inconclusive, it was finally decided to assume 'reasonable' values for these parameters, and to carry out an extensive sensitivity analysis of the results with respect to these assumptions.

With this background there was not much basis for differentiation between sectors. Thus it was assumed that the elasticity of substitution between the fuels–electricity composite and the labor–capital composite was 0.25 in all industrial sectors as well as in forestry and agriculture, while it was assumed to be 0.75 in the housing sector. The elasticity of substitution between fuels and electricity was assumed to be 0.50 in the housing sector and 0.25 in the other sectors. Finally it should be mentioned that the world market price of oil, in real terms, was assumed to increase by 3% per annum between 1979 and 2000, while the corresponding figures for coal and nuclear fuel were 3% and 1.7%.

3. The alternatives

The formulation of specific alternatives was constrained in various ways. For instance, the committee should only investigate discontinuation alternatives implying that the closing down on existing nuclear plants begin in 1985 and is completed before 1990. Moreover, in view of the uncertainties about both supply and demand conditions on the electricity market, the committee did not try to identify a minimum cost discontinuation strategy within the given time constraints of the discontinuation process. Instead the committee investigated three distinct strategies, each emphasizing different types of adjustment to the loss of nuclear capacity.

A major point of departure in the formulation of the alternatives was the judgement that due to bottleneck problems and other constraints, it would not be possible to replace all nuclear capacity with other types of power plants before 1990. As a consequence of various considerations, the committee also drew the conclusion that reductions in the growth of electricity consumption beyond a certain limit would lead to obviously unacceptable costs for society.

All the alternatives explicitly treated in the analysis are based on the same assumptions about the general economic development. Thus, they only differ with respect to the assumptions about nuclear policy and energy policy in general. Under conditions of unchanged nuclear power policy and energy policy in general, i.e., under 'reference' case conditions, the economic development assumptions underlying the alternatives imply an electricity consumption level of 125 TWh in 1990. According to the committee's judgement, a major effort to replace the nuclear capacity with other power plants would make it possible to generate 105 TWh electricity that year, while a major conservation effort would reduce the need for power capacity to a level corresponding to 95 TWh annual output. Thus, each of the alternatives can be characterized by a capacity development plan for the electricity sector. In general the investigated alternatives can be described in the following way:

The reference case. In this case the nuclear program would be fulfilled, which means that in addition to the six nuclear reactors in operation in 1979, six more reactors would be taken into operation before 1985 and all twelve reactors used over their full lifetime.

The replacement case. This case implies that no new nuclear reactors would be taken into operation, and those in operation in 1979 would be closed down between 1986 and 1990. A major effort to replace the nuclear capacity by coal fired plants would be made.

The conservation case I. This case is equivalent to the replacement case in terms of the use of nuclear power. However, in this case a relatively small share of the loss of nuclear capacity would be replaced by other electricity generation capacity. Instead there is a strong emphasis on measures reducing the use of electricity, and the conservation efforts would be concentrated on the non-industrial parts of the economy.[1]

The conservation case II. This case is equivalent to conservation case I in terms of the development of the electricity production system. However, the concentration of conservation efforts on the non-industrial part of the economy would not be as pronounced as in that case. Moreover, in conservation case II substitution of oil for electricity would be restricted so that the import of oil would not exceed oil imports in the replacement case.[2] In terms of electricity consumption in 1990, the reference case implies 125 TWh, the replacement case 105 TWh and the conservation cases 95 TWh.

[1]In the model analysis, this emphasis of the conservation efforts was represented by a sectorally differentiated tax on the use of electricity.

[2]This restriction was imposed by means of an extra tax on oil consumption.

In the following, the calculated development of the economy in each of the nuclear power discontinuation cases is compared with the development in the reference case. The differences will be taken as estimates of the impact on the economy of a discontinuation of the Swedish nuclear power program.

4. Results

To begin with the calculated impact on the macroeconomic level is discussed. It should be emphasized that, except for the electricity production sector, total net investments develop in the same way in all the cases. This has two implications. First, gross investments differ between the cases as a result of different amounts of investment in the electricity sector. Second, the total stock of capital in the economy will not differ much between the cases.

As the supply of labor is exogenously given and the same in all cases, and all product and factor markets are assumed to clear, differences between the cases in terms of the development of real *GNP* essentially are the results of differences in allocative efficiency. The results in tables 1–3 clearly suggest that such efficiency losses were insignificant. As the full-employment *GNP* is not much affected by the investigated policies, we turn to an analysis of how that *GNP* is used in the different cases.

It should then be noted that real public consumption is exogenously determined and grows by 1.5% per annum. The growth of total net investments is also exogenously determined and equal to 2.5% per annum. Thus the only 'truly' endogenous macroeconomic use categories are real household consumption and real net exports. Although not perfect, real household consumption is taken as an indicator of the real disposable income of the household sector. Accordingly much of the following discussion is focused on that variable.

As can be seen in tables 1–3, a discontinuation of the nuclear power program affects real household consumption both through an increase in net

Table 1

The impact on macroeconomic variables 1990 and 2000 in the replacement case.[a]

	10^9 SKr (1979)		Percentage points	
	1990	2000	1990	2000
Household consumption	−8.4	−6.7	−2.9	−1.9
Public consumption	0	0	0	0
Gross investments	3.3	0	2.3	0
Exports	3.2	4.4	1.2	1.2
Imports	0	−0.6	0	−0.2
GNP	−1.9	−1.7	−0.3	−0.2

[a]Absolute and relative differences from the reference case.

Table 2

The impact on macroeconomic variables 1990 and 2000 in the conservation case I.[a]

	10^9 SKr (1979)		Percentage points	
	1990	2000	1990	2000
Household consumption	−6.5	−11.3	−2.2	−3.2
Public consumption	0	0	0	0
Gross investments	−0.8	−1.2	−0.5	−0.7
Exports	−0.3	−0.5	−0.1	−0.1
Imports	−3.5	−5.6	−1.8	−2.2
GNP	−3.5	−7.4	−0.5	−0.9

[a]Absolute and relative differences from the reference case.

Table 3

The impact on macroeconomic variables 1990 and 2000 in the conservation case II.[a]

	10^9 SKr (1979)		Percentage points	
	1990	2000	1990	2000
Household consumption	−8.3	−16.5	−2.9	−4.7
Public consumption	0	0	0	0
Gross investments	−0.9	−1.5	−0.6	−0.8
Exports	−2.4	−2.9	−0.9	−0.8
Imports	−6.3	−10.5	−3.4	−4.3
GNP	−5.3	−10.4	−0.8	−1.3

[a]Absolute and relative differences from the reference case.

exports and a decrease in *GNP*. Generally, the former effect is quantitatively more important than the latter. Although the three discontinuation cases have many similarities, there are also some rather important differences. In the replacement case, the impact on *GNP* is smaller than in the conservation cases. This is, of course, due to the less ambitious electricity conservation program in the replacement case. However, in terms of the loss in real household consumption, the smaller loss in *GNP* is more than counterbalanced by an increase in gross investments during the first part of the period, here represented by the year 1990. That is the result of the far-reaching replacement of nuclear capacity with other electricity generating capacity in this case.

The replacement case also differs from the conservation cases in terms of the development of export and import. Due to the somewhat lower *GNP* the volume of non-energy imports is decreased, but as the use of coal for electricity production increases and oil replaces electricity in some uses, the import of fossil fuels increases. In the replacement case the net effect in volume, or constant price, terms is zero 1990 and slightly negative at the year 2000. Due to the assumption that fossil fuel prices increase faster than other import prices, however, the change in import composition increases total imports in value terms. Accordingly net exports in volume terms have to increase in order to maintain external balance. This effect explains why the level of household consumption in the replacement case is significantly lower than in the reference case in spite of the small differences in terms of real *GNP*. In the replacement case, the higher net exports imply a larger volume of gross exports than in the reference case. In the conservation cases, on the other hand, the decrease in *GNP* is larger and the increase in fossil fuel imports smaller than in the replacement case. As a result the necessary increase in net exports takes place at a lower level of gross exports than in the reference case.

The differences between the cases in terms of the macroeconomic development can be seen as a summary description of a number of differences on the microeconomic level. These include differences in terms of input–output relations in the production sectors as well as differences in foreign trade and domestic consumption patterns. Each of the cases represents an equilibrium in the economy. Consequently the system of relative goods and factor prices also differ between the cases.

In the discontinuation cases the equilibrium price of electricity is higher than in the reference case. This is primarily because the replacement of the nuclear capacity with other electricity capacity leads to higher production costs. But since there are also limitations on the rate at which replacement capacity can be installed, the market clearing price might be higher than the direct cost of producing electricity. Thus, the calculated equilibrium price of high voltage electricity in the replacement case is about 50% higher than in the reference case. The corresponding figures for conservation case I and conservation case II are 80% and 100% respectively.

In spite of the possibilities of substituting other inputs for electricity, the production costs for electricity intensive products will be higher in the discontinuation cases than in the reference case. Consequently the sector producing such products will be less competitive on domestic and foreign markets.

If some sectors are less competitive in the discontinuation cases than in the reference case, the opposite must hold for some other sectors. Otherwise there will be insufficient demand for labor and capital and external balance cannot be maintained. Accordingly equilibrium in the discontinuation cases implies that the higher electricity prices have to be balanced by lower prices on other inputs. Since the prices of produced inputs are derived from the prices of primary inputs, that is, capital, labor and natural resources, the

Table 4

Calculated equilibrium wage and profit indices.

	Reference case		Replacement case		Conservation case I		Conservation case II	
	1990	2000	1990	2000	1990	2000	1990	2000
Wage index[a]	100	100	98.8	97.1	97.6	95.0	95.6	93.3
Profit index[b]	100	100	96.4	96.0	96.4	96.0	92.9	96.0

[a]The variable W in eq. (2).
[b]The variable R in eq. (3).

higher electricity prices have to be balanced by lower wages, profits and rents. Since the model does not treat natural resources explicitly, these effects will be entirely reflected in wages and profits in this analysis. In table 4 the calculated equilibrium wage and profit indices can be seen.

In view of the significant increases in equilibrium electricity prices, the resulting adjustments in factor prices may seem small. However, generally the share of electricity costs in total production cost is lower than 2 to 3% in the Swedish economy. The exceptions from this rule can primarily be found in the iron and steel industry, the paper and pulp industry and the chemical industry. For example, in the electrochemical industry, which is a part of the aggregated chemical industry, the electricity cost share is over 20%. However, since other parts of these relatively electricity intensive aggregated sectors use much less electricity per unit of output, the electricity cost shares of the 26 aggregated sectors explicitly treated in the model are all lower than 4%.

With this background it is not likely that small changes in the relative price of electricity will have a significant impact on the sectoral composition of the economy. Electricity price increases in the order of magnitude discussed in the previous, that is 50 to 100%, are, however, likely to have such effects. These electricity price increases are likely to initiate a change in the structure of the economy in terms of the 26 aggregated sectors distinguished in the model, as well as a change in the internal structure of these sectors. By definition the model results are confined to the first, 'between-sector', type of structural change. In tables 5 and 6 the main results of the sectoral analysis can be seen. The estimated impact on the other sectors was quite insignificant.

It is clear from tables 5 and 6 that the combination of higher electricity prices and lower wages and profits implies an equilibrium structure where production and employment are lower in the most electricity intensive sectors, but higher in the less electricity intensive, and rather labor-intensive, manufacturing industry, than in the reference case. The reallocation of

Table 5

Calculated impact on output 1990 and 2000 in selected sectors.[a]

	Replacement case		Conservation case I		Conservation case II	
	1990	2000	1990	2000	1990	2000
Forestry	+0.4	−0.8	−1.2	−5.4	−7.9	−11.0
Paper and pulp industry	+0	−1.4	−2.9	−7.8	−14.5	−16.3
Chemical industry	−0.3	0	+0.3	+0.4	+5.5	−5.5
Iron and steel industry	+0.7	+0.5	+0.6	+0.6	−4.1	−1.2
Manufacturing industry	+1.2	+0.9	+0	+0.6	+2.1	+2.2

[a]Percentage difference in the level of output between the reference case and the discontinuation cases.

Table 6

Calculated impact on employment 1990 and 2000 in selected sectors.[a]

	Replacement case		Conservation case I		Conservation case II	
	1990	2000	1990	2000	1990	2000
Forestry	−1.0	−1.9	−1.9	−5.0	−9.6	−11.4
Paper and pulp industry	+0.4	−0.8	1.6	−5.6	−12.6	−14.1
Chemical industry	−0.3	−0.2	+0.9	+0.8	−4.3	−4.2
Iron and steel industry	+1.2	+1.0	+1.9	+2.1	−1.7	+0.5
Manufacturing industry	+1.1	+0.9	+0	+1.3	+2.3	+3.0

[a]Percentage difference in the level of employment between the reference case and the discontinuation cases.

resources from the iron and steel industry, forestry and the paper and pulp industry to the manufacturing industry represents an amplification of tendencies which are very pronounced already in the reference case. The relative contraction of the chemical industry, however, represents a weakening of the reference case trend.

The main reason for the contraction of the paper and pulp industry, the chemical industry, and the iron and steel industry, is the reduction in international competitiveness for these sectors, resulting from the electricity price increase. In the case of the paper and pulp industry, there is no counteracting factor, and the reduction in exports leads to a reduction in production and employment. It should be noted that the former effect is somewhat stronger. This is because the reduction in employment is counteracted by substitution of labor for electricity and consequently the methods of production becomes somewhat more labor-intensive.

In the iron and steel industry, however, the reduction in exports is counteracted by an expansion of the domestic market. Because of the electricity price increase, the iron and steel industry loses market shares both at home and abroad, but in spite of that the volume of sales to domestic users increases. The reason for this is the expansion of the manufacturing industry which is a big user of the output of the iron and steel industry.

The results for the forestry sector are also due to the, in this case somewhat dubious, intersectoral dependencies in the model. Presently the paper and pulp industry is the main buyer of the output of the forestry sector, and that is of course reflected in the input–output relations (based on data for 1975) incorporated in the model. However, a substantial electricity price increase may contribute to a change, which is already taking place, of the domestic market for forestry products. The relative competitiveness of the wood products industry is increasing and the use of the forestry output for energy purposes is becoming increasingly profitable. Accordingly, a decline of the paper and pulp industry need not lead to a similar reduction of production and employment in the forestry sector.

All these results depend on a number of assumptions on parameters and exogenous variables in the model. These assumptions are, of course, more or less uncertain. Consequently an analysis of the sensitivity of the results with respect to variations in strategic assumptions is needed.

A number of such sensitivity analyses were carried out. In many cases the results of an individual simulation turned out to be quite sensitive to the assumptions made on parameters and exogenous conditions. For instance, the calculated share of real household consumption in real *GNP* turned out to be quite sensitive to the assumptions on fossil fuel prices and the growth of Sweden's major export markets. However, the calculated difference between the cases were generally quite robust in the sense that they were not much affected by variations in the assumptions about the general economic conditions in terms of factor accumulation and world market conditions.

The assumptions which turned out to be most important for the difference between the four cases dealt with in this analysis were those about fossil fuel prices and the substitutability of energy and primary factors of production, i.e., labor and capital. Thus, when the assumed increase of fossil fuel prices was reduced from 3% to 2% per annum, the 1990 loss in terms of real household consumption in the replacement case was reduced from $8.4 \cdot 10^9$ SKr. to $7.1 \cdot 10^9$ SKr.

In the other sensitivity tests the substitutability of energy and primary inputs was varied. Thus, the elasticity of substitution between aggregated energy and aggregated capital/labor was increased from 0.25 to 0.75 in all industrial sectors. As a result the loss of real household consumption was reduced from $8.4 \cdot 10^9$ SKr to $6.3 \cdot 10^9$ SKr.

5. Conclusions

Clearly estimates of the type presented above are very uncertain; neither the conceptual nor the empirical basis for the analysis is good enough to provide definite answers to the type of questions posed. A model analysis of the type presented can, however, sort out factors which seem to be the important determinants of future economic development. The most important limitations of the adopted approach seems to be the neglect of disequilibrium phenomena and the relatively high level of aggregation.

When the impact of the investigated policy is defined in terms of differences between equilibrium allocations, various kinds of adjustment costs are, by definition, neglected. For instance, reallocations of the labor force between sectors, regions, and occupations are important parts of the adjustment to a new electricity supply situation. In connection with such reallocations there might be periods of unemployment. Most likely there are some costs for retraining, either in the form of costs for formal education or in the form of low productivity during periods with 'on the job training'. If people have to move between geographical locations there are costs for the physical transportation, but there can also be capital losses if the net outflow of people from a given location affects the housing market or the base for various kinds of public and commercial services.

The potentially most significant type of adjustment cost is probably the cost due to periods of increased unemployment in connection with reallocations of the labor force. If the attainment of the 'new' equilibrium allocation implies substantial reallocation of the labor force, the losses due to a temporary increase of unemployment can be substantial. That is also the case if it takes a considerable time before some industries can expand enough to absorb all those who lost their jobs in industries particularly hurt by the policy in question. The existence and length of such time lags primarily depends on the rate at which relative factor prices can be adjusted when the economy's productivity is reduced. It is obvious that if adjustment problems are significant, that will have an impact on the rate of capital formation and productivity growth.

It is very difficult to estimate the quantitative significance of adjustment costs in connection with a discontinuation of nuclear power. However, a rough indication is given by the difference, in terms of sectoral use of capital and labor, between the reference case and the discontinuation cases. That is, adjustment costs can be assumed to be an increasing function of the need to adjust. On this basis, and considering that the full impact of the nuclear power discontinuation would not have been felt until the end of the 1980s, adjustment costs do not seem to be a major share of the total cost of a nuclear power discontinuation; the investigated cases do not differ significantly in terms of the sectoral allocation of the labor force. However, it is quite possible that the relatively high level of aggregation in the model analysis 'hides' more significant structural changes.

Another neglected aspect in the model analysis is how the different alternatives affect Sweden's vulnerability to unexpected disturbances in the supply of energy. The discontinuation alternatives increase the economy's dependence on imported fossil fuels, but most of that is an increase of coal imports. However, before the coal power plants can be taken into operation (after 1987) the use of existing oil-fired power plants will increase.

That will make the power system more vulnerable to oil embargos and oil price increases. Moreover, the amount of reserve capacity in the power system will be smaller than in the reference case. This means that a dry year leading to a small output of electricity from hydropower plants will affect cost and capacity conditions more in the discontinuation cases than in the reference case.

However, after 1985, the reference case is more vulnerable to supply interruptions in the nuclear power plants. Thus, if the twelve-reactor program is fulfilled and, for some reason, a *rapid* discontinuation of these plants is regarded as necessary in the beginning of the 1990s, that is likely to have a significant impact on the economy. Apparently unexpected disturbances can appear in all cases and it is by no means clear whether the neglect of 'disturbance' costs means that the differences between the alternatives have been overestimated or underestimated.

One factor that could lead to an overestimation of the cost of nuclear power discontinuation is the way in which the assumptions about future coal prices were made. Since Sweden has no coal deposits the coal has to be imported. The committee's assumption was that the import price of coal would be closely linked to the import price of oil, i.e., that oil should be the price leader on the market for fossil fuels. Accordingly, coal prices were assumed to increase at the same rate as oil prices. That is a reasonable but not obvious assumption. Alternatively it is possible that future import prices for coal primarily will reflect the costs for mining and transportation. If that is the case, the assumption that coal prices will increase by 3% per annum in real terms seems to be on the high side.

The results of the analysis seem to suggest that if product and factor markets function smoothly enough to maintain full utilization of the economy's resources, an economy such as the Swedish can accommodate quite significant changes in electricity supply conditions without major changes in main economic indicators. If the adjustment to a new electricity supply situation entails periods of excess capacity and increased unemployment the outcome might be quite different. However, analysis of adjustment costs is beyond the scope of this study.

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