ENERGY IN SWEDISH MANU-FACTURING

The Industrial Institute for Economic and Social Research, Stockholm

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Energy in Swedish Manufacturing

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Energy in Swedish Manufacturing

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Foreword

During recent years a major research effort of IUI has been directed towards analyzing the role of energy in the Swedish economy and ways of adjusting the economy to disturbances in the energy markets. The project – called Energy and Economic Structure – has been funded by the Energy Research Commission. It was carried out in association with the Economic Research Institute at the Stockholm School of Economics. B.-C. Ysander has been coordinating the project at the IUI and K.-G. Mäler has been responsible for the Stockholm School part. The Energy System Research Group at the University of Stockholm – FFE – has also taken part in the project. Detailed documentation of this work has been and will be published by IUI.

The papers collected in this volume are mainly concerned with mapping and measuring energy use and energy substitution in Swedish manufacturing. Various kinds of models are used, ranging from static production functions and vintage models estimated from time-series data to LP-models based on cross-section data and engineering blueprints. In addition to these estimates of energy use, the postwar development of energy prices for the various industrial bransches is described in the beginning of the book. Projections into the future of industrial energy use are also presented.

Stockholm in October 1983

Gunnar Eliasson	Rune Castenäs	Åsa Sohlman
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Measuring Energy Substitution
An Introduction

by Bengt-Christer Ysander*

For a small open country like Sweden the ability of the manufacturing industry to adjust rapidly and smoothly to changes in relative world prices is of crucial importance. The oil price hikes in the 70s tested this ability in a dramatic fashion, creating at the same time a particularly good opportunity for studying the mechanisms and the adjustment problems involved in industrial factor substitution. Economists all over the world have hastened to exploit this opportunity and, as a result, our knowledge of industrial production structure and factor adjustment has increased considerably over the last few years.

The papers assembled in this volume, focusing on energy use in Swedish manufacturing, all share this common aim of mapping and measuring industrial adjustment to price changes. However, as appropriate for a still developing research area, they try alternative approaches, using different models and analytical techniques.

Mechanization and energy use - the postwar experience

From the end of the war and up to the first oil price hike the ongoing mechanization had a dominant influence on energy use in Swedish manufacturing. This is one of the main lessons to be learned from the first paper — by Joyce Dargay — tracing energy prices and energy use in the postwar period.

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Mechanization meant continuous substitution of both capital and energy for labor in industrial production and it usually also meant electrification. The specific use of electricity (i.e., electricity input per unit of output) in manufacturing thus increased steadily during the 50s in spite of sharply rising electricity prices, stagnated in the 60s when prices were falling both in absolute terms and relative to other energy prices, but started mounting again in the latter part of the 70s, when electricity prices were catching up with other energy prices.

The other dominant postwar trend in energy use, viz. the switch from solid fuels to oil, can also partly be interpreted as a way of saving labor, whose wages, up to 1973, grew steadily faster than both capital and energy costs. Although the coal price paid by manufacturing industry tended to keep pace with the oil price, although with a certain time-lag, the labor costs involved in handling coal made oil advantageous to use, at least up to the first oil price hike. In terms of specific usage the main switch to oil occurred already in the early 50s. Although prices for heavy oil were completely stagnant up to the middle 60s, the specific oil use in manufacturing did not increase further during this period. The first oil price hike led to a considerable drop in specific oil usage, which then further declined at the end of the decade.

The continued rapid decrease in the use of solid fuels together with the curtailed oil use during the 70s, resulted in a steady reduction in total specific energy use from the middle of the 50s. About a quarter of this total energy saving was due to the changing branch structure. With a few exceptions — printing, chemicals and shipbuilding — the energy/output ratio fell in all manufacturing branches.

The dominant influence of mechanization and labor saving on industrial energy demand underlines the importance of analyzing energy use within the framework of production models, incorporating all the substitution possibilities between different inputs.

There are wellknown reasons for distinguishing also between manufacturing branches with different technologies, different capital/ output and energy/output ratios. The price data collected by Dargay indicate another and less discussed reason for disaggregation. They show i.a. that in 1968 the energy intensive branches — pulp and paper, chemicals, primary metals and non-metallic mineral products — paid on the average 1/7 less for heavy oil and only half for electricity compared to other branches. After 1973 there is, however, a considerable convergence of energy prices between branches — in the case of petroleum products partly due no doubt to a shortening of contract lengths and a reduced significance of rebates to large consumers. The energy intensive branches thus faced a rise in energy prices during the first half of the 70s that was on the average 40 % larger than that experienced by the other sectors.

Alternative ways of measuring factor substitution

Any attempt to explain and measure the possibilities of factor substitution in industry must at the start make two kinds of basic choices: a choice of aggregation level and a choice of adjustment paradigm.

The choice of aggregation level involves at least three different dimensions of the production structure: technologies, factors and firms.

There is obviously a limit to the degree of technological detail that could and should be included in an economic production model. The use of approximate (or "generalized") descriptions of technologies in the form of production functions and of aggregations of those over different technologies has the advantage of small data requirements and computational ease. The disadvantage is the introduction of approximation and aggregation errors in the numerical results. The risk of distorted and biased results caused by the functional approximation is particularly great if the functions used are such as to place a priori restrictions on the factor substitution to be measured. Fortunately, theoretical research in the 60s and 70s has provided us with a family of flexible functional forms — like the generalized Leontief and the translog — which i.a. do not assume any restrictions on substitution elasticities. (For a short survey of these developments cf Field-Berndt, 1981). Simulation experiences indicate, however, that the aggregation error may still be large enough to make it difficult to get stable and consistent estimates on substitution relationships from aggregate descriptions of technologies (cf. Kopp-Smith, 1981).

The conditions for subsuming different machines and constructions under an aggregate capital measure in the production function, or for aggregating different labor inputs, have been thoroughly discussed over the past years. In the present studies we have to deal with yet another kind of factor aggregation — the aggregate treatment of different sources of energy: petroleum products, solid fuels and electricity. This brings into focus two new and interesting questions. Is the supply of energy to industrial plants so flexibly designed that energy production from different sources, the primary energy allocation system, can be treated as completely independent — or "separable" — from other technological decisions?

The second question is concerned with causation in the opposite direction. How much will the optimal internal allocation of "composite capital" depend on the relative price of energy and the way it is produced? As stated above already, our intuitive reading of the postwar experience indicates a rather strong dependence both ways. The rapid substitution of oil for coal in the 50s was probably not only motivated by labor saving but in part dictated by the new technologies imported from the U.S. On the other hand it seems evident that the oil price hikes in the 70s had an important and different impact on the profitability of different types and vintages of existing production capital. Any results of studies dealing with aggregate capital and energy in the conventional way must therefore be interpreted with great caution.

Aggregating over firms adds yet another problem dimension, since i.a. the rate of utilization in the firms may vary with their different positions and strategies in the market and the resulting allocation of production between firms may not be stable over time.

Having decided on the proper level of aggregation, one is still left with the choice of adjustment paradigm, i.e., the decision about how to model the way production is adjusted to market changes.

One part of this choice is concerned with modeling the market on which the producers are supposed to operate. If one should take into account the particular kind of say oligopolistic market structure involved, should discern both sides of the mutual adjustment of supply and demand, and consider also the possibility of disequilibrium pricing, the modeling ambitions could easily outrun the available resources for estimation. The market is therefore usually treated in a very simplified manner, e.g., by assuming the producers to be price takers and/or to operate within fixed market shares.

Changes in market conditions should call forth two kinds of supply adjustment. The short-run adjustment is concerned with accommodating the market changes within existing capacity by changing the current production and with that the cost-minimizing input demands. The long-run adjustment is initiated by capacity changes, due both to technological changes and to investment/scrapping activities. Since adjustment is costly and time-consuming the relevant decisions will stretch far into the future, and will depend on expectations which in turn may be built on historical experience going far back in time. Because of the obvious difficulties involved, very few attempts have been made so far to model this adjustment process explicitly as an intertemporal optimization under uncertainty. In most studies the dynamic element is simply represented by some rather ad hoc lag structure or accelerator relation. (For a thorough discussion of the various stages of dynamic adjustment representation, see Berndt, Morrison, Watkins, 1981). Indeed the majority of studies on factor substitution documented so far are based on static models which completely disregard the existence of adjustment constraints, assuming instead full and instant adjustment. As for technical change, whether embodied or disembodied, it is usually, for the sake of computational convenience, treated as neutral. This means disregarding the possibility — observed in many econometric studies — that the rate and direction of productivity change may depend on relative factor prices.

Most of these problems of simplification and model choice are exemplified in the four studies of industrial substitution possibilities contained in Part II. Table 1 gives some indication of the variety of models and methods used by the different authors. The first five columns are concerned with characteristics related to aggregation, the next two columns reflect the choices of "adjustment paradigm" while the last indicates the method of estimation.

Dargay uses time-series data to estimate factor cost shares for twelve manufacturing branches. Her translog cost functions include capital, labor, intermediate goods and energy as arguments, with the aggregate energy input being alternatively measured directly in terms of physical energy units or estimated indirectly as a cost-minimizing mix of primary energy inputs. Her model is essentially static with Hicks neutral technical change. Both a homothetic and a non-homothetic functional form were tried, with the non-homothetic formulation giving more significant and consistent results. Dargay did not, however, succeed in producing separate estimates of rates of return to scale and technical change. An FIML estimation program was used in two stages — firstly to estimate the cost-minimizing energy mix and secondly to estimate the cost-shares of the aggregate factors.

The Jansson study of the Swedish iron and steel industry is based on the same time-series data as the Dargay study, deals with the same aggregate factors — although assuming proportionality in

Table 1 **Four approaches to measuring factor substitution**

Author	Data	Coverage	Level of aggregation	Production factors in estimation	Form of cost function	Adjustment constraints	Technical change	Method of estimation
J. Dargay	Time-series 1952-76	Total manu-facturing	Twelve branches	C,L,M,E, E(e,o,s)[a]	Translog	-	Hicks neutral	Two-stage FIML
L. Jansson	Time-series 1952-75	Iron and steel	Capital vintages of branch	C,L,E[a]	-"-	Vintage capital, demand and profit de-velopment	-"-	FIML
L. Hultkrantz	Cross-section statistics and engineering data, 1979	Wood, pulp and paper in northern Sweden	Production activities within plants	I,L,M,e,o[a]	Linear	Supply constraints, current capacity and available investment options	-	LP
S. Lundgren	Engineering data	Iron and steel	Production activities	C,L,M, e,o,s[a]	-"-	Short run: capacity constraints Long run:-	-	LP

[a] C = Capital
L = Labor
E = Energy
M = Intermediate goods
I = Capital investment
e = electricity
o = oil
s = solid fuels

the use of intermediate goods — and used the same FIML estimation program. However, there are several important differences between his study and that of Dargay. In the Jansson study the different annual vintages of production capital are distinguished in the model. Even more important, Jansson's model, which is of the "putty-clay" type, attempts to explain adjustment in terms of gross investment and scrapping of production capacity, with the technology of the new capacity reflecting current factor prices. In such a dynamic model, "substitution effects" in terms of technological adjustment in new capacity to short-term changes in factor prices, may be overlaid and dominated by "vintage effects", resulting from adding new capacity to an existing stock which reflects techniques and prices over the past thirty years. Two inputs — like capital and energy — may then be substitutes in the technological sense and yet be complementary over time, even without non neutral technical change. In this way, the Jansson study reconciles the diverging and controversial results obtained in earlier studies of the elasticity of substitution between capital and energy in various manufacturing branches.

The two following studies both use a radically different approach. Instead of time-series data they use cross-section and/or engineering data and are then able to model individual production activities within the branch in question. For the same reason there is no need for them to try to aggregate the diverse kinds of primary energy resources. To be able to handle this mass of technological information, they are forced to linearize all relations, so that optimal production plans can be computed with linear programming techniques. While in the preceding studies elasticities of substitution could be computed from parameters of the estimated functions, they can now only be very roughly approximated by comparing the outcome of different runs of the LP-models.

Hultkrantz' study of the wood, pulp and paper industry in northern Sweden encompasses two periods and includes different packages of investment options for the two time horizons. The options are those currently considered by the firm at the time of the enquiry (1979). In terms of this multiperiod model Hultkrantz can define a concrete and specific meaning and measure for the distinction between short-run and long-run adjustment. A special feature of the Hultkrantz model is the fact that the paper and pulp industry is here embedded within a larger model, which takes explicit account of alternative uses of wood — for the sawing industry and more particularly for heat generation. One of his main conclusions, of great importance and relevance for current Swedish energy policy, is that only very drastic further increases in the relative oil price could make wood-based heating stations a serious competitive threat for the forest-products industries. This and related results are derived by maximizing the quasi-rents to industrial capacity and the price of stumpage subject to the constraints set by industrial capacity, investment opportunities and available volumes of wood of different kinds.

Lundgren's study of the iron and steel industry is entirely based on engineering data and blueprints for future technologies. His model is essentially a static one-period model with explicit capacity constraints. Long-run adjustment can be defined and measured by eliminating all capacity constraints. While Hultkrantz' experiments are based on maximizing profits or quasi-rents, Lundgren's simulations all deal with cost-minimization, holding the output mix constant.

Some numerical results

Four different ways to model reality lead to four different modes of designing questions about factor substitution — and imply four different types of answers. We will make no attempt here to survey or summarize the numerical results recorded in the four studies in Part II. The examples presented in Table 2 below merely serve the purpose of illustrating the variety of numerical experiments performed and of substitution mechanisms investigated.

Table 2 **Elasticities of substitution - some numerical results***

Author	Type of elasticity	Branch	Energy(oil) - - Capital	Energy(oil) - - Labor	Oil - Electricity	Energy (oil)
J. Dargay	Allen partial elasticity of substitution = σ	Total manufacturing	$\sigma_{EC} = -1.43$[1]	$\sigma_{EL} = 0.12$[1]	$\sigma_{oe} = 0.21$[2]	$\varepsilon_{oo} = -0.29$[3]
	Price elasticity = ε	Wood, pulp and paper	$\sigma_{EC} = -0.59$[1]	$\sigma_{EL} = 0.02$[1]	$\sigma_{oe} = 0.22$[2]	$\varepsilon_{oo} = -0.28$[3]
		Iron and steel (Primary metals)	$\sigma_{EC} = -0.66$[1]	$\sigma_{EL} = -0.61$[1]	$\sigma_{oe} = 0.24$[2]	$\varepsilon_{oo} = -0.26$[3]
L. Jansson	-"-	Iron and steel	$\sigma_{EC} = 0.82$[4]	$\sigma_{EL} = 2.63$[4]		$\varepsilon_{EE} = -0.98$[4]
L. Hultkrantz	Arc cross-price elasticity = e (profit maximization under supply and capacity constraints)	Wood, pulp and paper in northern Sweden	$e_{Io} = -0.57$[5]	$e_{Lo} = -0.29$[5]	$e_{eo} = -0.72$[5]	$e_{oo} = -0.49$[5]
S. Lundgren	Arc cross-price elasticity = e (cost minimization for given output mix)	Iron and steel			$e_{eo} = -0.26$[6]	$e_{oo} = -4.3$[6]

[1] Homothetic cost function, direct estimates.

[2] Partial substitution effects, total energy consumption constant.

[3] Total own-price elasticity, non-homothetic total cost function.

[4] Elasticities of the ex ante production function

[5] 50% oil price increase, long-run adjustment including output change.

[6] 50% oil price increase, long-run adjustment without investment constraints, output constant.

The different approaches are reflected in different notions and measures of the elasticity of substitution.

The concept of elasticity of substitution, as originally introduced by Joan Robinson (Robinson, 1933), is intended to measure the ease of substituting between two inputs, when output is held constant. It is usually defined as the derivative of the ratio of two input levels with respect to the ratio of the two corresponding input prices. For a production function with two inputs, $Q = f(x_1, x_2)$, and the corresponding input prices, p_1, p_2, the elasticity of substitution can be written as:

$$\sigma_{12} = \sigma_{21} = \frac{d \ln(x_1/x_2)}{d \ln(p_2/p_1)}$$

σ_{12} here grows larger as substitution becomes easier. Also, when $\sigma_{12} > 11$, the cost share of input 1 becomes larger relative to the cost share of input 2 when input 2 becomes relatively more expensive.

With more than two inputs involved, however, different definitions of elasticity result from different choices of the ceteris paribus conditions under which the partial derivatives are obtained.

The most commonly used definition — the Allen-Uzawa partial elasticity of substitution — is simply a price cross elasticity weighted by the inverted value of the corresponding cost share:

$$\sigma_{ij} = \left.\frac{d \ln(x_i/x_j)}{d \ln(p_j/p_i)}\right|_{Q=\bar{Q}} = \frac{1}{p_j x_j / \sum_i p_i x_i} \cdot \left.\frac{d \ln x_i}{d \ln p_j}\right|_{Q=\bar{Q}} = \frac{1}{k_j} \varepsilon_{ij},$$

where k_j denotes the cost share of the jth input. In this definition all other inputs adjust optimally to the price change.

As shown in Table 2, Dargay's elasticity measures for total manufacturing show complementarity between capital and energy, while energy and labor appear to be relatively independent of each other. Oil comes out as a rather poor substitute for electricity, and also registers a low own-price elasticity.

Her results for the wood, pulp and paper industry, also shown in the table, are very similar to those for total manufacturing although the complementarity between capital and energy does not register as strongly for this branch.

For iron and steel and other primary metal industries the one main divergence in results, compared to the wood, pulp and paper industry, is the complementarity here registered also between energy and labor.

As for intermediate goods, Dargay's results seem to support the conclusion from Parks' earlier study of Swedish manufacturing 1870-1950, that capital and labor in most branches are not separable from intermediate goods (Parks, 1971).

In Jansson's production model for the iron and steel industry a distinction can be made between the "potential" substitution possibilities of the ex ante production function and the actual realized substitutions, which may to a large degree be determined by "vintage effects", i.e. by the inertia due to older capital vintages. This may explain why energy shows up in his study as a strong substitute in the more narrow technological sense for both capital and labor, while the opposite result is derived from Dargay's static model.

The elasticity measures recorded in the LP studies of Hultkrantz and Lundgren are quite different from those used in the preceding papers. Firstly, they are arc elasticities, which means that instead of being computed from parameters of estimated production functions, they are rough measures of average effects of intramarginal — and in fact quite drastic — price changes in the model simulations.

Secondly, there are in the simulations important constraints — concerning production capacity and raw material supply — on the adjustment of inputs. In this regard their elasticity measures are not so much related to the Allen-Uzawa elasticity as to the concept of "direct" elasticity of substitution, which holds constant other inputs than those directly concerned (McFadden, 1963).

Thirdly, what they compute are straightforward cross price elasticities and not elasticities of substitution, although these two concepts are closely related (cf. above).

Finally, in the case of Hultkrantz, the elasticities are not computed with output held constant, which means that the measured effects of input price increases are also influenced by shrinking total production.

This last point probably to a large extent explains why Hultkrantz finds energy to be a complement not only to capital but also to labor. For the case of regular neoclassic production functions it has been shown (Field-Allen, 1981) that a cross price elasticity with freely variable output can be defined as;

$$\eta_{ij} = \left.\frac{d \ln x_i}{d \ln p_j}\right|_{\substack{p_k = \bar{p}_k \\ k \neq j}} = \varepsilon_{ij} + k_j \eta \psi,$$

where k_j is the cost share of the jth input, η denotes the (cost) price elasticity of output, while ψ represents a function of the rate of return to scale such that $\psi = 1$ when this rate is constant.

In Hultkrantz's model, output will decrease with rising costs while the rate of return to scale is non-increasing. Even if an oil price hike would mean that capital and labor tended to replace energy the consequent downscaling of production could therefore lead to complementarity being registered with this kind of elasticity measure. The same evidently is true in regard to the substitution relation between electricity and oil.

The weak complementarity between oil and electricity in Lundgren's model of the iron and steel industry seems instead to be caused mainly by switches between different technologies. In the short-run version, with effective constraints on investment, the sign of the elasticity is reversed due to the fact that the electric arc furnace is then still a viable option. The own-price elasticity for oil recorded by Lundberg for the long-run version seems surprisingly large, which may at least partly be due to his probably unrealistic assumption of flexible furnace equipment, making possible a costless switch from oil to internally generated fuels like coke-oven and blast-furnace gas.

Structural change and energy use in the future

One of the reasons for measuring substitution possibilities is the need to gauge the future energy requirements in Swedish manufacturing. To discern future trends in industrial energy demand, one must study the dynamics of industrial investment and growth, analyzing the effects on specific energy use and tracing the changing branch composition.

That is the aim of the study by Ysander-Nordström making up Part III of this volume. The authors try to accomplish it by simulations on a dynamic macro model of the Swedish economy, incorporating a vintage approach to industrial capital, and a relatively detailed description of the different mechanisms for energy substitution. Many of these mechanisms have been modeled using the estimates of price elasticities derived by Dargay and Jansson.

Some of the most interesting results of this study are summarized in Table 3. For each form of energy the change of total use in manufacuring during the period 1980-2000 is recounted as the change in production volume multiplied first by the change in energy coefficients (structure being held constant) and then by the change in energy use structure (energy coefficients being kept constant).

We see that for total energy the "structural" effect is of the same magnitude as the change in specific energy usage. The same is true for total fuels and for electricity. The change in specific usage varies, however, between the fuels as to both sign and magnitude. While specific usage is halved in the case of oil it increases almost by half for coal and by some thirty percent for domestic fuels.

Some rather dramatic changes in the energy system are moreover expected to occur during the period. The closing down of nuclear reactors, beginning in the 90s, will mean an end to the "electricity glut" and will imply higher electricity prices, which can be expected to cause a certain slow down both of mechanization and electrification and of oil saving in manufacturing.

Table 3 Factors determining change of energy use in manufacturing, 1980-2000

	Relative change 2000/1980 in:			
	total production volume •	specific energy usage[a] •	use structure[b] =	energy use
Oil	1.65	0.52	0.93	0.79
Coal	1.65	1.46	0.86	2.07
Domestic fuel	1.65	1.29	0.83	1.77
Total fuel	1.65	0.90	0.87	1.29
Electricity	1.65	0.92	0.91	1.38
Total energy	1.65	0.90	0.88	1.31

[a] Weighted average of specific energy usage with 1980 production shares as weights.

[b] Weighted average of production shares with specific energy usage in 2000 as weights.

One way of summarizing the findings reported in Table 3 would be to note that half the total energy savings up till the turn of the century would be realized even if the average energy-efficiency remained unchanged within each manufacturing branch. Having worked our way through the maze of econometric estimates of substitution possibilities within the manufacturing branches, we thus come back to the conclusion already derived intuitively from postwar experience. Energy saving and energy economy are not just matters of public and private energy policy. They depend as much on economic development in general and on the rate of industrial restructuring in particular.

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PART I

ENERGY IN THE PAST

Energy Usage and Energy Prices in Swedish Manufacturing

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Contents

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1 INTRODUCTION

The industrial sector accounts for somewhat less than 40 % of energy utilization in Sweden. This share has declined during the past three decades, from 45 % in 1950, mainly as a result of a more rapid expansion of other sectors of the economy, particularly of the public sector and the private service sectors, and of an increase in energy usage in the household sector. Despite industry's diminishing share of total energy usage, the effects of disturbances in energy supply or rising energy prices on economic growth and Sweden's competitive position are largely determined in the industrial sector.

In the following, we examine the development of energy consumption and energy prices in Swedish industries during the post-war period. Our intention is not to explain the many factors behind the changes in energy consumption patterns, but merely to describe the trends in energy use and factor prices during this period. No attempt has been made to correct the measures of specific energy use for either fluctuations in the business cycle or temperature variations.

The underlying data have been obtained primarily from Swedish Manufacturing Statistics and National Accounts. These data have also been used in the econometric studies presented in the following chapter (The Demand for Energy in Swedish Manufacturing), where a detailed description of data sources and the construction of price and quantity series can be found. The energy forms considered are electricity, oil products and solid fuels (coal, coke and wood fuels). Only energy purchased from outside the establishment is included.

Section 2 concerns total Swedish manufacturing, with the exception of energy-producing sectors.[1] Trends in specific energy usage, fuel mix and nominal and real energy prices are discussed. These are compared with the inputs and prices of other factors of production — labour and capital. Section 3 investigates the development of specific total energy use and the use of electricity and oil products in 12 subsectors of the manufacturing industry. Finally, implicit energy prices and aggregate energy price indices for the individual sectors are compared in Section 4.

2 TOTAL MANUFACTURING

Industrial energy usage increased an average of 4.3 % per year from 1950 to the mid 60's. The rate of increase was similar for other sectors of the economy, so that industry's share of total energy utilization remained constant during the 15 year period. From 1965 to 1970 energy demand in the industrial sector increased less rapidly than in the rest of the economy, with a rate of growth of 4.1 % per year as compared to 4.8 % for the economy as a whole. By 1970, industry's share of total energy usage had decreased to 42 %. The decrease in the rate of growth continued into the 1970's. From 1970 to 1973 the average yearly rate of growth had declined to 1.4 %. After 1973, and the

[1] I.e. petroleum refining is excluded from ISIC division 3.

first energy crisis, the absolute level of energy usage began to decrease.

The composition of energy usage in the industrial sector changed considerably during the after-war period. The most obvious change has been a substitution away from solid fuels and a rapid increase in the consumption of electricity and oil products. The use of solid fuels decreased 25 % during the 1950's and remained at the same level for much of the following two decades. Electricity consumption increased steadily over the entire period, although the rate of growth declined from the mid 60's. During the period 1952-1965 electricity usage rose by an average of 7 % per year, while the average growth for 1965-75 decreased to slightly less than one half this rate. The use of oil products increased somewhat more rapidly than electricity during the 50's and early 60's, at an average rate of 8.4 % per year. Oil usage continued to increase on an average of 3.6 % per year up until 1973, after which a sharp fall in consumption is noted.

The increase in energy demand in Swedish manufacturing since the 1950's is largely the result of an increase in manufacturing production. We find, in fact, that for the larger part of the period production increased more rapidly than energy consumption, suggesting a decrease in specific energy use. During the period of the most rapid rise in energy usage, i.e. the 50's and early 60's, output increased by an average of 5.8 % per year. From 1965 to 1975 the average yearly growth in production had declined to 3.7 % per year. By 1975 production had begun to decrease, and continued to do so for much of the later seventies.

The development of the energy/output ratio in the manufacturing industry for the period 1952-77 is shown in Figure 1. A decrease in specific energy usage is evident for the entire period, with the largest decrease occurring during the post-1970 period. With respect to the various energy forms, the general trend is towards a reduction in the use of solid fuels and an increase in the specific usage of oil and electricity.

During the 1950's, the specific use of electricity and oil products rose considerably. This increase was, however, more than compensated for by a 50 % decrease in the use of solid fuels. Oil consumption per unit output increased at a slower rate during the 60's and by 1970 had begun to fall. Between 1973 and 1974 specific oil usage fell sharply in response to the exceptionally large price increases and shortages associated with the first oil crisis. This downward trend appears to have continued through 1975, after which the oil/ output ratio remained more or less constant. A somewhat different development is noted for electricity. After a rapid increase in the 50's the specific use of electricity remained at a constant level during most of the 60's. The early 70's and particularly the most recent years exhibit once again a trend towards increasing electricity intensity. This, however, may in part reflect the low capacity utilisation associated with the post-1974 recession.

The observed development of specific energy use can partially be explained in terms of changes in relative energy prices. This can be seen in Table 1, which shows the price development of heavy fuel oil, coal, motor gasoline and electricity for various subperiods, along with the corresponding de-

Figure 1 Specific energy usage in manufacturing, 1952–1977

kWh/SEK production; constant 1975 prices

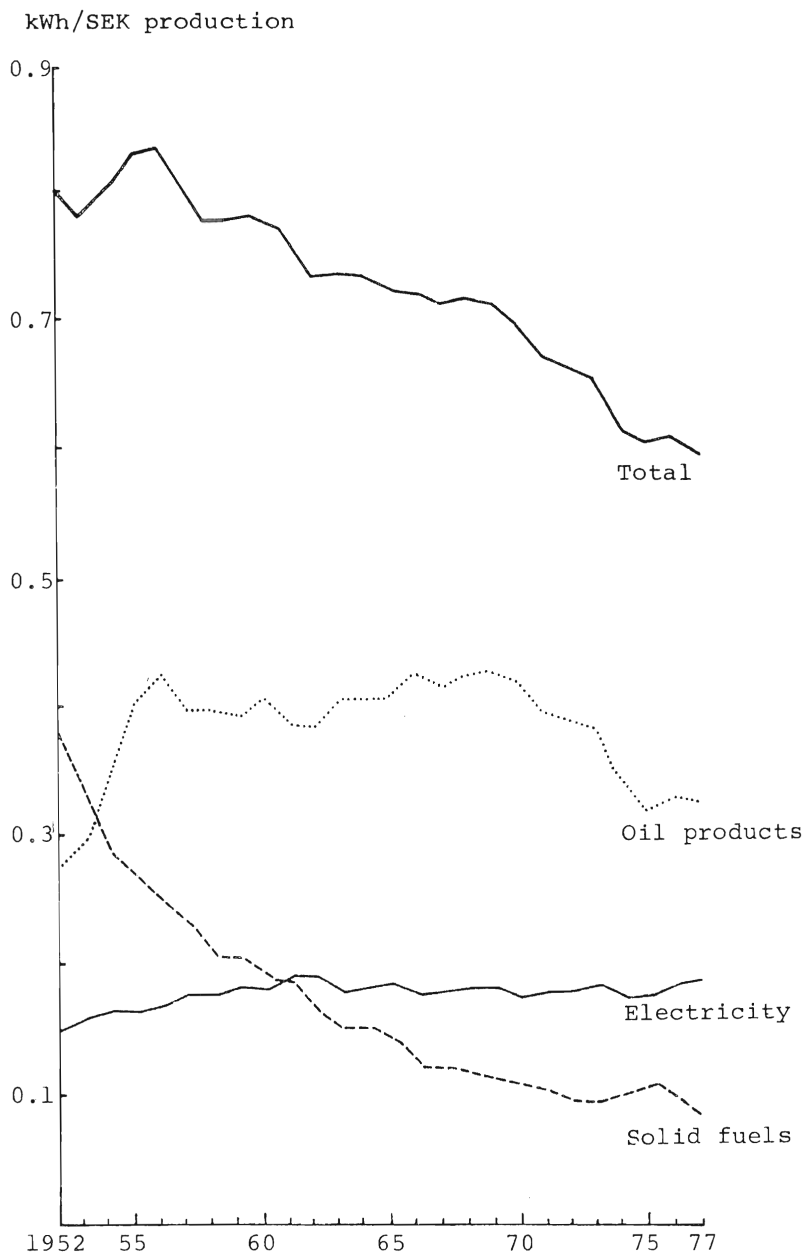

Table 1 Energy and factor prices in Swedish manufacturing, 1950–1977
Annual percentage change

	50-60	60-65	65-70	70-73	73-77	50-77
Heavy fuel oil	-0.5	0.0	4.3	11.5	26.0	5.4
Coal	0.5	0.8	4.4	0.4	26.0	3.5
Motor gasoline	0.0	1.0	1.7	7.5	11.2	2.9
Electricity[a]	7.6	-3.3	0.9	6.2	16.2	5.3
Energy price index	3.0	0.6	1.4	5.8	21.4	4.9
Producers' prices	3.8	1.9	2.2	5.2	12.8	4.6
Unit labour costs	8.9	10.4	9.7	11.8	16.4	10.7
User cost of capital[b]	-0.5	1.0	3.2	2.2	-16.3[c]	-1.2[c]

[a] Average price/kWh for a supply of 20-40 kV, 2 000 kW, 4 000 hrs (Vattenfall) plus electricity tax.

[b] The user cost of capital is calculated taking into consideration taxes and subsidies. Thus the large fluctuations.

[c] To 1976. The large decline in the user cost of capital in 1976 reflects investment subsidies.

velopment of the prices of manufacturing output, labour and capital services. We see that the prices of coal and motor gasoline increased slightly up until the mid 60's, while the nominal price of fuel oil fell somewhat. Although the relative prices of oil and coal changed only marginally, the relatively high labour requirements in the handling of solid fuels in combination with rapidly rising wages tended to accentuate this price difference. As shown in the figure, this period is characterized by the continued substitution of oil for solid fuels.

After 1965, the nominal prices of both of these fuels began to rise, with the most dramatic increase occurring after 1973. It can also be noted that the price of coal closely followed that of oil during the larger part of the period. The comparatively small price inceases for motor gasoline, particularly after 1973, can be explained by the fact that gasoline taxes and refining costs account for a large proportion of the price to consumers. The effect of crude oil price increases has therefore been of less significance than for other oil products.

The price of electricity, however, shows quite a different development: a considerable rise during the 50's was followed by a sharp fall in the early 60's. After the mid 60's, the nominal price began to rise gradually. The price development of electricity relative to fuels reached a turning point in the early 60's, after which relative electricity prices began a downward trend, the price gap between electricity and fuels widening substantially during the 70's. The reduction in oil and increase in electricity usage noted for this period may well reflect these relative price changes.

The development of the energy price index in manufacturing is also shown in Table 1.[1] We see that aggregate energy prices fall only slightly in relation to the producers' price index during most of the pre-1973 period. This is explained by the fact that the falling real fuel prices of the 50's were counterbalanced by rising real electricity prices. After 1973, however, a significant increase in real energy prices is evident.

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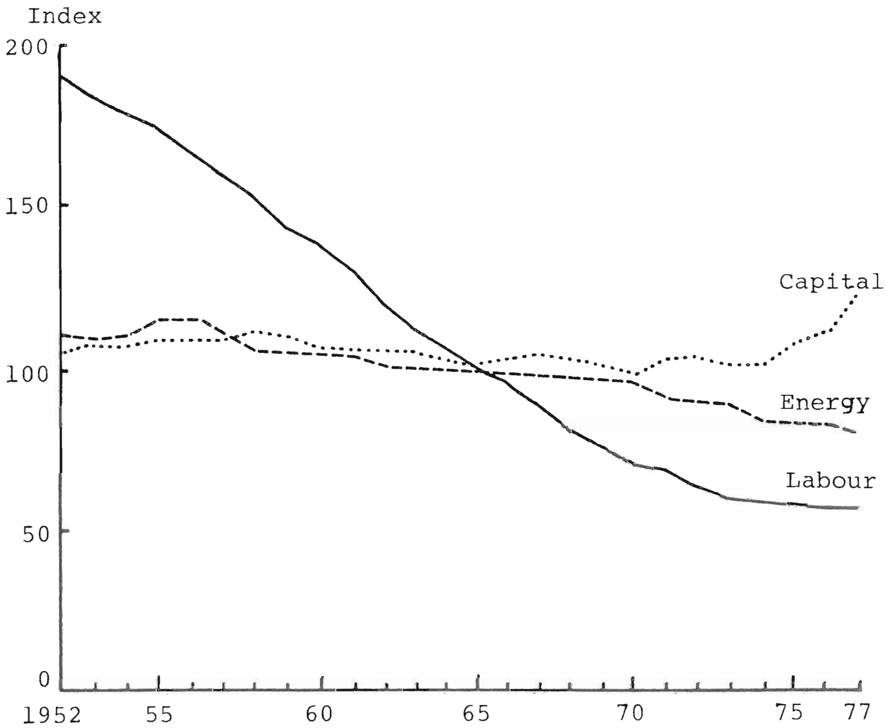
[1] The energy price index is calculated as a cost-share weighted average of the prices of electricity, oil products and solid fuels.

The general tendency towards falling specific energy use cannot, therefore, be explained in terms of these relative price changes, nor can the rapid increase in electricity use during the 50's. Energy is, however, only one of many inputs in the production process. Changes in energy utilisation patterns may also reflect a substitution between energy and other factors of production. As is evident from Table 1, labour costs have risen far more rapidly than the prices of both energy and capital over the period as a whole. Only after 1973 do oil and aggregate energy prices increase more rapidly, while electricity prices rise less rapidly throughout. Considering these changes in relative factor prices, one could expect a trend towards decreasing labour intensity and an increase in the relative use of energy and capital.

To explore the development in factor use, the inputs of labour, capital and energy per unit output are shown in Figure 2. It is apparent that the decline in specific energy use during this period is rather minimal in comparison to the dramatic fall in labour intensity. Energy and capital, on the other hand, follow very much the same path up until 1970, after which the continuing decline in specific energy usage is coupled with an increasing capital intensity. An ongoing rise in the capital/labour and energy/labour ratio is apparent, particularly from 1950-73, which is clearly a reflection of the continuous substitution of capital and energy for labour in production. The availability of relatively cheap energy has led to the introduction of less labour-intensive capital equipment.

Further, we note that the inputs of capital, labour and energy increased at a slower rate than

Figure 2 Inputs of labour, capital and energy per unit output in manufacturing, 1952-1977
Index 1965 = 100



Labour: Hours worked.

Capital: Capital stock, constant prices.

Energy: kWh electricity, petroleum products and solid fuels.

Output: Gross production, constant producers' prices.

Source: National Accounts of Sweden; Manufacturing annual reports 1952-1977.

output during the 50's and 60's. Technological development has thus led to an increased efficiency in the use of all production factors.

After 1973 the development is somewhat different. Specific energy use fell more rapidly than the labour/output ratio, while production appears to have become more capital intensive. These observations, and particularly the noted rise in the capital/output ratio must, however, be interpreted with caution. The period after 1973 is one of economic recession. Manufacturing output decreased between 1974 and 1977, and plants have not been operating at full capacity. Long-run changes in factor usage — at full capacity utilisation — are most certainly quite different from those observed here.

3 ENERGY USAGE IN MANUFACTURING SUBSECTORS

The noted decline in the energy/output ratio in manufacturing reflects not only an increased efficiency in energy usage but also the changing composition of manufacturing output. During the 50's and 60's energy-intensive industries, such as primary metals, pulp and paper, chemicals and rubber products, increased their shares of manufacturing output as did the less energy-intensive engineering industry. During the 1970's, however, production grew less rapidly in the energy-intensive sectors than in total manufacturing. The relative decline of these industries in manufacturing production has played a major role in the observed decrease in specific energy usage after 1973.[1]

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[1] Östblom (1980, 1981).

According to a recent study[1] of the factors influencing energy usage in Sweden, approximately 1/3 of the reduction in specific energy usage in the production system[2] from 1973 to 1980 can be attributed to structural change. For the manufacturing sector alone, the influence of structural change accounts for 1/4 of the observed decrease in energy intensity.[3]

In order to distinguish between the influences of changes in product composition and changes in specific energy usage it is essential to study the development of energy/output ratios on a more disaggregated level. In the following we shall examine 12 subsectors of the manufacturing industry.[4] The specific energy usage — subdivided into electricity and petroleum products — is calculated for each sector for the period 1965-1977 and displayed graphically in Figures 3 and 4. All series are normalised to 1 in 1965. It should be held in mind that the measure of specific energy usage reflects a combination of many divergent factors: both long- and short-term changes in energy utilisation as well as differences in capacity utilisation and climatic conditions over the period.

Before we examine these figures a few comments should be made concerning the development of specific energy use prior to 1965. During this period,

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[1] Sohlman, Stillerud and Östblom (1982).

[2] Besides manufacturing, this includes mining, agriculture, fishing, forestry, transport and communication, commerce, utilities, private services and construction.

[3] Calculated from the figures given in Sohlman et al.

[4] Only the sector miscellaneous manufacturing is excluded.

the energy/output ratio rose appreciably only in 3 sectors: Printing, chemicals and shipbuilding. A rapid replacement of solid fuels with oil products is also apparent in all industries, as is a significant increase in specific electricity use brought about by the rapidly increasing mechanization of production. Further, all industries display a continually increasing capital/labour and energy/labour ratio well into the 1970's.

Total energy usage (electricity, petroleum products and solid fuels) per unit output is shown in Figure 3 for the 12 manufacturing subsectors.[1] A downward trend in specific energy usage is discernible in the majority of industries. Only in the printing industry do we find an increasing energy intensity over the entire period. In the food industries, the large fluctuations make it impossible to distinguish any long-term changes in specific energy usage.

Of the remaining industries, all, with the exception of rubber products, exhibit a clear reduction in energy intensity during the period prior to 1974. The most significant decreases have occurred in chemicals, engineering, textiles and shipbuilding. Of the most energy intensive sectors, only wood, pulp and paper shows a decline in specific use of much less than 10 % during this period. This has to do mainly with our aggregation of two vastly different sectors: The energy intensive pulp and paper industry and the low-energy, wood and wood product industry. Disaggregating these two sectors, Sohlman-Stillerud-Östblom find a 7 % decline in the energy/output ratio in the pulp and

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[1] Electricity and fuels produced and used at the same plant are not included.

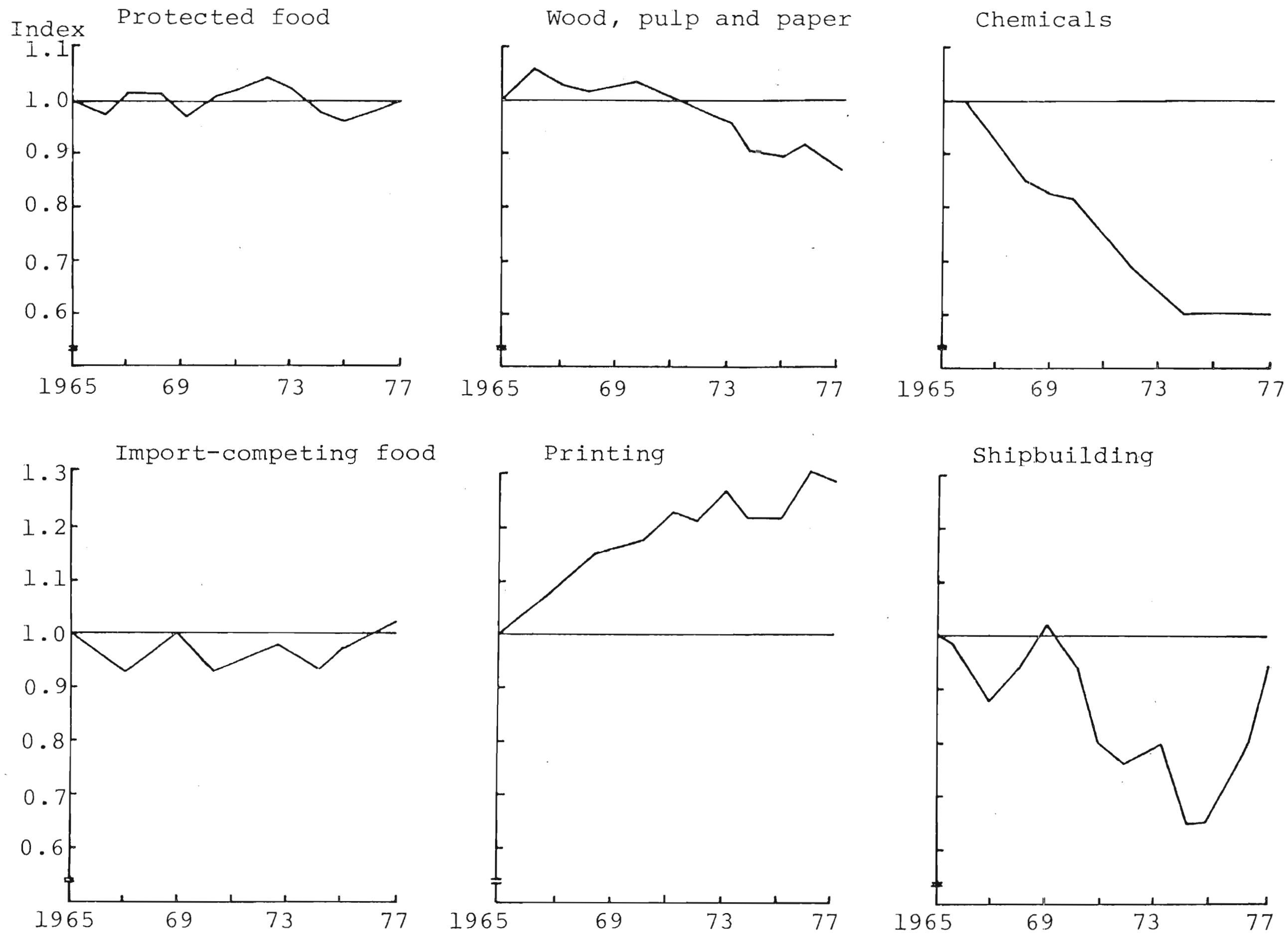
paper industry and a 35 % increase for wood and wood products over the period 1965-1973.

The development after 1973 is somewhat more difficult to interpret. In all sectors, with the exception of primary metals, the specific energy usage fell rapidly during 1974 and 75. After 1975, however, we find a tendency towards increasing energy usage in many subsectors. The most notable exceptions are 4 of the 5 most energy intensive sectors: non-metallic mineral products, wood, pulp and paper, chemicals, and rubber products. As noted earlier, the apparent increase in energy intensity may, in fact, reflect the low capacity utilisation of the post-1974 period.

The specific use of electricity and petroleum products in the twelve subsectors is shown in Figure 4. Regarding petroleum products we find a gradual decline from 1965 to 1973 in over half of the subsectors, and a significant increase only in the printing industry. During the two years following 1973, a considerable reduction in oil usage is apparent in all sectors. After 1975, the tendency is similar to that found for total energy, i.e. a trend towards increasing specific use in a number of industries. All but 3 of the subsectors, however, have a lower specific oil use 1977 than 1973. From these results, it would appear that the events of 1973-74 have had a long-term effect on oil usage. It is, of course, impossible to draw any definite conclusions regarding the effects of the 1974 oil price increases on the basis of the data presented here. The observations after 1974 are too few and the influence of differences in capacity utilisation and climatic conditions have not been taken into consideration.

Figure 3 **Specific energy use in manufacturing sectors, 1965-1977**

Index 1965 = 1.0



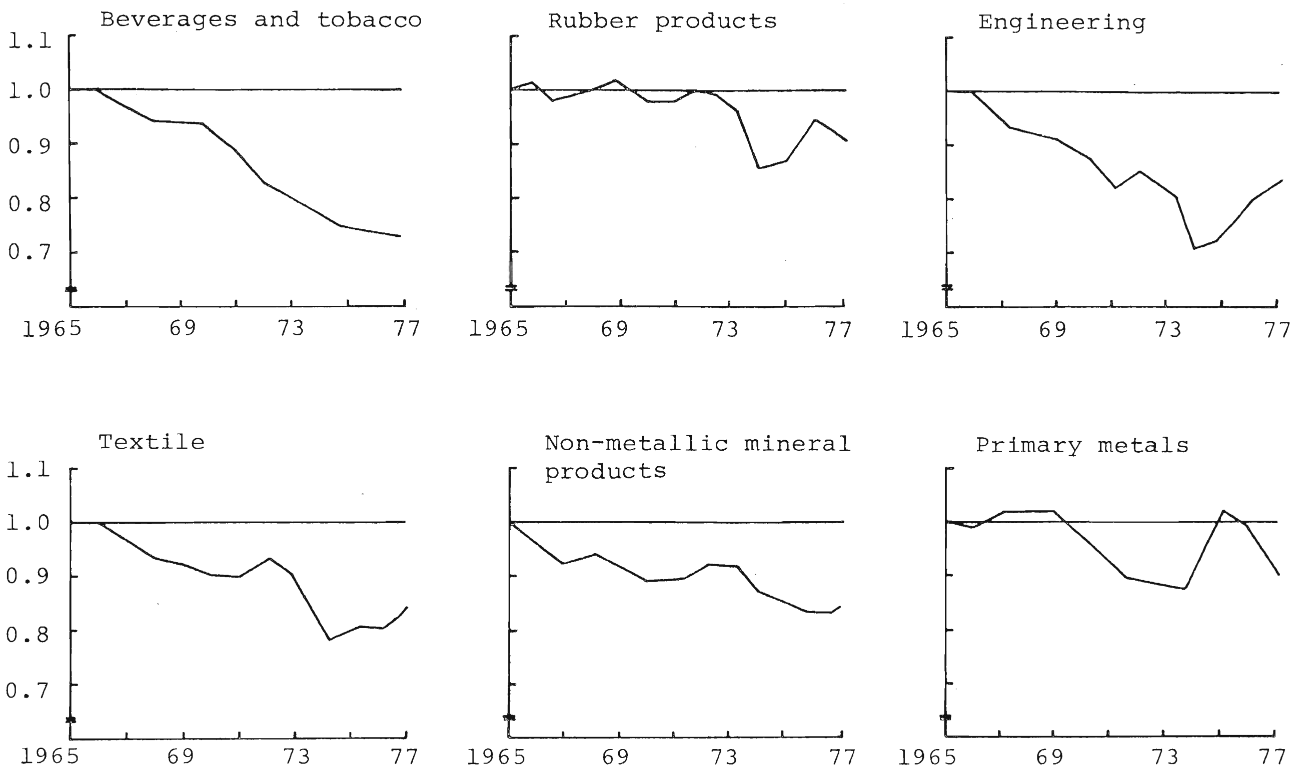
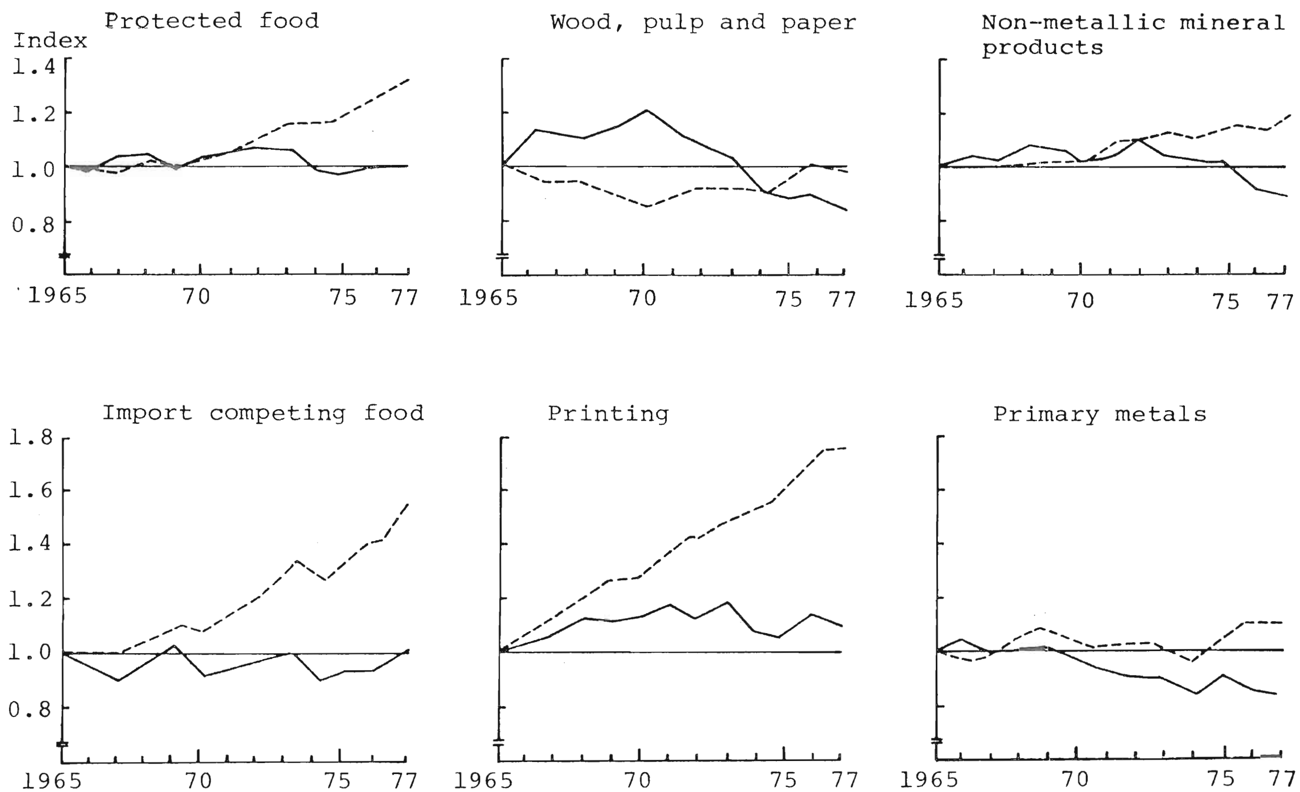
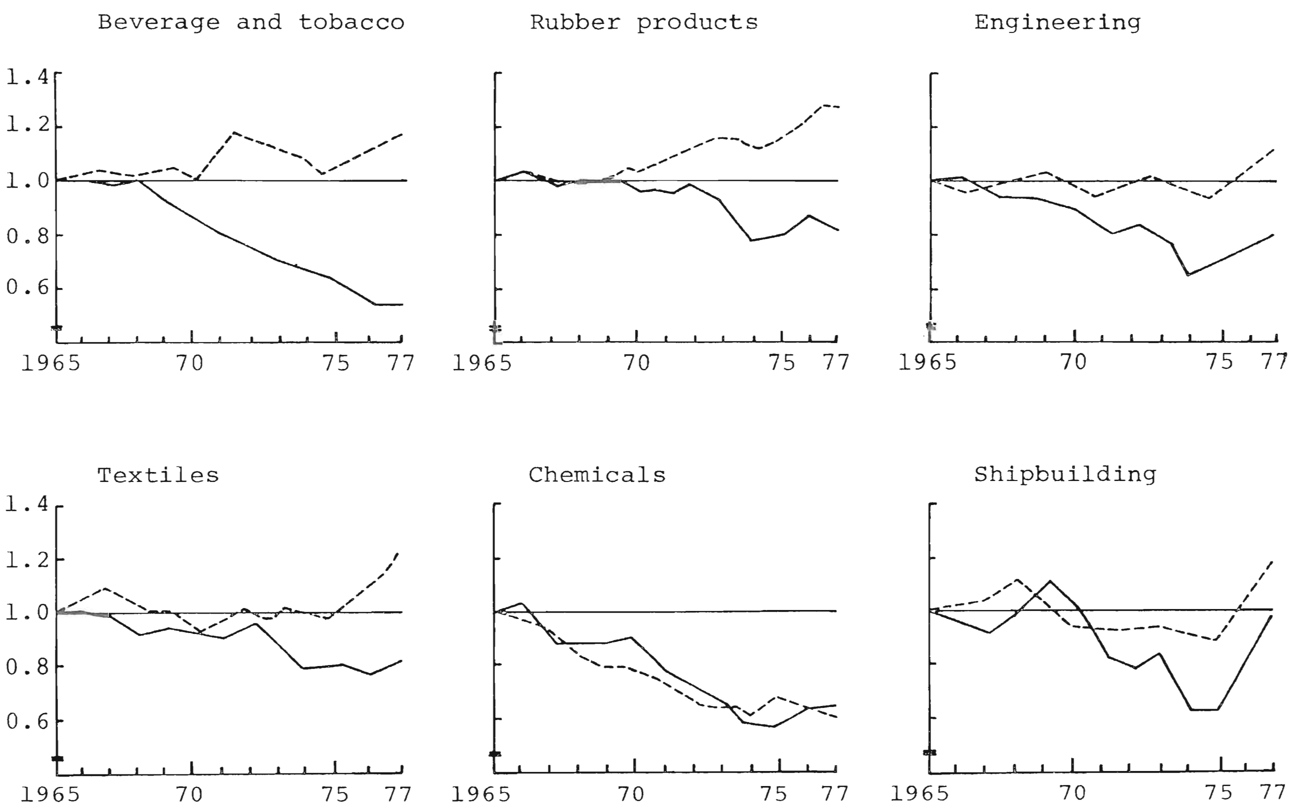

Beverages and tobacco
Rubber products
Engineering
Textile
Non-metallic mineral products
Primary metals
1.1
1.0
0.9
0.8
0.7
1965
69
73
77

Figure 4 Specific use of electricity and oil in manufacturing sectors, 1965–1977

Index 1965 = 1.0 Electricity (----) Oil (——)




Beverage and tobacco
Rubber products
Engineering
Textiles
Chemicals
Shipbuilding
1.4
1.2
1.0
0.8
0.6
1965
70
75
77

As mentioned previously, the increased mechanization of industry has resulted in a steady increase in electricity consumption in all sectors during the 50's and early 60's. We see that this trend towards rising electricity intensity has continued in the majority of subsectors during at least some part of the post-1965 period. The only exception is the chemical industry in which a sharp and more-or-less continuous downward trend is evident. Between 1965 and 1973 we find that specific electricity use increased markedly in 6 of the remaining 11 subsectors. Most of these are industries with relatively low energy intensity. After 1973, however, the electricity/output ratio rose substantially in all 11 industries.

Although this appears to suggest a tendency towards increasing electricity intensity, it may also to some extent be a reflection of under capacity utilisation. As noted earlier, the price of electric power relative to oil products fell somewhat during the 60's and considerably after 1973. The general trend towards increasing electricity and decreasing oil use seems to reflect these relative price changes.

4 ENERGY PRICES IN MANUFACTURING SUBSECTORS

In Section 2 we traced the development of average fuel and electricity prices to industrial consumers and the aggregate energy price index in manufacturing. The individual subsectors of the manufacturing industry have, however, faced slightly different price trends. As we have seen, the prices of individual energy forms have not necessarily followed the same paths. After 1965, the prices of electricity and motor fuels, for example, increased less rapidly than coal and considerably less than fuel oil. Thus, the development of the 'price of energy' for a particular industry depends largely on the composition of its energy consumption. As the relative use of electricity and fuels varies greatly among industries, we would expect significant differences in aggregate energy price development.

In the following, we shall investigate energy prices in manufacturing subsectors. These are calculated from yearly data on expenditures for and quantities of energy consumed in the various industries. The energy forms included are electricity, motor fuels, fuel oils, gas oil, coal, coke and wood fuels. Electricity and fuels produced and used at the same plant are excluded from the data. The effect of the omission of these fuels on aggregate energy prices is most serious in the pulp and paper industry, where internal supplies of wood fuels constitute an important energy source.

The average annual percentage change in the energy price index, and the prices of petroleum products, heavy fuel oil and electricity for the period 1968-1975 are shown in Table 2.

Aggregate energy price indices for each sector are calculated as cost-share weighted average of the implicit prices of electricity, petroleum products and solid fuels. On average we find that the price of energy increased at a rate of 10 % per annum during this period. There are, however, marked variations among the subsectors. Energy prices rose more substantially in the energy-intensive industries, at an average rate of 12.4 % per annum

Table 2 Energy prices in manufacturing subsectors and average annual percentage change, 1968-1975

	Energy price index	Petroleum products[a]	Heavy fuel oil[a] Price SEK/m^3			Electricity Price öre/kWh		
	%	%	1968	1975	% change	1968	1975	% change
Energy-intensive sectors								
Pulp and paper	12.3[b]	20.1[b]	80	333	22.7	3.0	5.8	9.9
Chemicals	10.8	16.3	84	340	22.2	3.4	6.1	8.4
Non-metallic mineral products	13.1	17.0	88	348	21.7	5.4	9.0	7.6
Primary metals	13.3	19.8	88	344	21.6	3.3	5.9	8.7
Average	12.4	18.3	85	341	22.1	3.8	6.7	8.7
Other sectors								
Sheltered food	8.5	9.4	97	348	20.1	6.7	10.7	6.9
Import-competing food	9.5	13.4				7.6	11.3	5.8
Beverages and tobacco	7.9	9.1	107	359	18.9	7.8	10.9	4.9
Textiles	10.0	15.3	95	364	21.2	7.8	11.9	6.2
Wood products	...	...	101	337	18.7	7.7	11.3	5.6
Printing	7.3	11.0	107	396	20.6	8.7	12.1	4.7
Rubber products	10.4	16.8	95	343	20.2	6.4	10.2	6.7
Engineering	8.4	13.9	94	363	21.2	7.0	10.2	5.5
Shipbuilding	8.0	15.4	94	360	21.1	7.5	10.3	4.6
Average	8.8	13.0	99	359	20.3	7.5	11.0	5.7

[a] Excluding energy tax.

[b] Includes wood product industry.

as compared to less than 9 % in other sectors. Of the high-energy sectors, the chemical industry has experienced the smallest price-rise, mainly as a result of the large proportion of electricity usage in this sector.

The differences in the development of energy prices are explained not only by differences in electricity intensity, but also by the composition of fuel usage. This can be seen by comparing the price development of petroleum products for the subsectors. Again, we find that prices increased more rapidly in the energy intensive sectors than in others, 18 % per year as opposed to 13 %. This discrepancy is explained mainly by the relatively high proportion of motor fuels in the less energy-intensive industries. As seen in Section 3, the price of these fuels increased considerably less than that of heavy fuel oil.

Implicit prices for heavy fuel oil (No. 4) in the different industries for the years 1968 and 1975 are also shown in Table 2. We find considerable differences in average prices, particularly for 1968. The lowest prices are noted for the largest consumers, the energy intensive industries. On average we find a price reduction of 14 %. In conjunction with the dramatic oil price increases of 1973-74 and thereafter the prices tend to converge. In 1975 we find the large consumers still paying less, but only 5 % less on average.

The differences in prices reflect price reductions to large consumers, for example, in the form of long-term contracts; or even the possibility for these consumers to purchase oil when prices are most advantageous. The rising uncertainties on the oil market since the 1st major OPEC crude oil price increase ought to have led to shortened contract lengths as well as reduced the significance of rebates to large consumers. In any event, the result appears to have been that large consumers have experienced a somewhat higher than average percentage price increase.

Finally, average electricity prices for 1968 and 1975 and the average annual percentage change during this period are given in the last three columns of the table. For both years we find that electricity prices vary considerably amongst industries. These price variations are primarily explained by differences in supply voltage. Also, because electricity tariffs are composed of a fixed charge and a kWh charge, the average price per kWh decreases with increasing consumption.

Energy-intensive industries such as primary metals, pulp and paper etc. generally purchase electric power at 130 kV, whereas smaller consumers — printing, textiles and most less energy-intensive industries — contract at a lower voltage, i.e. 6-40 kV. In 1968, the average price for a large industrial consumer (130 kV, 10 000 kW, 5 000 hrs) was about 4 öre/kWh and for a small consumer (10 kV, 500 kW, 3 000 hrs) was slightly less than twice this.[1]

We note also that average electricity prices increased more rapidly for energy-intensive sectors than for others. This, too, corresponds quite well to the average annual price changes 1968-75 of 9.6 % and 6.1 % for the large and small industrial consumers above. Changes in electricity tariffs and the introduction of the fuel price supplement

[1] Vattenfall.

have led to a price increase of approximately 4 öre/kWh for both types of consumer during this period. The result has thus been a proportionally higher price increase for large consumers with lower average prices.

In conclusion, it appears evident that the energy price increases of the mid 70's have been a double burden for energy-intensive industries. The impact on production costs has been greater for these industries not only because of their relatively high energy dependence, but also because of a diminishing price advantage on energy markets.

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PART II

POSSIBILITIES OF ENERGY SUBSTITUTION

The Demand for Energy in Swedish Manufacturing

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Contents

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1 INTRODUCTION

Understanding the role of energy in the structure of production is an essential prerequisite for many energy and industrial policy decisions. The formulation and evaluation of energy conservation measures, the analysis of the effects of energy price rises or the question of reducing dependence on imported oil require knowledge of the characteristics of energy demand and the interaction between energy utilisation and economic relationships.

A fundamental feature of energy demand is its derived nature. Energy demand arises from the utility derived from its use as light, heat and motive power. In industry, energy is essential for the operation of capital equipment — machines and plant. In production, capital and energy are combined with the inputs of labour, raw materials etc., all of these being inputs in the production process. The demand for energy can be explained by the same mechanism that determines the demand for other factors of production: by production level, relative factor prices and the substitution possibilities amongst inputs.

Analysis of industrial energy demand must, therefore, simultaneously consider the complexity of relationships among all inputs in the production process. This study represents a first attempt to estimate these relationships for Swedish manufacturing. We examine the substitution possibilities between energy and other factors of production as well as interfuel substitution possibilities. Our approach, similar to that employed in a number of recent studies of energy demand, is to consider energy as one of a series of inputs in the production process. The theoretical basis of our study stems from Neoclassical production theory: the existence of a production function relating output to various inputs, cost-minimising behaviour on the part of firms and duality between production and cost functions.

We begin by specifying a cost function which relates production costs to the prices of aggregated production factors: energy, capital, labour and intermediate goods. For a given level of production and given factor prices, it is assumed that firms choose that input-mix which corresponds to minimum production costs. The theory of duality between production and cost allows us to derive demand equations for energy and the remaining inputs from the cost function and assures that these are consistent with the substitution possibilities inherent in the underlying technology. Energy demand is thus modeled as a part of an interrelated system of equations relating factor demand to production level and relative factor prices. Estimation of the model results in estimates of price elasticities of demand for each production factor as well as estimates of the substitution relationships amongst them.

Our approach allows us not only to study the price-sensitivity of energy demand but also to explain this response in terms of the substitution relationships between energy and other production factors. If these possibilities for substitution are substantial, higher energy prices could be absorbed with minimal effects on production. On the other hand, if substitution possibilities are limited, adjustment by industry to higher energy prices will be difficult.

The nature of the substitution relationships has obvious implications for economic growth and employment. If energy is a substitute for both capital and labour, then higher energy prices will tend to accelerate investment and increase employment. In this case, the effects on economic growth will be minimal. If on the other hand, a complementary relationship exists between energy and capital and/or labour, then higher energy prices will reduce investment and/or increase unemployment. The effects on individual industries and on the economy could be serious indeed.

The need for distinguishing between effects in different time perspectives is evident. The substitution possibilities between energy and other inputs or among different energy forms are certainly greater in the long run than in the short run. In the short run, physical capital — machinery and plant — is given and only limited possibilities exist for reducing energy usage. In the longer run, industry is no longer bound to a given production process or product-mix. Energy conserving production processes can be introduced, thereby reducing energy utilisation by the additional inputs of other factors of production. Shifts can occur towards less energy-intensive products. The introduction of alternative technologies and changes in product composition entail investment in new capital equipment. The time that is required for the complete adjustment is thus dependent on the technical life-span of physical capital, relative factor prices and the competitive conditions and technological development within the particular industry.

A thorough analysis of energy demand should, then, not only describe factor substitution relationships, but should also distinguish between short- and long-run factor demand responses. Our study, as the majority of others to date, falls short of this. Our model is not dynamic in the sense that it distinguishes between short- and long-run demand relationships. The results presented here should therefore be viewed as only a first step towards a consistent analysis of industrial energy demand.

A technical description of our model is presented in Section 2. This includes a brief summary of the underlying economic theory of cost and production, a presentation of the translog cost function and the derived factor demand functions as well as formal definitions of elasticity measures employed in the remainder of the paper. The statistical model and estimation procedure are presented in Section 3. Both these sections are highly summaric and readers not familiar with production theory or econometric methods may wish to move directly on to Section 4, where a rather detailed — and hopefully accessible — discussion of the empirical results is presented. In Section 5, we compare our findings with those of other energy demand studies in different countries. A discussion of the questions raised by our analysis and suggestions for further research concludes the paper.

2 THE MODEL

Our study of energy demand begins with an analysis of the total demand for energy in various manufacturing subsectors. A derivation of the model for the demand for aggregate inputs is given in Section 2.1 below. In the next phase of our study, we extend our model to include the demand for individual energy forms — electricity, oil products and solid fuels. The two-stage model used in this analysis is presented in Section 2.2.

2.1 The Demand for Aggregate Inputs

In order to explore the substitution possibilities between energy and other production factors certain assumptions must be made regarding the structure of production. We begin by assuming that technology can be represented by a production function which relates gross production (Q) to the input of aggregated production factors: energy (E), capital (K), labour (L) and intermediate goods (M).

$$Q = q\ (E,K,L,M). \qquad (1)$$

This specification implicitly assumes that the production function is weakly separable in the E, K, L and M aggregates, that is to say, the marginal rates of substitution between individual energy forms (or types of K, L and M) are independent of the quantities of the remaining inputs demanded.

Further we assume that the producers minimise the costs of production and that factor prices and output level are exogenously determined. According to the theory of duality between production and cost, the production structure (1) can, under certain regularity conditions, alternatively be described by a cost function relating total production costs (C) to the level of output (Q) and factor prices (P_i):

$$C = c(Q, P_E, P_K, P_L, P_M). \qquad (2)$$

For purposes of empirical implementation it is necessary to specify an explicit functional form for c. It is desirable to choose a functional form which places minimal a priori restrictions on the characteristics of the production function, and in particular on the elasticities of substitution. Several functional forms fulfilling these requirements have been proposed recently; among these are the translog, generalised Leontief, generalised Cobb-Douglas and generalised square root quadratic.[1] All of these forms provide a local approximation to an arbitrary cost function, but their global properties are not generally known and there are no theoretical grounds for choosing among them.[2] In the present study we have chosen the translog form because it reduces to fairly

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[1] The generalised Leontief, Cobb-Douglas and square-root quadratic forms have been introduced by Diewert (1971, 1973, 1974) and the translog by Christensen, Jorgenson and Lau (1973).

[2] The choice of flexible functional forms has been the subject of a number of recent articles. Berndt and Khaled (1979) and Appelbaum (1979) estimate a generalised Box-Cox functional form which provides a statistical basis for choosing among the translog, generalised Leontief and the square-root quadratic forms. Estimating cost functions for U.S. manufacturing, Berndt and Khaled find the generalised Leontief form to be the preferred whereas the Appelbaum study supports the square-root quadratic.

simple demand relationships which are comparatively easy to work with.[1]

The translog cost function can be interpreted as a second-order approximation to an arbitrary cost function. Denoting factor prices as P_i and assuming Hicks neutral technical change, the translog function has the following form

$$\ln C = \alpha_o + \alpha_q \ln Q + \sum_i \alpha_i \ln P_i + \tfrac{1}{2}\gamma_{qq}(\ln Q)^2 + \\ + \tfrac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \sum_i \gamma_{qi} \ln Q \ln P_i + \lambda T, \quad (3)$$

where $\gamma_{ij} = \gamma_{ji}$.[2] The time trend T is included in the cost function to allow for the effects of neutral technical change on total production costs. This specification assumes that technological change affects the demand for all factors equally without altering cost-minimising factor proportions.[3] In order to assure that the underlying production function is well-behaved, the cost function must be homogeneous of degree one in input prices. That is, for a given level of output a proportionate increase in all factor prices results in a proportionate increase in total produc-

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[1] A recent Monte Carlo study by Guilkey and Lovell (1980) indicates that the translog model provides adequate estimates of quite complex technologies. The accuracy of the estimates decreases, however, when the elasticities of substitution differ greatly from unity.

[2] γ_{ij} and γ_{ji} are the cross partial derivatives $\partial^2 \ln c / \partial \ln P_i \partial \ln P_j$ and $\partial^2 \ln c / \partial \ln P_j \partial \ln P_i$. These are necessarily equal.

[3] The model can be extended to the more general case of biased technological change. See, for example, Stevenson (1980).

tion costs. This implies the following relationships among the parameters:[1]

$$\sum_i \alpha_i = 1 \tag{4}$$

$$\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0$$

$$\sum_i \gamma_{iq} = 0.$$

Without any further restrictions on the parameters, the cost function as specified in (3) allows for non-homotheticity and non-constant returns to scale. The translog approximation is homothetic if it could be written as a separable function of output and factor prices, that is if $\gamma_{iq} = 0$ for all i. In terms of the cost function, homotheticity implies that the cost-minimising input-mix is determined solely by input prices and is independent of the level of production. Further, a homothetic cost function is homogeneous if the elasticity of cost with respect to output is constant, i.e. if $\gamma_{qq} = 0$. Given the above restrictions, the degree of homogeneity of the cost function is determined by the coefficient α_q. Thus, if $\alpha_q = 1$, the cost function is linearly homogeneous and the underlying technology is characterised by constant returns to scale.

Although it is, in principle, possible to analyse the structure of production by estimating the cost function directly, the number of parameters to be estimated is quite large and multicollinearity among exogenous variables may be a problem, resulting in imprecise parameter estimates. It is common

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[1] See, for example, Berndt and Christensen (1973).

practice, therefore, to base empirical studies of substitution possibilities not on the cost function itself, but on the derived demand equations.

The input demand functions are derived from the cost function using a result first noted by Hotelling and formally established by Shephard.[1] This result, commonly known as Shepard's lemma, states that the cost function is related to the cost-minimising demand functions through its partial derivatives with respect to input prices. Further, since total cost (C) is equal to the sum of the costs for the individual factor inputs ($\Sigma X_i P_i$), we have $\partial \ln c / \partial \ln P_i = P_i X_i / C = S_i$, where S_i is the share of the ith input in total costs. Thus, the factor demand functions in terms of cost shares follow from partial logarithmic differentiation of the cost function (3) with respect to factor prices. We have

$$S_i = \alpha_i + \sum_j \gamma_{ij} \ln P_j + \gamma_{iq} \ln Q \qquad i,j{=}E,K,L,M \tag{5}$$

where $\Sigma\, S_i = 1$.

Comparing the cost share equations with the cost function (3) we see that the majority of the parameters of the cost function can be determined by estimation of the system of equations given in (5), with the constraints $\gamma_{ij} = \gamma_{ji}$ and restrictions implied by (4). The parameters α_o, α_q, γ_{qq} and λ, and thus the returns to scale of the cost function and the influence of technical change are, however, not identified unless the cost function is estimated directly.

Our particular interest, however, lies in the structure of factor substitution and price respon-

[1] Hotelling (1932), Shephard (1953).

siveness. The most commonly used measure of factor substitution is the Allen partial elasticity of substitution.[1] This measures the percentual change in the relationship between two production factors which results from a 1 % change in their relative prices, all other inputs being allowed to adjust to their cost minimising levels. For the cost function, the Allen partial elasticities of substitution between inputs i and j are given by[2]

$$\sigma_{ij} = \frac{C(\partial^2 C/\partial P_i \partial P_j)}{(\partial C/\partial P_i)(\partial C/\partial P_j)}. \qquad (6)$$

For the translog cost function these measures can be calculated as[3]

$$\sigma_{ij} = (\gamma_{ij} + \hat{S}_i \hat{S}_j)/\hat{S}_i \hat{S}_j \qquad i \neq j$$
$$\sigma_{ii} = (\gamma_{ii} + \hat{S}_i^2/\hat{S}_i)/\hat{S}_i^2 \qquad (7)$$

where $\hat{S}_i$ are the predicted cost shares.

As shown in Allen[1], the partial elasticities of substitution are related to the price elasticities of demand for factor inputs (η_{ij}) according to

$$\eta_{ij} = \hat{S}_j \sigma_{ij}. \qquad (8)$$

It should be noted that the translog function does not constrain these elasticities to be constant. As functions of the cost shares, they are dependent on the level of factor prices, and for the

[1] Allen (1959).

[2] Uzawa (1962).

[3] Berndt and Wood (1975).

non-homothetic cost function, even on production level. Thus, the estimated elasticities are allowed to vary over the observation period.

A disadvantage of the translog function is that one cannot test for zero substitution between factor pairs directly from the estimated demand functions. It is clear from expression (7) that the elasticity of substitution between factors i and j is equal to unity if $\gamma_{ij} = 0$. Thus if all $\gamma_{ij} = 0$, the translog cost function corresponds to a Cobb-Douglas production structure. We can test this hypothesis[1] using a simple likelihood ratio test. The appropriate test statistic is

$$-2\ln(L_R/L_U), \qquad (9)$$

where L_R and L_U are the maximum likelihood values for the restricted and unrestricted models respectively. This statistic is asymptotically distributed as Chi-square under the null-hypothesis of the more restrictive model with degrees of freedom equal to the number of parameters being tested.

2.2 The Demand for Individual Energy Forms - The Two-Stage Model

Next we extend our model to encompass the substitution possibilities among individual energy types. Ideally, we would like to estimate a model that places minimal a priori restrictions on the substitution relationships not only between individual energy forms but also among the individual energy forms and other production factors. In prin-

[1] or similarly the hypothesis of homotheticity, $\gamma_{iq} = 0$ for all i.

ciple, this can be achieved by specifying the production function (1) with total energy, E, disaggregated into its constituent fuel types and deriving the corresponding cost function. Estimation of the many-input case, however, poses computational problems. Not only do the number of share equations increase, but multicollinearity among the price variables is likely to be a problem. In order to minimise estimation problems, we chose a somewhat more simplified model.

Our approach, similar to that introduced by Fuss,[1] is to specify the demand for energy as a two-stage process. First, the structure of energy demand is determined by choosing the fuel-mix that minimises energy costs. This provides an analysis of interfuel substitution and allows us to construct a consistent aggregate price index for energy. Secondly, overall energy demand is optimised in conjunction with the inputs of capital, labour and intermediate goods, providing estimates of substitution possibilities between aggregate energy and each of the three non-energy inputs.

Although the two-stage procedure facilitates estimation of a cost function with many inputs, it does impose restrictions on the structure of production. Specifically, it requires that the cost function is weakly separable in the energy aggregate, that is to say, that the cost-minimising energy-mix is independent of the prices and level of capital, labour and intermediate goods.[2] Thus

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[1] Fuss (1977).

[2] This assumption is also implied by the aggregate model presented in Section 2.1. Weak separability is in fact a prerequisite for the existence of aggregates.

the relationship between the individual energy components and the remaining production factors are determined solely through the energy aggregate.

The first stage of the analysis involves the specification and estimation of an energy submodel for electricity (e), oil (o) and solid fuels (s). The total cost of energy, C_E, is represented by a translog cost function with constant returns to scale. Under these conditions, the unit cost function for the energy aggregate follows directly from the cost function, providing an aggregate price index for energy:

$$\ln P_E = \ln \frac{C_E}{Q} = \alpha_0 + \sum_i \alpha_i \ln P_{Ei} + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_{Ei} \ln P_{Ej} \qquad i,j = e,o,s \qquad (10)$$

where P_{Ei} represent the prices of the energy components.

As in the previous section, we derive the share equations implied by this cost function

$$S_{Ei} = \alpha_i + \sum_j \gamma_{ij} \ln P_{Ej} \qquad i,j = e,o,s \qquad (11)$$

Again, the properties of production require the restrictions $\gamma_{ij} = \gamma_{ji}$, $\Sigma \alpha_i = 1$ and $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0$ for all i, j.

Estimation of the system of cost shares allows us to calculate the partial own- and cross-price elasticities for the three energy forms. These elasticities are partial in the sense that they reflect substitution among the fuel types within the energy aggregate, given that total energy utilisation remains constant.

By substituting the estimated coefficients α_i and γ_{ij}, i,j = e,o,s into (10) we are able to construct a price index, $\hat{P}_E$, for the energy aggregate.[1] This index is then used as an instrumental variable for the price of energy in the second stage of the analysis, which entails estimation of the translog cost share equations (5) for the E, K, L and M aggregates. In addition to providing information concerning the substitution relationships between the energy aggregate and the remaining inputs, this permits calculation of the total price elasticities of demand for each energy form. Since a change in the price of an energy component also changes $\hat{P}_E$, it results in a substitution between energy and other inputs, affecting the demand for aggregate energy and thereby the demand for each energy component. This effect combined with those of interfuel substitution form the total price elasticity of demand for each fuel. This is given by

$$\eta^T_{ij} = \frac{d\ln X_{Ei}}{d\ln P_{Ej}} = \left[\left(\frac{\partial \ln X_{Ei}}{\partial \ln P_{Ej}}\right)_{X_E} + \frac{\partial X_{Ei}}{\partial X_E}\,\frac{\partial X_E}{\partial P_E}\,\frac{\partial P_E}{\partial P_{Ej}}\right]\frac{\partial P_{Ej}}{\partial X_{Ei}}, \qquad i,j = e,o,s \tag{12}$$

where the X_{Ei} are the quantities of each fuel demanded, X_E the total quantity of energy demanded and P_E is the price index for energy. Since P_E is given by (10) and since the energy cost function is homogeneous this reduces to

$$\eta^T_{ij} = \eta^P_{ij} + \eta_{EE}\, S_{Ej} \qquad i,j = e,o,s \tag{13}$$

[1] Since the price indices for the individual energy forms are normalised to 1 for 1975, a similarly normalised price index for the energy aggregate is calculated by setting a_0 to 0 in (10).

where the η^P_{ij} are the partial price elasticities obtained from the energy submodel and η_{EE} is own-price elasticity for the energy aggregate.

Finally a few words should be said about the properties of the translog cost function in relation to neoclassical production theory. In general, a cost function is well behaved, that is, satisfies the requirements of cost-minimising demand theory, if it is concave in input prices and if its input demand functions are strictly positive. The translog function does not satisfy these requirements globally,[1] that is to say, for all possible values of factor prices. It is therefore necessary to test for positivity and concavity at each observation. Positivity is satisfied if all fitted cost shares are positive. A necessary condition for concavity is that all own-price elasticities are negative, while a necessary and sufficient condition is the negative semidefiniteness of the Hessian matrix[2] based on the estimated parameters.

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[1] Nor do any of the other generalised functional forms mentioned earlier.

[2] The matrix of second-order partial derivatives of the cost function with respect to factor prices.

3 ESTIMATION PROCEDURE

Characterisation of the structure of production entails estimation of the input demand equations (5) subject to the restrictions imposed by linear homogeneity in prices (4).[1] The stochastic model includes the specification of additive disturbances for each of the share equations. These disturbances may be interpreted alternatively as random errors in cost-minimising behaviour or as the random influence of unspecified explanatory variables. In either case, it is probable that these factors are related for the share equations, and allowance should be made for non-zero contemporaneous correlation across equations.

The stochastic specification of (5) takes the following form

$$S_i = \alpha_i + \sum_i \gamma_{ij} \ln P_j + \gamma_{iq} \ln Q + \varepsilon_i \qquad i,j=E,K,L,M \tag{14}$$

Letting $\tilde{\varepsilon}_t$ denote the vector of error terms for the four share equations we assume that $\tilde{\varepsilon}_t$ is joint normally distributed with zero mean and variance-covariance matrix Σ, that is

$$\tilde{\varepsilon}_t \sim N(0, \Sigma) \qquad \text{for all } t \tag{14a}$$

such that

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[1] Since the input shares must sum to unity, these restrictions are equivalent to $\gamma_{ij} = \gamma_{ji}$; $i \neq j$. Thus the validity of the assumption of homogeneity of degree one in input prices is directly testable through the symmetry conditions.

$$E(\tilde{\varepsilon}_t \tilde{\varepsilon}_s') = \delta_{ts}\,\Sigma \qquad \delta_{ts} = \begin{matrix} 1 \text{ if } t=s \\ 0 \text{ if } t \neq s \end{matrix} \tag{14b}$$

This specification implies that the error terms ε_i have a constant variance-covariance matrix and allows for non-zero correlation between contemporaneous error terms of the share equations. In (14b) we assume zero intertemporal correlations between all error terms.[1]

Similarly, the stochastic specification of the energy submodel (10) includes additive disturbances for each energy component share equation

$$S_{Ei} = \alpha_i + \sum_j \gamma_{ij} \ln P_{Ej} + u_i \qquad i,j=e,o,s \tag{15}$$

where, as above,

$$\tilde{u}_t \sim N(0,\Omega) \qquad \text{for all } t \tag{15a}$$

and

$$E(\tilde{u}_t \tilde{u}_s') = \delta_{st}\,\Omega \qquad \delta_{ts} = \begin{matrix} 1 \text{ if } t = s \\ 0 \text{ if } t \neq s \end{matrix} \tag{15b}$$

Estimation of the two-stage model requires specification of the relationship between error terms in (14) and (15). For the sake of simplicity we assume that the error term vectors $\tilde{\varepsilon}_t$ and $\tilde{u}_t$ are uncorrelated so that the distribution for

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[1] Ideally one would like to estimate a stochastic specification which in addition allows for non-zero intertemporal correlations. This, however, would further complicate the estimation procedure and could not easily be done with the programs available.

$\binom{\tilde{\varepsilon}_t}{\tilde{u}_t}$ is given by

$$\binom{\tilde{\varepsilon}_t}{\tilde{u}_t} \sim N\left\{0, \begin{bmatrix} \Sigma & 0 \\ 0 & \Omega \end{bmatrix}\right\}. \tag{16}$$

Further, since the share equations must sum to unity, the estimated disturbance covariance matrix is singular. The most common method of dealing with this problem is to delete one equation from the system and choose an estimation to which equation is deleted. In this study we employ a full information maximum likelihood estimation procedure.[1]

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[1] The computer program was written by L. Jansson, and entails maximisation of the concentrated likelihood function. For a formulation of this, see Barten (1969).

4 THE EMPIRICAL RESULTS

Various versions of the models described in the previous sections were estimated for total manufacturing, excluding energy production sectors, and for 12 manufacturing subsectors. The subsector miscellaneous manufacturing is excluded from individual analysis, but is included in total manufacturing. The sector divisions and sector numbers correspond to those used in the long-term economic surveys prepared by the Swedish Ministry of Finance.[1] Comparison with ISIC nomenclature is given in the appendix. A description of data sources and the construction of the cost and price series is also contained in the appendix.

First, we analyse the demand for aggregate inputs — energy, capital, labour and intermediate goods. This gives us information regarding the substitution possibilities between energy and other factors of production and the price elasticity of demand for aggregate energy. The results are presented and discussed in Section 4.1 below.

The second stage of our study, presented in Section 4.2, involves an analysis of interfuel substitution. Three energy forms are considered: electricity, oil products and solid fuels.

4.1 The Aggregate Demand for Energy

The demand for aggregate production factors is analysed by estimating the system of share equa-

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[1] so called LU-(långtidsutredningen)sectors.

tions given in (14). In accordance with the discussion in Section 3 the equation for intermediate goods is dropped from the estimation procedure, and the coefficients for that equation are calculated from the identities given in (4). The data for each sector include annual observations on costs and prices for labour, capital, energy and intermediate goods and production volume for the period 1952-1976. All price indices and production volume are normalised to unity for 1975.

Both homothetic and non-homothetic versions of the cost function are estimated. This allows us to statistically test for the more restrictive assumption of separability between prices and production level (homotheticity) and to compare the estimated elasticities for the two specifications.

Homothetic specification

The first results presented here are based on the assumption that the cost-function is homothetic, that is, we estimate equation system (14) under the constraints that $\gamma_{iq} = 0$ for all $i = K,L,E,M$. The estimated parameters for the fitted translog share equations along with their estimated standard errors, R^2 and the maximum likelihood value for each system of equations are shown in Table A1 in the appendix.

The majority of slope-coefficients (γ_{ij}) are significantly different from zero at normal confidence levels, suggesting that the variation in cost shares is at least partially explained by changes in relative factor prices. As mentioned in Section 2 above, we can test the hypothesis that all corresponds to a Cobb-Douglas production structure. The likelihood ratio test statistics, which are given in the first column of Table A3 in the appendix, fall in the interval 96-217. For all branches, the test statistic is clearly significant at the 1 % level, so that the hypothesis of unitary elasticities of substitution between all factor pairs can be rejected.

In order to analyse price-responsiveness and factor substitution possibilities we compute the Allen partial elasticities of substitution (σ_{ij}) and the price elasticities (η_{ij}) for all cost-share observations according to equations (7) and (8). Although the resulting elasticities vary somewhat over the time period analysed, no significant trends are discernable. We therefore present the elasticities calculated at the mean values of the exogenous variables as representative results.

The own-price elasticities of demand for energy, capital, labour and intermediate goods are shown in Table 1 along with their asymptotic standard errors.[1] These elasticities measure the percentage change in the use of a given input resulting from a 1 % change in its price. In accordance with cost minimising principles we would expect these elasticities to be negative. For example, a rise in the price of energy in relation to other production factors should lead to a substitution away from energy and thus decrease its use in production.

From Table 1 we see that the majority of the estimated own-price elasticities of demand are

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[1] Approximate standard errors are calculated at mean input shares under the assumption that these are non-stochastic.

Table 1 Own-price elasticities for Energy, Capital, Labour and Intermediate goods

Homothetic cost function

	Sector	Energy	Capital	Labour	Intermediate goods
4	Sheltered food	-.13 (0.16)	-.14 (0.02)	-.54 (0.02)	-.06
5	Import-competing food	-.47 (0.09)	-.18 (0.03)	-.66 (0.02)	-.13
6	Beverage and tobacco	-.15 (0.20)	-.16 (0.04)	-.74 (0.04)	-.24
7	Textiles and clothing	-.98 (0.16)	-.26 (0.05)	-.53 (0.01)	-.28
8	Wood, pulp and paper	.02 (0.11)	-.28 (0.03)	-.63 (0.03)	-.19
9	Printing	-.54 (0.11)	-.40 (0.06)	-.43 (0.01)	-.48
10	Rubber products	-.52 (0.17)	-.18 (0.09)	-.43 (0.01)	-.21
11	Chemicals	-.26 (0.12)	-.24 (0.03)	-.54 (0.02)	-.32
13	Non-metallic mineral products	-.41 (0.10)	-.29 (0.05)	-.62 (0.01)	-.66
14	Primary metals	.33 (0.14)	-.25 (0.05)	-.65 (0.03)	-.28
15	Engineering	-.64 (0.12)	-.24 (0.05)	-.57 (0.01)	-.41
16	Shipbuilding	-.56 (0.09)	-.15 (0.04)	-.65 (0.03)	-.33
	Total manufacturing	-.25 (0.09)	-.28 (0.01)	-.57 (0.05)	-.28

Note: Approximate asymptotic standard errors are in parenthesis. As the share equation for intermediate goods was excluded from the estimation, standard errors are not readily available.

negative[1] and with few exceptions significantly so at least at the 5 % level. Furthermore, the estimated own-price elasticities of demand are less than unity for all inputs and for all sectors, indicating that input demand is inelastic. Although the elasticities do vary somewhat for the individual industries, a few general trends are apparent. First, we find that the own-price elasticities for capital and labour are rather similar for the majority of branches. For total manufacturing, as well as for at least half of the subsectors, labour appears to be the most price-sensitive production factor with an elasticity generally on the order of -0.5. Capital, on the other hand, exhibits the most inelastic demand, with an average elasticity around -0.25. Although the results for intermediate goods show somewhat more variation, the elasticities are generally rather low.

Our prime concern, however, is with the price sensitivity of energy demand. Here, the elasticities show a far wider range of variation. Although the own-price elasticities for energy generally fall in the interval -0.4 to -0.6, the extremes range from non-significance to nearly -1.0. It is worth noting that of the four subsectors that show positive and/or non-significant energy price elasticities two of these — Wood, pulp and paper (8) and Primary metals (14) — are the most energy intensive Swedish industries.

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[1] The fitted shares were positive for all observations and all sectors insuring the positivity of the cost function. Although the estimated own-price elasticities are negative for the overwhelming majority of observations, a few sign reversals did occur in some sectors, indicating a local departure from concavity. More rigorous tests for concavity have, however, not been carried out.

In the case of Wood, pulp and paper (8) the large standard errors of the estimated elasticities make it impossible to reject the null hypothesis that energy demand is insensitive to price changes. This result may partially be due to a misspecification of the cost share for energy in this sector. Our measure of energy costs includes only expenditures for fuels purchased from outside the establishment so that the use of internal energy supplies — for example, of wood fuels — is omitted from the cost function. Wood fuels constitute an important energy source in paper and pulp production, and the omission of a large proportion of these fuels may have some effect on the estimated elasticities. In view of this specification error, it would be rash to draw any conclusions concerning the price elasticity for energy in this sector.

For the Primary metal industry, on the other hand, we find a significant positive energy price elasticity.[1] This, of course, is economic nonsense and must be rejected. A possible explanation to this spurious relationship may lie in the model formulation, and particularly in its inability to capture the effects of technological development. This is of utmost importance in the Primary metal industry where factors such as the development of blast furnaces and the increased use of oxygen converters have lead to a considerable decrease in specific energy usage since the beginning of the 60's.[2] The gradual introduction of new techniques has been contemporaneous with falling real energy prices. One can thus suspect that the positive

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[1] The calculated own-price elasticities were positive for nearly all the observations.

[2] Carling, Dargay, Dettinger, Sohlman (1978).

estimated price elasticity reflects an energy-saving technical change that has not been specified in our model.

The results for these two highly energy intensive industries illustrate the weakness of our model and suggest the need of further model development, particularly towards an explicit specification of non-neutral technological change.

Finally, our results indicate that energy is less price-elastic for aggregate manufacturing than it is for 8 out of 12 of the manufacturing subsectors. This is perhaps not surprising considering that two of the industries with positive elasticities account for nearly 2/3 of energy utilisation in the manufacturing sector. It should be pointed out, however, that estimates based on aggregate manufacturing partially reflect the changes in relative production shares among the individual industries that have occurred under the 1952-1976 time period.[1] These elasticities therefore are not directly comparable with those obtained for the disaggregated sectors.

Next, we turn to an examination of the substitution possibilities among inputs. For this purpose the Allen-Uzawa elasticity of substitution is calculated for each input pair. For a given factor pair, this elasticity measures the percentage change in the input ratio that results from a 1 % change in their relative prices. A negative value denotes that the factors are complements, that is

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[1] A description of the development of the composition of industrial production in Sweden under the period 1965-75 and a discussion of the effects of changes in branch structure on energy utilisation can be found in Östblom (1980).

to say, that a relative increase in the price of one factor leads to a decrease in the use of the other. A positive value denotes substitutability: a relative increase in the price of one factor leads to a relative increase in the use of the other.

These elasticities are shown in Table 2 together with their asymptotic standard errors. Of particular interest for energy policy are the substitution possibilities between energy-capital and between energy-labour. In six subsectors (5,7,8, 9,15,16) we may conclude that energy and capital are complements.[1] Only one sector, sheltered food (4), exhibits capital-energy substitutability. In the remaining sectors, all of which show negative elasticities, the standard errors make it impossible to reject the hypothesis that the elasticity is 0. The predominance of energy-capital complementarity in the individual industries is consistent with the results obtained for total manufacturing. We see, however, that the aggregate measure overestimates the degree of complementarity for all but 2 subsectors. The results for the substitution relationship between energy and labour are quite the opposite. In 6 of the Swedish manufacturing industries (4,5,7,9,10,16), the elasticities are significantly positive, indicating substitutability, while only two sectors (6,13) exhibit energy-labour complementarity at normal significance levels. Finally, in the remaining two sectors the high standard errors preclude any conclusions concerning energy-labour relationships. The statistically significant elasticities between energy and labour fall in a rather wide region, ranging from

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[1] These parameters are significant at the 5 % level.

Table 2 Substitution elasticities for Energy (E), Capital (K), Labour (L) and Intermediate goods (M)

Homothetic cost function

	Sector	E-K	E-L	E-M	K-L	K-M	L-M
4	Sheltered food	2.81 (1.27)	0.33 (0.01)	-0.03 (0.14)	1.60 (0.12)	-0.09 (0.03)	0.56 (0.03)
5	Import-competing food	-2.11 (0.64)	1.06 (0.19)	0.62 (0.14)	0.28 (0.14)	0.22 (0.05)	0.80 (0.02)
6	Beverage and tobacco	-0.18 (0.48)	-1.26 (0.21)	0.84 (0.27)	1.50 (0.26)	-0.36 (0.06)	1.00 (0.03)
7	Textiles and clothing	-3.73 (0.99)	0.31 (0.14)	2.08 (0.34)	1.11 (0.07)	-0.06 (0.12)	0.75 (0.02)
8	Wood, pulp and paper	-0.59 (0.28)	0.02 (0.10)	0.08 (0.19)	1.19 (0.08)	0.06 (0.06)	0.79 (0.03)
9	Printing	-1.82 (0.48)	1.06 (0.15)	0.74 (0.39)	0.42 (0.10)	0.56 (0.19)	0.90 (0.06)
10	Rubber products	-0.07 (0.87)	0.46 (0.14)	0.75 (0.43)	0.78 (0.08)	-0.17 (0.21)	0.63 (0.04)
11	Chemicals	-0.11 (0.20)	-0.21 (0.19)	0.55 (0.16)	-0.08 (0.07)	0.46 (0.06)	0.96 (0.05)
13	Non-metallic mineral products	-0.32 (0.36)	-0.24 (0.12)	1.34 (0.34)	0.31 (0.10)	0.50 (0.14)	1.41 (0.04)
14	Primary metals	-0.66 (0.42)	-0.61 (0.21)	-0.17 (0.29)	0.61 (0.10)	0.29 (0.14)	1.10 (0.06)
15	Engineering	-0.91 (0.47)	0.02 (0.06)	1.30 (0.26)	0.21 (0.09)	0.34 (0.10)	1.02 (0.02)
16	Shipbuilding	-0.60 (0.32)	0.37 (0.09)	0.85 (0.20)	0.54 (0.10)	-0.02 (0.10)	1.02 (0.06)
	Total manufacturing	-1.43 (0.49)	0.12 (0.10)	0.66 (0.20)	0.66 (0.09)	0.24 (0.08)	0.84 (0.01)

Note: Approximate asymptotic standard errors are in parenthesis.

strong complementarity — nearly -1.3 in sector (6) — to a degree of substitutability somewhat greater than +1.0 in sectors (5) and (9). Because of these divergences in the sign and magnitude of the elasticities of substitution across the individual industries, the estimates based on aggregate manufacturing could be quite misleading. Our results for total manufacturing indicate that energy and labour are rather weak substitutes.

The relationship between energy and materials is, in all statistically significant cases, positive, indicating that these factors are substitutes. The elasticities range from about 0.6 to somewhat over 2.0.

With regard to non-energy inputs, we see that capital and labour are substitutes in all but the Chemical industry (11) where the elasticity is not statistically significant. In four sectors (4,6,7,8) we find the elasticity to be somewhat greater than unity while in others (5,13,15) the substitution possibilities are rather small (σ_{kl} = +0.2 to +0.3).

Finally, we see that capital and intermediate goods are statistically significant, but weak substitutes in six industries, while a weak complementary relationship exists in two. The large standard errors of the remaining three estimates do not allow rejection of the hypothesis of zero substitution between these inputs. In general, the results are indicative of a more or less independent relationship between capital and intermediate goods. This is strikingly contrary to the results obtained for labour-materials. As is seen, all industries exhibit a high degree of substitutability between labour and intermediate goods.

Non-homothetic specification

The results presented above are based on the assumption that the cost function is homothetic, that is to say that the cost-minimising input shares are independent of the level of production. For the sake of comparison, we now examine what happens when this restriction is relaxed, by estimating equation system (14) with the γ_{iq} no longer constrained to zero. This allows us to empirically test for homotheticity by the likelihood ratio test.

The estimated coefficients for the non-homothetic specification along with their asymptotic standard errors, R^2 and maximum likelihood values are given in Table A2 in the appendix. In particular, two results are worth noting. First, we find that production volume generally has a significant influence on the factor demand shares, which suggests that the cost function is non-homothetic. This is also supported by the likelihood ratio test statistics which are given in the second column of Table A3 in the appendix. The null-hypothesis of homotheticity is strongly rejected for all sectors, with the exception of the Non-metallic mineral products industry (13). Secondly, a strong negative relationship exists between labour's cost share and production level for the majority of the industries. According to the assumptions of our model this is indicative of an output elasticity of labour demand that is less than unity.[1] However, as production volume increases

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[1] The output elasticity of demand for factor i is given by

$$\eta_{iq} = \gamma_{iq}/S_i+\alpha_q+\gamma_{qq}\ \ln Q+\sum_j \gamma_{jq}\ \ln P_j \qquad i=K,L,E,M.$$

It can be computed only if α_q and γ_{qq} are known, that is, by estimating the cost function directly.

over time, it is exceedingly difficult to separate scale effects from, for example, the effects of biased technological change. It may be that the output variable is partially capturing the effects of a labour-saving technical development,[1] which is not specified in our model. We therefore consider it unwarranted to attempt to interpret our results in terms of scale effects, until an explicit allowance is made for non-neutral technological progress.

The own-price elasticities and the elasticities of substitution for energy, capital, labour and intermediate goods implied by the non-homothetic cost function are shown in Tables 3 and 4. We see that resulting own-price elasticities are quite similar to those obtained from the homothetic specification (compare Table 1). In seven out of the twelve subsectors the own-price elasticity for energy falls in the interval from -0.4 to -0.7. For the remaining sectors, the large standard errors do not allow us to reject the hypothesis of zero price-responsiveness. Again, we find positive, although non-significant, price elasticities in the two most energy intensive branches: Wood, pulp and paper (8) and Primary metals (14).

Further, we find that the own-price elasticities for capital are more or less identical to those presented earlier. The major differences between the homothetic and non-homothetic specifications lie in the resulting price elasticities of demand for labour and intermediate goods. In nearly all

[1] Evidence of a labour-saving technological development in Swedish industrial sectors is noted in the capital-labour production function studies of Bergström and Melander (1979) and Eriksson, Jakobsson and Jansson (1976).

Table 3 Price elasticities of demand for Energy, Capital, Labour and Intermediate goods

Non-homothetic cost function

	Sector	Energy	Capital	Labour	Intermediate goods
4	Sheltered food	-0.16 (0.12)	-0.15 (0.02)	-0.15 (0.06)	-0.00
5	Import-competing food	-0.44 (0.03)	-0.19 (0.02)	-0.18 (0.02)	-0.01
6	Beverage and tobacco	0.05 (1.68)	-0.11 (0.04)	-0.05 (0.01)	-0.07
7	Textiles and clothing	-0.67 (0.14)	-0.15 (0.04)	-0.54 (0.02)	-0.21
8	Wood, pulp and paper	0.08 (0.08)	-0.24 (0.03)	-0.02 (0.08)	-0.08
9	Printing	-0.55 (0.12)	-0.25 (0.05)	-0.16 (0.05)	-0.15
10	Rubber products	-0.63 (0.18)	-0.26 (0.06)	-0.14 (0.03)	-0.09
11	Chemicals	-0.19 (0.12)	-0.23 (0.03)	0.06 (0.02)	0.03
13	Non-metallic mineral products	-0.46 (0.11)	-0.30 (0.06)	-0.50 (0.05)	-0.52
14	Primary metals	0.29 (0.16)	-0.26 (0.03)	-0.22 (0.11)	-0.06
15	Engineering	-0.57 (0.15)	-0.24 (0.05)	-0.18 (0.07)	-0.12
16	Shipbuilding	-0.47 (0.14)	-0.16 (0.05)	-0.28 (0.07)	-0.12
	Total manufacturing	-0.10 (0.08)	-0.21 (0.03)	-0.25 (0.09)	-0.12

Note: Approximate asymptotic standard errors are in parenthesis. As the share equation for intermediate goods was excluded from the estimation, standard errors are not readily available.

branches, these elasticities decrease considerably when the homotheticity constraints are relaxed. The estimated price elasticity of demand for labour is under -0.2 for all but three sectors – Textiles (7), Non-metallic minerals (13) and Shipbuilding (16). This result is quite different from that implied by the homothetic model, which indicated labour to be the most price-sensitive production factor with an average elasticity on the order of -0.5. Finally, intermediate goods show very little price-responsiveness with elasticities of demand very near zero in the majority of industries.

Regarding the substitution relationships among inputs, our estimates show the same general pattern as that obtained for the homothetic specification. A few changes in sign do occur, but these estimates are generally non-significant in both cases. The most notable exception is the relationship between energy and capital in total manufacturing, where the relationship switches from strong complementarity (σ_{EK} = -1.4) to a positive, but non-statistically significant value. Again, energy and capital are seen to be complements in most significant cases, while substitutability predominates between energy and labour and between energy and intermediate goods. The magnitudes of these relationships are, however, somewhat different than those obtained when homotheticity is imposed. The general trend seems to be towards weaker energy-capital complementarity and greater energy-labour substitutability. The most substantial difference between the two specifications is the elasticity of substitution between labour and intermediate goods. With the assumption of homotheticity, this elasticity is greater than +0.5 for all sectors, whereas relaxing this assumption re-

Table 4 Substitution elasticities among Energy (E), Capital (K) and Labour (L) and Intermediate goods (M)

Non-homothetic cost function

	Sector	E-K	E-L	E-M	K-L	K-M	L-M
4	Sheltered food	1.98 (0.91)	4.88 (1.28)	-0.59 (0.12)	0.66 (0.40)	0.06 (0.06)	0.08 (0.07)
5	Import-competing food	-1.70 (0.64)	4.18 (1.57)	0.03 (0.30)	1.19 (0.37)	0.07 (0.04)	0.05 (0.11)
6	Beverage and tobacco	0.27 (0.45)	-3.40 (1.06)	1.32 (0.28)	0.57 (0.24)	-0.07 (0.08)	0.14 (0.13)
7	Textiles and clothing	-0.66 (0.85)	0.65 (0.10)	0.91 (0.31)	1.34 (0.06)	-0.48 (0.10)	0.72 (0.03)
8	Wood, pulp and paper	-0.06 (0.15)	-0.36 (0.52)	0.01 (0.21)	0.71 (0.12)	0.14 (0.06)	0.01 (0.10)
9	Printing	-1.23 (0.38)	0.65 (0.61)	1.05 (0.91)	0.40 (0.08)	0.19 (0.11)	0.25 (0.14)
10	Rubber products	-1.22 (0.73)	0.06 (0.56)	1.57 (0.57)	0.68 (0.18)	-0.13 (0.08)	0.09 (0.01)
11	Chemicals	0.14 (0.20)	0.38 (0.25)	0.14 (0.04)	0.52 (0.08)	0.15 (0.05)	-0.23 (0.04)
13	Non-metallic mineral products	-0.52 (0.49)	-0.17 (0.40)	1.47 (0.39)	0.53 (0.18)	0.39 (0.14)	1.01 (0.14)
14	Primary metals	0.14 (0.46)	-0.20 (0.90)	-0.47 (0.32)	0.51 (0.26)	0.25 (0.10)	0.28 (0.18)
15	Engineering	-0.70 (0.47)	0.48 (0.49)	0.85 (0.51)	0.42 (0.24)	0.19 (0.10)	0.26 (0.12)
16	Shipbuilding	-0.93 (0.42)	1.07 (0.26)	0.36 (0.23)	0.53 (0.30)	-0.00 (0.15)	0.37 (0.11)
	Total manufacturing	0.33 (0.52)	0.17 (0.82)	0.03 (0.45)	0.26 (0.21)	0.21 (0.08)	0.36 (0.14)

Note: Approximate asymptotic standard errors are in parenthesis.

duces it to insignificance in well over half the cases.

In conclusion, our results indicate that the majority of the elasticities are at least slightly sensitive to the specification of homotheticity.[1] Some of these, and especially those pertaining to labour, are highly so. The discrepancies are mainly in the magnitude of the estimated elasticities, whereas the pattern of substitution possibilities is largely in agreement for the two specifications. Of most relevance for the purposes of our study, however, is the result that the own-price elasticities for energy and the substitution relationships between energy and other production factors are quite robust to differences in homotheticity assumptions.

4.2 Interfuel Substitution

Thus far our analysis has concentrated on aggregate energy and the substitution relationships between total energy and other factors of production. Our next task is to extend our analysis to encompass the substitution possibilities among individual energy types.

Three energy subgroups are considered: electricity (e), oil products (o) and solid fuels (s).[2] Oil

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[1] The sensitivity of the elasticities to the specification of homotheticity was also observed by Denny, May and Pinto (1978) for Canadian manufacturing. They found that the imposition of homotheticity decreases the elasticities of substitution. In particular, energy-capital complementarity was reduced and strong energy-labour substitutability was reversed to complementarity.

[2] Because of their limited usage, gases are excluded from the analysis.

products include fuel oil, gas oil and motor gasoline while solid fuels include coal, coke and wood fuels. We have chosen to aggregate all oil products and all solid fuels because of the similar price development of the individual fuels within each group. A further disaggregation of fuel types would only increase multicollinearity problems and reduce the precision of the estimates. It should be noted that fuel oils account for the greatest part of the oil aggregate for all industries. Regarding solid fuels, coal predominates in all but the Wood, pulp and paper industry (8) and Primary metals (14) where the major solid fuels used are, respectively, wood fuels and coke.

In addition to total manufacturing, we limit our analysis to five subsectors that account for approximately 90 % of energy usage in manufacturing and 70 % of manufacturing production. Four of these are the most energy intensive Swedish industries: Wood, pulp and paper (8), Primary metals (14), Chemicals (11) and Non-metallic mineral products (13). The last, Engineering (15), is the largest in terms of production and employment.

The share equations for the two-stage model are estimated using annual data over the period 1962-1976. The pre-1962 time period is excluded from the estimation to eliminate the remaining effects of the substitution away from solid fuels that had begun in the previous decade. This substitution of liquid for solid fuels cannot be explained solely in terms of the energy price relationships specified in our model.

The energy submodel

The first stage of our analysis involves the estimation of the energy submodel given in equation system (15) under the constraints implied by linear homogeneity in prices. The equation for solid fuels is deleted from the estimation procedure.

The estimated coefficients for the energy submodel, along with their estimated standard errors, R^2 and maximum likelihood values are given in Table A4 in the appendix. We test the hypothesis that the slope coefficients (γ_{ij}) are all zero, i.e., that the cost shares for the individual fuels are independent of relative fuel prices. The likelihood ratio test statistics, which are given in the last column of the table, are significant at the 0.5 % level, so that this hypothesis can be rejected.

The partial price elasticities and elasticities of substitution corresponding to these parameter estimates are shown in Table 5.[1] It should be held in mind that these elasticities are derived under the constraint that total energy input remains constant. Thus they represent only the effects of interfuel substitution, i.e. η_{ij}^{P} in (13).

One observes a high degree of similarity in the results for the different industries. Firstly, we see that the own-price elasticities for oil and electricity clearly fall in the inelastic range. Of all energy components, electricity appears to be the least sensitive to price changes. This elasticity is less than 0.2 in absolute value for all industries, but nevertheless is found to be

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[1] The elasticities are calculated at the mean values of the exogenous variables. Little variation was found over the 62-76 time period. Fitted shares were positive and own-price elasticities negative for all observations included in the sample.

significantly different from zero. Oil products are somewhat more price-sensitive, with an elasticity on the order of -0.25. On the other hand, we find solid fuels to be highly price-sensitive, with elasticities of demand greater than 1.0 in absolute value in four out of the five manufacturing subsectors. The most significant exception is the low price elasticity obtained for solid fuels in the Primary metal industry (14). This can be attributed to the fact that the solid fuel component in this sector is primarily comprised of coke, which is used not as a source of energy but as a reduction agent. The limited possibility of replacing coke with other fossil fuels is similarly reflected in the comparatively low elasticity of substitution between solid fuels and oil products in this sector.

Table 5 Partial price and substitution elasticities for the Energy subcomponents: Electricity (e), Oil products (o) and Solid fuels (s)

	Sector	Own-price elasticity			Substitution elasticity		
		e	o	s	e-o	e-s	o-s
8	Wood, pulp and paper	-0.12 (0.03)	-0.24 (0.34)	-1.39	0.22 (0.08)	1.00 (0.21)	2.28 (0.33)
11	Chemicals	-0.09 (0.04)	-0.15 (0.17)	-1.80	-0.23 (0.17)	1.54 (0.33)	3.29 (1.44)
13	Non-metallic mineral products	-0.12 (0.03)	-0.25 (0.06)	-1.42	-0.24 (0.10)	1.40 (0.41)	1.91 (0.46)
14	Primary metals	-0.12 (0.06)	-0.26 (0.07)	-0.14	0.24 (0.12)	0.18 (0.29)	0.39 (0.20)
15	Engineering	-0.20 (0.03)	-0.27 (0.06)	-1.02	0.36 (0.07)	1.11 (0.42)	1.05 (1.07)
	Total manufacturing	-0.16 (0.03)	-0.26 (0.06)	-0.60	0.21 (0.06)	0.55 (0.17)	0.96 (0.30)

In the majority of the remaining subsectors, as well as in total manufacturing, we find that the most important substitution possibilities exist between oil products and solid fuels. These elasticities are particularly high for those industries in which solid fuels account for a significant proportion of total energy supply, e.g. Wood, pulp and paper (8) and Non-metallic minerals (13).

Regarding the relationship between oil and electricity, our results suggest marginal, but generally non-zero, substitution possibilities. The only exceptions are two cases of complementarity between electricity and oil products in the Chemical industry (11) and the Non-metallic mineral products industry (13). Although a strict complementary relationship is highly unlikely, there are reasons for expecting minimal substitutability between oil and electricity in these industries. In the Chemical industry, a large proportion of electricity is used for electrolysis and as such is indispensible. In the production of non-metallic mineral products — cement, lime, etc. — oil is the dominant source of thermal energy whereas electricity is chiefly a source of motive power.

Finally, our results suggest a surprisingly high degree of substitutability between electricity and solid fuels. Considering the nature of the usage of these energy forms, this result seems highly unlikely. Although there is some scope for substitution between electricity and solid fuels, we hardly expect these possibilities to outweigh those between electricity and oil products. One explanation for these results may be that the trend towards increased mechanization — and thereby electricity use — has coincided with the substitution away from solid fuels.

Aggregate energy demand

The estimates of the energy cost function for each of the subsectors are now used to generate the corresponding aggregate price indices for energy. These, in turn, serve as instrumental variables for the price of energy in the estimation of the total (E,K,L,M) cost functions. The estimated parameters and the resulting price and substitution elasticities are shown in Tables A5-6 in the appendix. As homotheticity is clearly rejected for all sectors, only the results for the non-homothetic specification are presented.

The estimated demand relationships provide little information in addition to the results discussed in Section 4.1, so only a few comments need to be made. Firstly, we find that the elasticity estimates for capital, labour and intermediate goods are in agreement with those presented earlier (Tables 1-4) for the 1952-1976 time period. There are, however, considerable discrepancies in the estimated own-price elasticities for energy, as well as in the magnitude of substitutability/complementarity between energy and the remaining production factors. As noted previously, an overall pattern of energy-capital complementarity and energy-labour substitutability is suggested, but again, the high standard errors of the estimates do not allow rejection of the null-hypothesis in the majority of cases.

A comparison of the aggregate energy price elasticities obtained from the two-stage estimation with those presented in Section 4.1 for the non-homothetic model is given in the first two columns of

Table 6.[1] We find that for Primary metals (14) the elasticities are in agreement, but these must be rejected on the basis of sign in both cases, whilst for Wood, pulp and paper (8) and Total manufacturing the elasticities are not statistically significant. It is apparent, however, that the resulting elasticities for the remaining three sectors (11, 13 and 15) differ considerably for the alternative estimations.

The explanation for these discrepancies cannot be found solely on the basis of these results since the estimates are based not only on different time periods, but also on different price indices for aggregate energy. Although a thorough sensitivity analysis has not yet been carried out, our findings thus far seem to suggest that choice of observation period is the determining factor for the resulting estimates, while construction of the price index is of minor importance.[2]

A plausible explanation for the sensitivity of the estimates of the energy elasticities to estimation period may be the drastic energy price-rises from 1974 onwards. These have a greater influence on the estimates based on 1962-1976 than on those based on the longer time period. It is not obvious precisely what effects the relative up-weighting of the post-1974 time period has on the estimates and it is possible that the mere inclusion of this

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[1] The elasticities are calculated at the mean values of the exogenous variables for each sample. This, however, has no relevance for the comparison since the calculated elasticities vary only slightly over time in both cases.

[2] The aggregate energy price indices based on the energy submodel estimates are, in fact, nearly identical to those constructed as simple weighted averages of the individual energy forms.

Table 6 **Own-price elasticities for aggregate energy (η_{EE}), mean cost-shares (S_i) and partial (η^P_{ii}) and total (η^T_{ii}) own-price elasicities for the energy components**
Non-homothetic total cost function

Sector	Aggregate energy (η_{EE}) 1952–76	Aggregate energy (η_{EE}) Two Stage 1962–76	Electricity S_e	Electricity η^P_{ee}	Electricity η^T_{ee}	Oil products S_o	Oil products η^P_{oo}	Oil products η^T_{oo}	Solid fuels S_s	Solid fuels η^P_{ss}	Solid fuels η^T_{ss}
8 Wood, pulp and paper	0.08 (0.08)	−0.13 (0.08)	.62	−0.12	−0.20	.34	−0.24	−0.28	.04	−1.39	−1.40
11 Chemicals	−0.19 (0.12)	−0.57 (0.11)	.68	−0.09	−0.48	.23	−0.15	−0.28	.09	−1.80	−1.85
13 Non-metallic mineral products	−0.46 (0.11)	−0.05 (0.05)	.32	−0.12	−0.14	.51	−0.25	−0.28	.17	−1.42	−1.43
14 Primary metals	0.29 (0.16)	0.29 (0.11)	.38	−0.12	−0.12[a]	.18	−0.26	−0.26[a]	.44	−0.14	−0.14
15 Engineering	−0.57 (0.15)	−0.17 (0.14)	.57	−0.28	−0.30	.37	−0.27	−0.33	.06	−1.02	−1.03
Total manufacturing	−0.10 (0.08)	−0.09 (0.07)	.51	−0.16	−0.21	.33	−0.26	−0.29	.16	−0.60	−0.60

[a] Calculated with the price elasticity for aggregate energy set to 0.

period has a significant influence on the estimated parameters.[1] As mentioned earlier, the translog function provides only a local approximation to the underlying cost function. It is possible that the validity of this approximation may be weakened by fitting a single cost function to a period that is characterised by so vastly divergent factor prices. The effects, if any, of including the post-1974 time period could be determined by re-estimating the model excluding this data and comparing the resulting parameter estimates with those obtained when the post-1974 data are included. Until a thorough investigation into the causes of the sensitivity of the elasticity estimates is carried out, our results must be interpreted with utmost caution.

With this in mind, we proceed, mainly for illustrative purposes, to calculate the total price elasticities for the individual energy components on the basis of the two-stage model. The results are presented in Table 6 along with the mean cost shares for each fuel type. The partial price elasticities for the energy components presented previously are also given for the sake of comparison.

We recall that according to the assumptions of our model the total price-sensitivity (η^T_{ij}) of an individual fuel is determined in a bi-level adjustment process. Firstly, a change in the price of an energy component results in interfuel substitution. This effect on demand is measured in the partial price elasticities η^P_{ij}. Secondly, the price change affects the aggregate price index for

[1] The sensitivity of the estimates to the inclusion of years with rapid price changes (1972-74) is also noted by Berndt, Fuss and Waverman (1979).

energy, resulting in substitution between energy and other production factors. The resultant change in aggregate energy demand in turn affects the demand for the energy component. The magnitude of this effect is determined by the energy components' share of total energy costs (S_i).

From Table 6 we see that for the majority of the subsectors, as well as for total manufacturing, the total price elasticities are only marginally greater than the partial. This clearly follows from the "inelasticity" of aggregate energy demand in these sectors. The total price-sensitivity of the individual fuels is therefore attributed primarly to the effects of interfuel substitution. For the Chemical industry (11), on the other hand, substitution between energy and other production factors plays a substantial role. The effect on electricity demand is particularly large due to electricity's high cost share. For solid fuels, which account for a very small part of total energy costs, the effects are minimal.

These results are meaningful, of course, only if we accept the estimates of the two-stage model. It is obvious that the estimates of aggregate elasticities based on the 1952-76 time period (column 1) would lead to somewhat different conclusions for at least three subsectors (11, 13, 15).

5 COMPARISON OF RESULTS WITH OTHER STUDIES

As mentioned in the introduction, the analysis of energy demand and of the relationships between energy and other production factors has been the topic of a large number of econometric studies. It can be of interest to compare our results for Sweden with those of other studies of energy demand. For this purpose, we present in the following tables a survey of estimates of energy demand elasticities obtained by other authors and for other countries. The estimates shown in the tables are all based on cost-minimising multifactor demand models similar to those estimated for Sweden. Choice of functional form, separability assumptions, observation period and data construction vary, however, from study to study. The majority of these studies, as our own, are based on static models some using time-series data for individual countries, others using a combination of time-series and cross-section data for a number of countries or regions. The study by Denny, Fuss and Waverman (j) is based on a dynamic adjustment model which allows estimation of both short- and long-run elasticities.

In Table 7 we present a comparison of estimates of the own-price elasticity for aggregate energy and the elasticities of substitution between energy and other aggregate production factors: capital (K), labour (L) and intermediate goods (M). Estimates of the elasticity of substitution between capital and labour are also shown. It is not within the scope of this paper to thoroughly discuss this enormous wealth of results, much less to analyse the apparent discrepancies amongst them.

Table 7 Comparison of estimates of the own-price elasticity for energy and the elasticities of substitution between energy (E) and capital (K), labour (L) and intermediate goods (M)

Key to table follows after Table 8, p.108.

Source	Country	Data			Energy own-price elasticity	Elasticity of substitution E-K	E-L	E-M	K-L
a)	USA	1947-71	TS	TM	-0.47	-3.22	0.65	0.70	1.01
b)	Canada	1941-70	TS	TM	H -	0.60	-1.28	0.37	2.26
					NH -0.50	-11.91	4.86	0.12	5.46
c)	Canada	1961-71	CSTS	TM	-0.49	-	+	-	0.80 to 0.86
d)	Netherlands	1950-76	TS	TM	-0.16	-2.30	1.25	...	0.30
This study	Sweden	1952-76	TS	TM	H -0.25	-1.43	0.12	0.66	0.66
					NH -0.10	0.33	0.17	0.03	0.26
e)	9 countries	1955-69	CSTS	TM	-0.77 to -0.82	1.02 to 1.07	0.80 to 0.87	...	0.06 to 0.52
f)	10 countries	1963-73	CSTS	TM	-0.83 to -0.87	0.36 to 1.77	0.03 to 1.23	...	0.64 to 1.43
g)	USA	1971	CS	10MS	-0.54 to -1.65	-3.80/2.09[1]	+	...	+
h)	Belgium	1960-75	TS	4MS	-0.08 to -0.15	-	+	-	0.99
This study	Sweden	1952-76	TS	12MS	H 0 to -0.98	-3.73 to 2.81	-1.26 to 1.06	-0.17 to 2.08	0 to 1.60
					NH 0 to -0.67	-1.70 to 1.98	-3.40 to 4.88	-0.59 to 5.08	0.42 to 1.34
i)	USA	1948-71	TS	18MS	SR 0 to -1.09		-6.28 to 3.54	na	
					LR -0.01 to -1.10	-22.40 to 8.04	-6.40 to 10.93		-22.40 to 8.05
j)	Canada	1962-75	CSTS	18MS	SR 0 to -1.46		-2.16 to 5.86	na	-9.00 to 18.6
					LR -0.03 to -2.86	-9.00 to 18.60	-4.71 to 5.08		

[1] Physical capital and working capital respectively

Our comments will only be brief and the interested reader is referred to the original articles for a complete description of model formulation and empirical results.

Studies (a-d) analyse factor demand relationships in total manufacturing for individual countries. Studies (a, b, d) are based on national time-series data, while (c) is based on time-series data for Canadian provinces. These results can be compared with our own for total Swedish manufacturing. Our estimates based on the homothetic specification (H) seem in closest agreement with those of the other studies, which, with the exception of (b), all assume homotheticity. We see that the results of the Canadian study (b) show a substantial sensitivity to homotheticity assumptions. As in the case with Sweden, the homothetic model is rejected on the basis of the statistical tests. Further, we find that our estimate of the own-price elasticity for energy is lower than in studies (a-c), but quite similar to that obtained for the Netherlands (d), which also includes post-1973 data in the estimation.

Studies (e, f) are based on a combination of time-series and cross-section data for total manufacturing in a sample of industrialised countries. The most striking difference between the results of the international studies and those for individual countries is that the former find energy and capital to be substitutes in total manufacturing rather than complements. The resulting own-price elasticities for aggregate energy are also somewhat higher in the international studies. The authors argue that observations across countries capture long-run adjustments whereas time-series data reflect short-run effects. Thus, they conclude that although energy and capital may be complements in the short run, they will be substitutes in the long run. These results should, however, be interpreted with care, as there may be other explanations for the contradictory findings regarding energy-capital relationships. Berndt and Wood (1979) suggest that they may be due to the fact that different elasticities are being measured. The international studies, in contrast to studies (a-c) and to our own study, omit intermediate goods (M) from the estimation, thereby assuming that intermediate goods are weakly separable from the remaining (KLE) inputs. As shown by Berndt and Wood substitution between energy and capital in the three factor (KLE) subset does not necessarily rule out overall energy-capital complementarity when the substitution relationships amongst all factors (KLEM) are considered. Even if the assumption of separability is valid, these two elasticities are equivalent only if the substitution possibilities between intermediate goods and the remaining inputs are zero.[1]

Study (g) is an attempt to resolve the controversy regarding the relationship between energy and capital. The authors maintain that an explanation to the contradictory results noted in previous studies lies in the differences in definition of capital. Studies b, e and f use a value-added approach in estimating the cost of capital, in which capital costs are defined as value-added minus labour costs. Studies a and c — as well as our own — use a service price approach, in which capital costs are defined as physical capital × service price. The value-added definition includes more

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[1] This is the case because the Allen elasticity of substitution is a partial elasticity and is dependent on factor grouping.

than the cost of physical capital, and the authors argue that it is the difference between them, which they term the contribution of "working capital", that is the cause of the divergent results. To investigate this, the authors disaggregate the "capital" component of value added into costs for physical and working capital. The results obtained for ten manufacturing subsectors suggest that physical capital and energy are complements whereas substitutability exists between energy and working capital.

The remaining studies are also based on disaggregated manufacturing subsectors. The Belgian study (h) covers only the most energy-intensive industries: Primary metals, Non-ferrous metals, Chemicals and Building materials. The low energy price elasticities obtained for these industries are not vastly different from our own findings. As in the majority of the other studies, they find that capital-energy complementarity and energy-labour substitutability predominate.

The final study (j) employs a dynamic partial-adjustment model to explain the intertemporal relationship between factor prices and input-mix. Briefly, the firm is assumed to minimise the present value of future production costs. Lags in adjustment to factor price changes are explained by the increasing marginal costs that would be incurred during rapid adjustment of the capital stock. By specifying the adjustment mechanism, both short- and long-run responses are estimated. It is difficult to adequately summarise their results. As shown in the table, both the short- and long-run elasticities fall in a wide range for the industries studied. The results indicate that, on average, in the first year after a factor price rise, firms adjust about 30-40 % of the difference between their new desired stock and the existing capital stock at the beginning of the period. The price elasticity of energy demand is less than 1 in absolute value even in the long run and differences between short- and long-run price elasticities of energy demand are generally rather small. Regarding the substitution relationship between energy-capital and energy-labour, they find a wide variety of responses across industries within each country as well as across the two countries studied.

Table 8 gives a comparison of partial price elasticities for individual energy forms. With the exception of study (j), which is based on a dynamic model formulation, all of the elasticity estimates shown are based on static models similar to the energy submodel employed in this study. The elasticities are thus partial and represent the price response due to interfuel substitution only. The breakdown of total energy differs somewhat in the various studies. Many include gases and some further disaggregate oil products and/or solid fuels.

Although the magnitude of the price-responses varies from study to study as well as across individual industries, a number of conclusions are evident. The general consensus seems to be that solid fuels are most sensitive to relative price changes, whereas oil and electricity are considerably less responsive to changes in relative prices. Secondly, although the results are not shown here, all studies indicate substitution possibilities between the majority of energy forms, with the most substantial substitution generally existing between solid and liquid fuels.

Table 8 Comparison of partial price elasticities for individual fuels

Source	Country	Data	Electricity	Oil	Solid fuels	Gas
c)	Canada	1961–71 CSTS TM	−0.52	−1.22, −1.56[1]	−1.41	−1.21
f)	10 countries	1959–73 CSTS TM	−0.07 to −0.16	−0.08 to −0.72	−1.04 to −2.17	−0.33 to −2.31
h)	Belgium	1960–75 TS 4MS	−0.33 to −1.07	−0.57 to −1.19	−0.66 to −5.19[2] −0.33 to −2.91	−0.91 to −2.10
i)	USA	1974–75 CSTS TM	−0.13 to −0.88	−0.08 to −0.70	−0.34 to −1.91	−0.13 to −0.88
j)	Canada[3]	1962–75 CSTS 18MS	LR −0.01 to −1.77	−0.05 to −1.26	−0.64 to −2.18	−0.81 to −1.97
This study	Sweden	1962–76 TS TM 1962–76 TS 5MS	−0.16 −0.12 to −0.20	−0.26 −0.15 to −0.27	−0.60 −0.14 to −1.80	... ...

[1] fuel oil and motor gasoline respectively
[2] coal and coke respectively
[3] total elasticities based on a dynamic model

Key to Tables 7 and 8

TS = time-series data
CS = cross-section data
TM = total manufacturing
x MS = x manufacturing sectors
... = not included in the estimation
na = included but estimates not available
H = homothetic specification
NH = non-homothetic specification
SR = short run
LR = long run

Sources

a) Berndt and Wood (1975)
b) Denny, May and Pinto (1978)
c) Fuss (1977)
d) Magnus (1979)
e) Griffen and Gregory (1976)
f) Pindyck (1979)
g) Field and Grebenstein (1980)
h) Bossier, Duwein and Gouzée (1979)
i) Uri (1979)
j) Denny, Fuss and Waverman (1980)

6 SUMMARY AND CONCLUSIONS

In the preceding sections we have presented demand models designed to study the interaction between energy and other aggregate production factors and to analyse interfuel substitution possibilities. Empirical implementation of these models has resulted in estimates of price and substitution elasticities for individual energy forms, aggregate energy and other aggregate production factors for total Swedish manufacturing and disaggregated manufacturing sectors. It is impossible to adequately summarise the results; there is a variety of responses across industries and a number of questions concerning the sensitivity and interpretation of the estimates remain unanswered. A few tentative conclusions are, however, evident. Those most relevant to energy demand are the following:

- It is important to disaggregate manufacturing into its component industries. The magnitude and even the nature of the demand and substitution responses vary according to the production structure of the individual industry.

- Energy demand is at least somewhat sensitive to changes in its own price. The own-price elasticity is less than unity but the magnitude of response varies from industry to industry.

- Complementary relationships prevail between energy and capital, while substitutability predominates between energy-labour and energy-intermediate goods.

- Regarding the partial elasticities of the energy subcomponents, solid fuels appear to be highly price-sensitive, while the demands for petroleum products and electricity seem to be less sensitive to price variations.

- The elasticities between energy types generally indicate substitution possibilities, with the most substantial substitution existing between petroleum products and solid fuels.

Although the results presented in this study provide an insight into the complicated relationships that govern energy demand, they also illustrate the difficulties involved in estimating and interpreting these relationships. For example, the experiences with varying the homotheticity assumptions and the observation period for the aggregate demand estimations produce a number of interesting, although in some cases disconcerting, results. Regarding homotheticity, we find, on the basis of statistical tests, that the non-homothetic specification is the preferred. Although this suggests that the cost-minimising input-mix is dependent on the level of production, we feel that our model is far too simplified to justify interpreting these results very strictly. The results indicate that the estimated elasticities — and particularly those pertaining to labour — are sensitive to the specification of homotheticity. We find, however, that the price elasticities for energy and the nature of substitution relationships between energy and other aggregate production factors are, with few exceptions, quite robust to homotheticity assumptions.

Far more problematic for the analysis of energy demand is the sensitivity of the estimated energy elasticities to choice of observation period. Significant differences are found particularly for the own-price elasticity of energy as estimated on the basis of the 1952-1976 contra the 1962-1976 time periods. These results clearly emphasise the need of analysing the sensitivity of the estimates to variations in sample periods and in particular, of investigating the effects of including the drastic energy price-rises of the post-1973 period in the estimation.

Another question which requires further investigation, and which has only been touched upon in this study, is that of technological development. Although our model does allow for neutral technical change, its influence on production costs and factor demand has not been estimated. This can be done by estimating the cost function simultaneously with the share equations, thus identifying the effects on production costs of increased efficiency of factor use.

A further improvement would be to extend our model to allow for biased technical change. This is most likely a more realistic specification in view of the long time-period under consideration, and would be more consistent with the results of other Swedish production function studies which indicate a significant labour-saving technical change.

The most serious shortcoming of the majority of multi-factor demand studies is the inability of the models to distinguish between short- and long-run responses and to specify the adjustment path over time. As discussed in the previous section these studies have traditionally been based on static cost-minimisation models, which are derived under the assumption that production technique is fully optimised with respect to the prevailing factor price relationships. Estimation of the model requires, therefore, a data sample that includes combinations of production techniques and factor prices which represent long-run equilibria. Historic data on actual techniques and prices hardly fulfil this requirement. Because of this, the results obtained by estimation of static models based on such data are exceedingly difficult to interpret. A strict implementation of static models on the basis of time-series data is equivalent to assuming that all inputs fully adjust to their long-run equilibrium levels within one time period (in our case, one year). As this nearly "instantaneous" adjustment is highly unrealistic — particularly in the case of physical capital — the resulting elasticities can hardly be considered to represent long-run relationships.

The necessity of incorporating intertemporal adjustment mechanisms in energy demand models is apparent. Only on the basis of such dynamic models can the adjustment process from short- to long-run be determined. The recent advances in the specification and estimation of dynamic interrelated factor demand models form an obvious point of departure for further research into the characteristics of energy demand in Swedish industry.

Appendix DATA SOURCES AND TABLES

Data Sources

(1) Energy variables

Quantities and costs of energy consumed in Swedish manufacturing subsectors are taken from the Official Statistics of Sweden: Manufacturing, annual reports 1952-58 (Board of Trade) and 1959-1976 (Swedish Central Bureau of Statistics-SCB). The data include quantities (1952-1976) and costs (1962-1976) for individual fuels: motor gasoline, fuel oils, gas oil, coal, coke and wood fuels, costs (1952-1976) for aggregate fuels and quantities and costs (1952-1976) for electricity. Fuels and electricity produced and used at the same plant are not included. Most data pertain to establishments with five or more persons employed.

The following subsector classification is used.

LU	Sector	Swedish industry nomenclature 1952-1967	ISIC (SNI)
4	Sheltered food	7a-c, e, f	3111-3112, 3116-3118
5	Import-competing food	7d, g-k	3113-3115,3119 3121-3122
6	Beverages and tobacco	8	313-314
7	Textiles	9a-d, f-r 10a-d, i	32
8	Wood, pulp and paper	4, 5	33, 341
9	Printing	6	342
10	Rubber products	10g, h	355
11	Chemicals	9e, 11a-d, g-m	351,352,356
13	Non-metallic mineral products	3d-k	36
14	Primary metals	2a, b	37
15	Engineering	2c-e, g-i, l, m	38 excl.3841
16	Shipbuilding	2k	3841

Expenditures for electricity and total fuels consumed, in current and constant prices, were also supplied by the National Accounts Department of the Swedish Central Bureau of Statistics. These are based on the Manufacturing statistics above, but in addition include information on establishments with less than five employees.

Prices for electricity and each fuel are calculated for each subsector on the basis of the costs and quantities obtained from the manufacturing statistics. Since costs for individual fuels were not available for the pre-1962 time period, the subsector fuel prices for these years were constructed using average fuel prices for industrial consumers. This was done assuming that the relationship between sector price and average price for each fuel noted for the 1962-1970 time period was the same for 1952-1961.

Sources for average energy prices are:

Oils and motor gasoline - Swedish Petroleum Institute: En bok om olja (1970).

Coal, coke and wood fuels - implicit import prices calculated from the Official Statistics of Sweden: Foreign Trade, annual reports 1950-1976 (SCB).

The prices for energy aggregates in each sector are calculated as a weighted average of the prices of the individual energy forms.

(2) Non-energy variables

Data on labour, capital, material inputs and production volume were provided by the Industrial Institute for Economic and Social Research (IUI).

Labour

Total labour costs are taken from the National Accounts of Sweden (SCB). Total labour costs include wages plus social security charges, wage fees paid by employers, etc. The price of labour is taken as the total wage cost, including the above benefits.

Capital

Data on capital stock in current and constant prices are taken from the National Accounts of Sweden (SCB). The user cost of capital p^K is calculated[1] as

$$p^K = p^I(r+\delta);$$

where

p^I = price of investment goods (branch specific)
r = expected rate of return
δ = depreciation rate (branch specific)

Capital costs are obtained by multiplying capital stock by the user price of capital.

Intermediate goods

Data on costs for goods and services in each sector in current and constant prices are taken from the National Accounts of Sweden (SCB). Costs for intermediate goods are obtained by subtracting energy costs. Implicit price indices for intermediate goods are formed by using the current and constant price data adjusted for energy inputs.

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[1] A detailed discussion of procedures used in constructing the expected rate of return is found in Bergström (1976).

Production volume

Data on gross production in producers' prices for each sector are obtained from the National Accounts of Sweden (SCB). Output indices are defined as production in constant prices.

Homothetic cost function. Estimation period 1952-1976.

Sector	α_E	γ_{EE}	γ_{EK}	γ_{EL}	γ_{EM}	α_K	γ_{KK}	γ_{KL}	γ_{KM}	α_L	γ_{LL}	γ_{LM}	α_M	γ_{MM}	R^2_E	R^2_K	R^2_L	LogL
4 Sheltered food	.0150	.0110	.0010	-.0010	-.0110	.0469	.0350	.0030	-.0390	.1544	.0400	-.0420	.7837	.0920	.80	.97	.87	372.36
	(.0005)	(.0020)	(.0007)	(.0005)	(.0015)	(.0007)	(.0009)	(.0006)	(.0014)	(.0033)	(.0030)	(.0030)						
5 Import-competing food	.0139	.0062	-.0029	.0001	-.0036	.0583	.0572	-.0073	-.0471	.1549	.0278	-.0206	.7729	.0711	.71	.94	.86	343.11
	(.0003)	(.0012)	(.0006)	(.0003)	(.0013)	(.0015)	(.0027)	(.0014)	(.0030)	(.0022)	(.0022)	(.0020)						
6 Beverage and tobacco	.0207	.0242	-.0042	-.0171	-.0029	.1183	.0856	.0152	-.0966	.2520	.0025	-.0006	.6090	.1001	.90	.93	.20	283.20
	(.0008)	(.0058)	(.0017)	(.0016)	(.0048)	(.0026)	(.0046)	(.0025)	(.0045)	(.0061)	(.0063)	(.0050)						
7 Textiles and clothing	.0153	.0001	-.0072	-.0041	.0111	.0819	.0551	.0031	-.0510	.3639	.0483	-.0473	.6349	.0871	.58	.90	.79	315.41
	(.0007)	(.0029)	(.0015)	(.0008)	(.0035)	(.0018)	(.0044)	(.0019)	(.0056)	(.0046)	(.0049)	(.0036)						
8 Wood, pulp and paper	.0467	.0431	-.0086	-.0098	-.0246	.1061	.0731	.0053	-.0699	.2443	.0330	-.0285	.6029	.1230	.84	.94	.51	296.50
	(.0007)	(.0048)	(.0015)	(.0010)	(.0052)	(.0018)	(.0036)	(.0021)	(.0044)	(.0047)	(.0057)	(.0044)						
9 Printing	.0073	.0034	-.0029	.0002	-.0008	.1040	.0627	-.0355	-.0243	.4827	.0540	-.0187	.4061	.0484	.27	.78	.91	319.76
	(.0024)	(.0008)	(.0005)	(.0005)	(.0012)	(.0047)	(.0081)	(.0063)	(.0106)	(.0026)	(.0061)	(.0112)						
10 Rubber products	.0250	.0116	-.0038	-.0047	-.0038	.1279	.0955	-.0104	-.0812	.4037	.0775	-.0624	.4434	.1468	.46	.85	.93	273.66
	(.0011)	(.0042)	(.0031)	(.0012)	(.0031)	(.0039)	(.0124)	(.0039)	(.0145)	(.0045)	(.0045)	(.0061)						
11 Chemicals	.0454	.0320	-.0059	-.0142	-.0120	.0854	.0753	-.0321	-.0371	.2882	.0527	-.0371	.5810	.0550	.82	.96	.68	293.15
	(.0005)	(.0057)	(.0011)	(.0022)	(.0043)	(.0019)	(.0039)	(.0020)	(.0044)	(.0055)	(.0060)	(.0072)						
13 Non-metallic mineral products	.0675	.0389	-.0174	-.0321	.0106	.1264	.0929	-.0401	-.0354	.3505	.0151	.0570	.4556	-.0311	.72	.80	.55	262.40
	(.0030)	(.0078)	(.0047)	(.0032)	(.0106)	(.0053)	(.0083)	(.0056)	(.0099)	(.0044)	(.0046)	(.0060)						
14 Primary metals	.0830	.0949	-.0185	-.0273	-.0491	.1178	.0891	-.0128	-.0578	.2366	.0275	.0126	.5626	.0942	.72	.94	.43	260.10
	(.0027)	(.0106)	(.0047)	(.0034)	(.0123)	(.0024)	(.0072)	(.0033)	(.0114)	(.0052)	(.0073)	(.0071)						
15 Engineering	.0129	.0053	-.0025	-.0052	.0025	.0582	.0570	-.0236	-.0308	.3736	.0258	.0031	.5553	.0252	.92	.91	.60	319.50
	(.0025)	(.0019)	(.0006)	(.0003)	(.0021)	(.0023)	(.0041	(.0026)	(.0050)	(.0040)	(.0049)	(.0043)						
16 Shipbuilding	.0103	.0047	-.0015	-.0022	-.0010	.0535	.0653	-.0124	-.0514	.3275	.0110	.0036	.6087	.0487	.85	.95	.01	316.69
	(.0003)	(.0010)	(.0003)	(.0003)	(.0013)	(.0022)	(.0027)	(.0027)	(.0052)	(.0074)	(.0096)	(.0109)						
Total Manufacturing	.0296	.0209	-.0071	-.0076	-.0062	.0819	.0610	-.0086	-.0452	.3006	.0420	-.0263	.5879	.0777	.70	.95	.81	332.10
	(.0009)	(.0026)	(.0012)	(.0009)	(.0035)	(.0018)	(.0029)	(.0021)	(.0039)	(.0033)	(.0039)	(.0024)						

Note: Asymptotic standard errors are given in parenthesis. As the equation for intermediate goods was excluded from the estimation, standard errors for α_M and γ_{MM} and R^2_M are not readily available.

Table A2 Translog cost function parameter estimates

Non-homothetic cost function. Estimation period 1952-1976

Sector	α_E	γ_{EE}	γ_{EK}	γ_{EL}	γ_{EM}	α_K	γ_{KK}	γ_{KL}	γ_{KM}	α_L	γ_{LL}	γ_{LM}	α_M	γ_{MM}	γ_{QE}	γ_{QK}	γ_{QL}	γ_{QM}	R^2_E	R^2_K	R^2_L	LogL
4 Sheltered food	.0155	.0107	.0005	-.0057	-.0170	.0463	.0348	-.0017	-.0336	.1589	.0843	-.0884	.7793	.1390	-.0330	.0210	-.2100	-.2220	.93	.98	.95	391.36
	(.0003)	(.0015)	(.0005)	(.0019)	(.0013)	(.0006)	(.0009)	(.0020)	(.0020)	(.0021)	(.0073)	(.0067)			(.0078)	(.0093)	(.0339)					
5 Import-competing food	.0144	.0066	-.0025	.0050	-.0091	.0595	.0564	.0020	-.0559	.1615	.0904	-.0975	.7645	.1624	-.0070	-.0135	-.0877	.1082	.89	.94	.76	247.17
	(.0004)	(.0012)	(.0006)	(.0025)	(.0028)	(.0055)	(.0028)	(.0038)	(.0025)	(.0159)	(.0115)	(.0116)			(.0034	(.0055)	(.0166)					
6 Beverage and tobacco	.0218	.0303	-.0026	-.0333	.0056	.1208	.0926	-.0130	-.0762	.2382	.1764	-.1302	.6192	.2008	.0301	.0589	-.3526	.2636	.92	.94	.57	298.61
	(.0009)	(.0072)	(.0016)	(.0078)	(.0056)	(.0026)	(.0050)	(.0074)	(.0057)	(.0043)	(.0024)	(.0204)			(.0134)	(.0156)	(.0474)					
7 Textiles and clothing	.0180	.0056	-.0025	-.0021	-.0010	.0878	.0643	.0094	-.0711	.3612	.0448	-.0521	.5331	.1241	-.0216	-05379	.0174	.0579	.90	.97	.76	329.07
	(.0005)	(.0025)	(.0013)	(.0006)	(.0032)	(.0014)	(.0036)	(.0017)	(.0048)	(.0067)	(.0074)	(.0065)			(.0033)	(.0107)	(.0444)					
8 Wood, pulp and paper	.0464	.0458	-.0058	-.0137	-.0264	.1060	.0777	-.0081	-.0639	.2448	.1585	-.1367	.6029	.2271	.0054	.0204	-.1819	.1561	.86	.95	.85	321.53
	(.0007)	(.0035)	(.0013)	(.0052)	(.0058)	(.0017)	(.0036)	(.0033)	(.0048)	(.0028)	(.0180)	(.0147)			(.0071)	(.0076)	(.0247)					
9 Printing	.0073	.0033	-.0023	-.0019	.0001	.1064	.0842	-.0370	-.0449	.4889	.1747	-.1365	.3974	.1813	.0040	.0576	-.2241	.1625	.44	.87	.94	338.19
	(.0002)	(.0009)	(.0004)	(.0021)	(.0028)	(.0033)	(.0072)	(.0051)	(.0060)	(.0024)	(.0234)	(.0264)			(.0030)	(.0177)	(.0386)					
10 Rubber products	.0242	.0089	-.0079	-.0081	.0072	.1284	.0834	-.0151	-.0605	.4215	.1764	-.1533	.4259	.2066	.0062	.0143	-.1401	.1197	.25	.82	.94	296.00
	(.0014)	(.0047)	(.0026)	(.0049)	(.0072)	(.0041)	(.0079)	(.0086)	(.0058)	(.0042)	(.0115)	(.0123)			(.0068)	(.0122)	(.0162)					
11 Chemicals	.0441	.0349	-.0046	-.0072	-.0230	.0823	.0770	-.0142	-.0581	.2641	.2028	-.1814	.6095	.2626	-.0090	-.0207	-.1695	.1992	.88	.96	.99	340.57
	(.0006)	(.0057)	(.0011)	(.0029)	(.0053)	(.0019)	(.0036)	(.0023)	(.0035)	(.0014)	(.0051)	(.0063)			(.0026)	(.0030)	(.0057)					
13 Non-metallic mineral products	.0673	.0353	-.0200	.0302	.0150	.1281	.0909	-.0272	-.0437	.3569	.0560	.0014	.4477	.0273	-.0052	-.0213	-.0522	.0787	.72	.81	.45	266.19
	(.0034)	(.0085)	(.0064)	(.0104)	(.0123)	(.0055)	(.0111)	(.0105)	(.0102)	(.0044)	(.0182)	(.0202)			(.0163)	(.0206)	(.0273)					
14 Primary metals	.0823	.0918	-.0096	-.0202	-.0620	.1197	.0869	-.0160	-.0613	.2466	.1250	-.0888	.5514	.2121	-.0053	.0031	-.1058	.1080	.99	.94	.74	276.99
	(.0029)	(.0125)	(.0052)	(.0152)	(.0135)	(.0024)	(.0051)	(.0089)	(.0083)	(.0038)	(.0256)	(.0227)			(.0152)	(.0095)	(.0257)					
15 Engineering	.0127	.0063	-.0022	-.0028	-.0013	.0577	.0574	-.0176	-.0376	.3620	.1638	-.1435	.5676	.1824	-.0024	-.0059	-.1350	.1433	.92	.91	.71	330.77
	(.0004)	(.0022)	(.0006)	(.0026)	(.0042)	(.0020)	(.0046	(.0073)	(.0050)	(.0039)	(.0242)	(.0237)			(.0026)	(.0078)	(.0244)					
16 Shipbuilding	.0100	.0057	-.0018	.0003	-.0041	.0519	.0648	-.0126	-.0504	.3065	.1290	-.1166	.6316	.1711	-.0030	-.0021	-.1424	.1475	.92	.95	.62	328.49
	(.0003)	(.0015)	(.0004)	(.0009)	(.0015)	(.0023)	(.0042)	(.0083)	(.0078)	(.0055)	(.0229)	(.0209)			(.0011)	(.0100)	(.0272)					
Total Manufacturing	.0301	.0256	-.0019	-.0067	-.0170	.0827	.0683	-.0197	-.0466	.3009	.1309	-.1046	.5863	.1682	-.0008	.0175	-.1291	.1124	.80	.96	.89	343.96
	(.0006)	(.0026)	(.0015)	(.0065)	(.0080)	(.0013)	(.0027)	(.0056)	(.0047)	(.0027)	(.0240)	(.0236)			(.0092)	(.0081)	(.0334)					

Note: Asymptotic standard errors are given in parenthesis. As the equation for intermediate goods was excluded from the estimation, standard errors for α_M, α_{MM} and γ_{QM} and R^2_M are not readily available.

Table A3 Likelihood ratio test statistics

	Sector	Hypothesis: Cobb-Douglas Production Structure $H_o:\gamma_{ij}=0$ K,L,E,M	Hypothesis: Homotheticity $H_o:\gamma_{iq}=0$ K,L,E,M
4	Sheltered food	217.66	38.00
5	Import-competing	143.82	28.70
6	Beverage and tobacco	129.44	30.82
7	Textiles and clothing	137.98	27.32
8	Wood, pulp and paper	142.92	50.06
9	Printing	96.02	36.86
10	Rubber products	143.94	44.68
11	Chemicals	150.80	94.84
13	Non-metallic mineral products	122.04	7.58
14	Primary metals	116.12	33.78
15	Engineering	126.10	22.54
16	Shipbuilding	134.12	23.60
	Total manufacturing	171.78	23.72
	Degrees of freedom:	6	3

	χ^2 values		
	Degrees of freedom:	6	3
	Significance level:		
	.005	18.55	12.84
	.01	16.81	11.34
	.05	12.59	7.81

Table A4 Two-stage translog cost function parameter estimates: energy submodel
Estimation period 1952-1976

Sector	α_e	γ_{ee}	γ_{eo}	γ_{es}	α_o	γ_{oo}	γ_{os}	α_s	γ_{ss}	R^2_e	R^2_o	LogL	$-2(L_R/L_U)$
8 Wood, pulp and paper	.5349	.1627	-.1627	-.0001	-.4183	.1438	-.0192	.0468	.0193	.87	.82	102.93	46.68
	(.0090)	(.0152)	(.0180)	(.0055)	(.0107)	(.0217)	(.0064)						
11 Chemicals	.6154	.1585	-.1925	.0340	.3055	.1430	.0495	.0791	-.0835	.82	.84	86.36	33.22
	(.0110)	(.0249)	(.0261)	(.0206)	(.0114)	(.0408)	(.0309)						
13 Non-metallic mineral products	.2439	.1811	-.2030	.0218	.5982	.1243	.0787	.1579	-.1005	.97	.88	89.70	64.44
	(.0037)	(.0071)	(.0141)	(.0157)	(.0089)	(.0384)	(.0434)						
14 Primary metals	.2970	.1885	-.0513	-.1373	.2086	.0990	-.0477	.4944	.1850	.86	.90	93.92	51.70
	(.0103)	(.0216)	(.0082)	(.0233)	(.0038)	(.0129)	(.0164)						
15 Engineering	.5111	.1315	-.1351	.0035	.4322	.1340	.0011	.0567	-.0046	.87	.82	86.92	31.34
	(.0077)	(.0136)	(.0155)	(.0123)	(.0081)	(.0325)	(.0263)						
Total manufacturing	.4346	.1692	-.1326	-.0366	.3878	.1347	-.0021	.1776	.0387	.94	.91	96.76	47.88
	(.0058)	(.0120)	(.0106)	(.0132)	(.0052)	(.0216)	(.0204)						

Note: Asymptotic standard errors are given in parenthesis. As the equation for solid fuels was excluded from the estimation, standard errors for α_s, γ_{ss} and R^2_s are not readily available.

Likelihood ratio test statistics for Ho: $\gamma_{ij} = 0$ for all e,o,s.

$\chi^2 = 12.84$ for significance level 0.005 and 3 degrees of freedom.

Table A5 Two-stage translog cost function parameter estimates: total cost function

Non-homothetic specification. Estimation period 1962-1976

Sector	α_E	γ_{EE}	γ_{EK}	γ_{EL}	γ_{EM}	α_K	γ_{KK}	γ_{KL}	γ_{KM}	α_L	γ_{LL}	γ_{LM}	α_M	γ_{MM}	γ_{QE}	γ_{QK}	γ_{QL}	γ_{QM}	R^2_E	R^2_K	R^2_L	LogL
8 Wood, pulp	.0482	.0350	-.0064	-.0108	-.0179	.1070	.0732	-.0034	-.0633	.2394	.1444	-.1301	.6055	.2110	.0090	.0181	-.1972	.1701	.97	.96	.83	212.76
and paper	(.0004)	(.0039)	(.0011)	(.0032)	(.0069)	(.0018)	(.0038)	(.0039)	(.0029)	(.0019)	(.0094)	(.0092)			(.0051)	(.0078)	(.0135)					
11 Chemicals	.0445	.0171	-.0065	-.0109	.0003	.0809	.0712	-.0143	-.0504	.2664	.1832	-.1580	.6082	.2080	-.0022	-.0195	-.1543	.1760	.94	.96	.98*	214.11
	(.0004)	(.0049)	(.0011)	(.0026)	(.0056)	(.0017)	(.0044)	(.0036)	(.0029)			(.0074)	(.0013)	(.0095)	(.0024)	(.0041)		(.0068)				
13 Non-metallic	.0802	.0575	-.0127	.0031	-.0479	.1361	.0706	-.0465	-.0465	.3592	.0526	-.0444	.4245	.1388	-.0008	-.0152	-.1194	.1354	.92	.74	.16	191.32
mineral products	(.0011)	(.0041)	(.0023)	(.0049)	(.0066)	(.0021)	(.0075)	(.0043)	(.0043)	(.0029)	(.0134)	(.0126)			(.0099)	(.0321)	(.0379)					
14 Primary metals	.0888	.0848	-.0063	-.0134	-.0651	.1235	.0760	-.0327	-.0369	.2382	.1009	-.0549	.5496	.1569	.0084	.0410	-.1444	.0950	.93	.96	.91*	202.15
	(.0017)	(.0077)	(.0034)	(.0077)	(.0078)	(.0020)	(.0041)	(.0037)	(.0054)			(.0113)	(.0025)	(.0173)	(.0093)	(.0075)		(.0130)				
15 Engineering	.0133	.0113	-.0015	-.0018	-.0080	.0654	.0499	-.0225	-.0259	.3525	.1303	-.1060	.5688	.1399	-.0023	.0186	-.1474	.1311	.96	.97	.91	237.15
	(.0002)	(.0019)	(.0005)	(.0021)	(.0041)	(.0011)	(.0023	(.0035)	(.0037)	(.0019)	(.0158)	(.0174)			(.0018)	(.0042)	(.0151)					
Total Manu-	.0321	.0242	-.0032	-.0098	-.0112	.0859	.0628	-.0190	-.0407	.2927	.1400	-.1113	.5892	.1632	.0090	.0329	-.1829	.1410	.99	.98	.95	244.72
facturing	(.0002)	(.0008)	(.0005)	(.0023)	(.0028)	(.0009)	(.0021)	(.0032)	(.0036)	(.0012)	(.0152)	(.0159)			(.0033)	(.0054)	(.0021)					

* R^2 for equation for intermediate goods.

Note: Asymptotic standard errors are given in parenthesis. As the equation for labour in sectors 11 and 14 and that for intermediate goods in the remaining sectors were excluded from the estimation, the respective standard errors and R^2 are not readily available.

Table A6 Own-price elasticities and elasticities of substitution for energy (E), capital (K), labour (L) and intermediate goods (M)

Two-stage non-homothetic specification

Sector	Own-price Elasticities				Elasticities of substitution					
	E	K	L	M	E-K	E-L	E-M	K-L	K-M	L-M
8 Wood, pulp and paper	-0.13 (0.08)	-0.28 (0.03)	-0.16	-0.05 (0.02)	-0.24 (0.21)	-0.08 (0.34)	0.29 (0.26)	0.88 (0.12)	0.14 (0.04)	0.09 (0.06)
11 Chemicals	-0.57 (0.11)	-0.23 (0.04)	-0.06	-0.06 (0.01)	-0.35 (0.21)	0.11 (0.24)	1.01 (0.23)	0.51 (0.14)	0.18 (0.05)	-0.01 (0.04)
13 Non-metallic mineral products	-0.05 (0.05)	-0.38 (0.05)	-0.50 (0.04)	-0.25	-0.28 (0.20)	1.14 (0.17)	-0.69 (0.20)	0.78 (0.17)	0.30 (0.07)	0.71 (0.08)
14 Primary metals	0.29 (0.11)	-0.32 (0.03)	-0.32	-0.16 (0.03)	0.35 (0.31)	0.17 (0.50)	-0.68 (0.21)	0.58 (0.08)	0.53 (0.60)	0.58 (0.08)
15 Engineering	-0.17 (0.14)	-0.26 (0.04)	-0.28 (0.05)	-0.20	-0.48 (0.47)	0.64 (0.42)	-0.06 (0.28)	0.18 (0.13)	0.37 (0.09)	0.47 (0.07)
Total manufacturing	-0.09 (0.03)	-0.24 (0.02)	-0.23 (0.05)	-0.13	-0.23 (0.29)	0.25 (0.29)	0.30 (0.17)	0.30 (0.11)	0.27 (0.06)	0.35 (0.09)

Note: Approximate asymptotic standard errors are given in parenthesis. As the share equation for labour in sectors 11 and 14 and the share equation for intermediate goods in the remaining sectors were excluded from the estimation, standard errors are not readily available.

Table A7 Likelihood ratio test statistics
Two-stage model. Total cost function

	Sector	Hypothesis: Cobb-Douglas production structure $H_o: \gamma_{ij}=0$ K,L,E,M	Hypothesis: Homotheticity $H_o: \gamma_{iq}=0$ K,L,E,M
8	Wood, pulp and paper	41.87	22.53
11	Chemicals	44.58	30.05
13	Non-metallic mineral products	45.76	11.87
14	Primary metals	38.71	34.13
15	Engineering	52.07	17.39
	Total manufacturing	57.55	23.14
	Degrees of freedom	6	3
	χ^2 values		
	Significance level		
	.005	18.55	12.84
	.01	16.81	11.34
	.05	12.59	7.81

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A Vintage Model for the Swedish Iron and Steel Industry

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Contents

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1 INTRODUCTION

The ISAC (Industrial Structure And Capital Growth) is a multisectoral macro model of the Swedish economy designed to simulate both short-term responses and long-term adjustment to sudden price changes.[1] The impact of past investments, depreciations and choices of technique on future production and substitution possibilities is therefore of particular interest. The industrial sector in the ISAC consists of 15 subsectors. A vintage model has been set up for each subsector in order to analyze the dynamics of growth.

So far, paucity of data has so far set narrow bounds on the possibilities for empirical work on the industrial production structures. However, special efforts have been made with respect to one subsector — the iron and steel industry.

The iron and steel industry was chosen because it is very energy intensive and thus a major energy consumer. As a result, this subsector is a very important part of the energy studies now in progress

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[1] The ISAC model was developed on the basis of earlier macro models used at IUI. The first model of this kind developed at the Institute was designed for medium-term forecasting; see Jakobsson, Normann and Dahlberg (1977). This model was developed further for the next IUI economic survey in 1979 by including i.a. investment functions and price formation equations; see Jansson, Nordström and Ysander (1979).

Since then the model has undergone major restructuring. It now incorporates adjustment mechanisms for wage rates, prices, industrial capital, local government actions, etc. and some of the development of industrial productivity is endogenously explained; see Jansson, Nordström and Ysander (1981).

using the ISAC. It is also a highly capital intensive industry, which makes a vintage approach particularly attractive since it is very unlikely that the technique already installed could be adjusted to rapid price changes.

Another reason for using a vintage model rather than a less complicated putty-putty approach, with one homogeneous production structure, is that the new techniques introduced during the estimation period are distinctly different from the average existing production structure in this subsector.

One problem associated with using vintage models in empirical studies involves specifying the econometric equations so as to match the available data. If observations on individual production units are available, quite general models can be used which allow, e.g., for substitution between factors of production both ex ante and ex post, as in Fuss (1977, 1978).

When only aggregate data are available, it is difficult to test such a general approach empirically. More stringent assumptions have to be imposed. Earlier studies tended to assume fixed factor proportions both ex ante and ex post — the so-called clay-clay type of vintage model. This approach is used in studies by Attiyeh (1967), Smallwood (1972) and Isard (1973). But the effects of changes in relative prices on the input factor mix cannot be studied using a clay-clay model. This, however, is one of the main interests in this paper, as well as in many other studies.

The other main group of vintage models, the putty-clay version, allows for price substitution ex ante and assumes fixed factor proportions ex post.

This approach is used here and was earlier adopted by Bischoff (1971), King (1972), Ando et al. (1974), Mizon (1974), Sumner (1974), Görzig (1976), Hawkins (1978), Bentzel (1977) and Malcomson and Prior (1979).

With the exception of Hawkins (1978), earlier putty-clay studies considered only two factors of production, labor and capital, and used a Cobb-Douglas production function. In this paper energy is also included and a translog cost function is used to derive ex ante demand functions for the input factors.

A constant or infinite lifetime of capital equipment was assumed in most of the above putty-clay studies. Exceptions are Görzig, Bentzel, and Malcomson and Prior. In this study the depreciation rate is a function of gross profitability, thereby allowing the average life span of capital equipment to vary over time.

2 OVERVIEW OF THE MODEL

The decision to invest in new production capacity is assumed to be divided into two stages: one where the new technique is determined and one where the amount of new capacity is decided. It is also assumed that there is a three-year lag from the year of decision to the first year of operation of a new vintage. This choice of time lag is based on some initial estimations described in Appendix 1.

The new technique is chosen to minimize production cost with respect to input prices. The ex ante production structure is represented by a translog cost function (see Section 2.1).

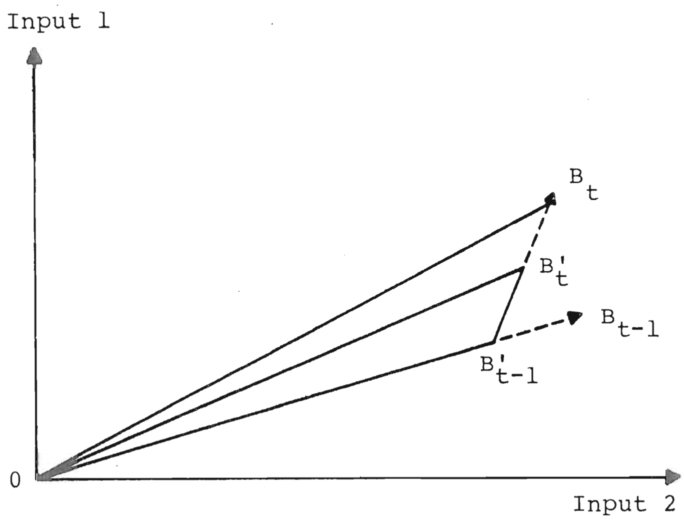
The amount of new production capacity depends on the net increase in total capacity and the scrapping of old units. The net increase in capacity is assumed to depend on expected demand, utilization of existing capacity and the profitability situation. The capacity growth model is described further in Section 2.2.

All vintages are assumed to have the same depreciation rate, which varies over time as a function of the gross profit margin of the subsector. Scrapped capacity is replaced by a new cost-minimizing technique. We expect a priori the depreciation rate to be negatively correlated with the profit margin.

There is also reason to believe that the depreciation rate might vary across vintages due to differences in individual profit margins. But this assumption would complicate the econometric model considerably.

The utilization rate is assumed to be the same for all vintages. This approach can to some extent be justified as follows. In a process industry such as the iron and steel industry, there is a serial dependence between different units since output from, i.e., blast furnaces is used as input in steel manufacturing. These vertically linked production units are run mostly under one company, so that their production levels are jointly dimensioned. The impact of differential profitability on the utilization in each unit is diminished in the short run by the fact that the subsector consists

Figure 1



mainly of large production units, each of which is often the major employer in its geographical vicinity. As a result, the production of unprofitable companies is often maintained by subsidies from the central government.

Changes in technique and capacity between two periods are outlined in Figure 1, where for simplicity only one old vintage is included. The arrow OB_{t-1} is the input mix which corresponds to the capacity available at t-1. The old unit is then partially scrapped, which decreases the maximal input demand from B_{t-1} to B'_{t-1}. The new vintage B_t is then added, which moves the maximal input mix to OB_t.

The putty-clay description of the model cannot be distinguished from a putty-putty interpretation since the same technique is used for both net investments and replacement. In other words, by means of the combined scrapping/reinvestment activity, the given capacity is modified from B_{t-1} to B'_t and then extended by the addition of net investment to B_t. In the following, however, we continue to express our arguments in terms of the putty-clay assumption.

It should also be emphasized that the role of the investment model in this study differs from that in other aggregate growth studies of production. Interest is usually focused on the model of investment. The development of production capacity is not observed directly and therefore has to be explained indirectly via investments and the capital/output ratio. The investment model then becomes the key to explaining the dynamic growth of production.

In this study, we have benefited from observations of capacity development which enable us to estimate a model that explains capacity growth directly. Thus, the equations which explain the net increase in production capacity replace the strategic position usually held by the investment model.

The investment equation is discussed further in Section 2.3.

2.1 Ex Ante Choice of Technique

In the ISAC model there are substitution possibilities between the following four aggregate inputs in each industrial subsector: energy, other intermediate goods, labor and capital. The time-series for the input/output ratios for intermediate goods in the iron and steel industry is extremely stable over the whole observation period. This suggests that they are perfect complements to the aggregate of the other inputs. As a result, the input share of intermediate goods, in both new and old plants, is constant and independent of price changes.

With constant i/o shares of intermediate goods and separability between energy, labor and capital, producers are assumed to minimize the cost of production of new vintages. The minimal cost function for energy, labor and capital is assumed to be represented by a translog form. The technology is restricted to be linear homogeneous, and embodied technical change to be neutral and an exponential function of time. The minimal cost function[1] for new units of production can now be written as

$$c = A \cdot q \cdot \exp\left[\Sigma\alpha_i \ln p_i + \sum_{ij}\Sigma \beta_{ij} \ln p_i \ln p_j + \lambda t\right] + p_m m, \qquad (1)$$

where

q = value added including energy

m = intermediate goods

i,j = e, k, l (energy, capital and labor, respectively).

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[1] A well-behaved cost function can be derived from a well-behaved production function by taking the input mixes which minimize cost of production at given prices and output. Denote these inputs $x_{i,min}(p,y)$ and then calculate the total cost for the input combination:

$$C = \sum_i p_i x_{i,min}(p,y).$$

This minimum cost function corresponds to c in (1). However, when c takes the form as in (1), an algebraic expression for the production function related to (1) cannot be given. However, a well-behaved production structure exists for every well-behaved cost function, and vice versa, as proved by Shephard (1953).

$$\sum \alpha_i = 1$$

$$\sum_j \beta_{ij} = 0, \quad \sum_j \beta_{ji} = 0, \qquad \beta_{ij} = \beta_{ji}. \tag{1a}$$

The translog part of the above cost function is a second order local approximation of any regular cost function and its flexible form places few a priori restrictions on the production structure. However, it might not be a proper cost function in all instances. The questions of if and where (1) is a proper cost function have to be checked after the parameters have been estimated. Unfortunately, this is generally not an easy task and it has to be carried out for every set of input prices (see Berndt and Christensen, 1973). Other known flexible forms such as the generalized Leontief function also have these disadvantages.

From Hotelling's Lemma (Hotelling, 1932), it is known that

$$\frac{\partial c}{\partial p_i} = x_i,$$

where x_i is the cost-minimizing input of good i.

If we incorporate the assumption of a three-year lag between the date of decision to invest in a new unit and the first year of operation, we get

$$\varepsilon_{t,i}(p,t) = \frac{p_{q(t-3)}}{p_{i(t-3)}} \cdot \left(\alpha_i + \sum_j \beta_{ij} \ln p_j(t-3)\right) \frac{q}{y}, \tag{2}$$

where the subscript t refers to the initial year of a vintage, t in parentheses denotes current time, ε_i is the i/o share x_i/y, and the aggregate i/o ratio q/y is calculated from the observations.

However, there are no observations of the unit cost of production p_q for separate vintages. The only index that can be observed is the average unit price for the whole subsector. Therefore, p_q for the new vintage which occurs in (2) is the unit cost index obtained from the translog cost function. Thus

$$p_q = e^{\lambda t} \prod_i p_i^{\alpha_i} \prod_j p_i^{\beta_{ij} \ln p_j} \qquad i,j=e,k,l \qquad (3)$$

Expression (2) now becomes nonlinear in the parameters, although the calculation cost remains modest. The price variables should express expected prices. Moving average price variables were tried as proxies. However, since the use of actual prices at time t-3 did not change the results, this alternative was chosen to keep the model as simple as possible.

The i/o ratios of installed vintages are assumed to be independent of the utilization rate. Some correlation between the cyclical changes in the utilization variable and the i/o ratios can indeed be observed. But this dependence does not appear too strong to prevent the above assumption from serving as a fairly good approximation. However, this approximation will probably not hold for the years after 1975 (which are not included in the observation period), since the utilization rate then dropped to its lowest level since 1950 and several disturbances occurred in the iron and steel industry.

2.2 The Model of Net Growth

We assume that firms base their decisions to expand or contract production capacity on expectations of future demand for their products. Since the iron and steel industry is a process industry with large units of production, several years elapse between the date a decision is made and the date of installation. With an assumed construction period of three years, today's investment plans will be influenced by the expected change in demand three years from now. The expected change in demand at year t+3 is assumed to be calculated at year t as

$$yp_t(3) = \sum_{i=1}^{3} y_{t-1} / \sum_{i=1}^{3} y_{t-i-1},$$

where

$yp_t(3)$ = expected change in demand at time t+3
y_t = total production level.

That is, the expected change in demand is the ratio between the two most recent three-year moving averages of production.

If firms base their decision to expand solely on expected growth in demand, the desired level of production capacity in three years' time would be

$$ycap^*_{t+3} = yp_t(3) \cdot ycap_{t+2}.$$

But if firms consider both adjustment costs such as costs for internal education of personnel, etc., and the costs of their inability to meet demand fully, they might partially adjust to the desired capacity level, see e.g. Griliches (1967).

In multiplicative form, the adjustment is given by:

$$ycap_{t+3} = ycap^{*\gamma}_{t+3} \cdot ycap^{1-\gamma}_{t+2}$$

or, in growth terms:

$$ycap_{t+3}/ycap_{t+2} = yp_t(3)^{\gamma}. \qquad (4)$$

However, firms are certainly aware of the business cycle and it is therefore likely that predictions of growth by simple extrapolation are adjusted to take expected recessions and booms into account. One way of predicting the upswings and downswings around some long-term growth trend is to look at past utilization rates. We assume that past growth in capacity has been more smooth than demand development. This has definitely been the case during the estimation period. Capacity growth does vary with short-term swings in production, but to a lesser extent. This indicates that capacity growth has been affected similar to the business cycle.

The above argument suggests that the past utilization rate should also be included in the capacity growth model. Since we do not know with certainty the length of time involved until past utilization rates begin to influence investment decisions, the observed values for year t and the two preceding years are included. The new variables are included in such a way that the model remains log-linear in the estimated parameters. We then get

$$ycap_{t+3}/ycap_{t+2} = yp_t(3)^{\gamma_1} \cdot \prod_{i=1}^{2} ur_{t-i}^{\gamma_{i+1}}, \qquad (5)$$

where the utilization rate is simply the ratio of production level to total installed capacity. Thus

$$ur_t = y_t/ycap_t.$$

The development of profitability is probably also an important factor in explaining past growth in the Swedish iron and steel industry. Increased competition on foreign markets during the past few decades has caused a declining trend in profitability during the 1960s and 1970s by way of decreasing world market prices relative to domestic production costs.

Profitability might also have other effects on decisions in addition to the formation of expectations of future profits. High profitability often seems to have a rapid positive effect on investments, even if prospects in a longer perspective appear gloomy. There are several explanations for such behavior, e.g., institutional inertia and tax legislation in Sweden which tend to "lock" profits inside a company.

There are then reasons to include a measure of both past and current profits in the growth model. The next problem is then the choice of profit measure. One is the gross profit margin, i.e., the ratio of value added minus wages to value added. Since the iron and steel industry is highly capital intensive and has undergone rapid technical change it is preferable, however, to use a measure that captures possible changes in the cost of capital over time. Therefore, we have chosen an "excess" profit variable defined as

$$ep = p^vV/[wL + p^i(r+dr)K],$$

where

p^vV = value added (current prices)
wL = total wages
$p^i(r+dr)K$ = user cost of capital
r = discount rate[1]
dr = depreciation rate.

The way in which depreciation rates are determined in the model is described in the next section. The capital stock is a function of depreciation and consistent with the estimated depreciation rate; see Appendix 1.

The excess profit variable is incorporated in the same way as the utilization rate variable. The estimated growth model then has the following form.

$$ycap_{t+3}/ycap_{t+2} = A \cdot yp_t^{\gamma_1} \prod_{i=0}^{2} ur_{t-i}^{\gamma_{i+2}} \cdot \prod_{i=0}^{2} ep_{t-i}^{\gamma_{i+5}}. \quad (6)$$

2.3 Depreciation

All vintages in the industry have the same depreciation rate, but this rate varies over time as a function of the aggregate gross profit margin. As for net investments, a time lag of three years is also assumed between the time of scrapping and the time of replacement. The replaced capacity of vintage v at time t is assumed to be the following function of the gross profit margin gp at time t-3:

---

[1] Calculations of the discount rate are given in Bergström (1979).

$$d_v(t) = \delta \cdot [1 - gp(t-3)] \cdot ycap_v(t-3),$$ [1]

where

$$gp = 1 - \sum_i \varepsilon_i \; p_i/p_y \qquad i=1,e,m.$$

Thus the term 1-gp is equal to unit operating cost oc and we can write:

$$d(t) = \delta \cdot oc(t-3) \cdot ycap(t-3). \qquad (7)$$

2.4 Average Input Shares and Investments

So far, only the net growth function can be estimated on the basis of available aggregate data. But owing to the assumed equivalence of depreciation and utilization rates across vintages and the assumed independence of the input shares of the utilization level, the average i/o ratios can be expressed in a form which can be estimated using aggregate data. The aggregated i/o ratio becomes

---

[1] More correctly, depreciation at time t should be calculated with respect to earlier depreciation decisions according to the following formula:

$$d_v(t) = \delta[1-gp(t-3)] \cdot [ycap_v(t-3) - \delta \sum_{i=4}^{5} (1-gp(t-1)) \cdot ycap_v(t-1)], \qquad (a)$$

i.e. the depreciation calculated at time t-3 should be made on the capacity of vintage v, minus the capacity decrease already decided at time t-4 and t-5, which is represented by the sum in (a). However, this last term will be of minor importance for likely values of δ since it is multiplied by the squared value of δ. Thus (6) is likely to be an acceptable approximation of (a).

$$\varepsilon_t(t) = \{\Delta ycap(t) + d(t)\}/ycap(t) \cdot \varepsilon_{t,i}(p,t) + \{ycap(t-1) - d(t)\}/ycap(t) \cdot \varepsilon_i(t-1), \quad (8)$$

where $\Delta ycap(t)$ is the net increase in capacity.

Thus, the aggregated i/o ratio is the weighted sum of the i/o ratio of the new vintage, which is a function of past prices, and of the fixed i/o ratio of the old vintages.

Investments are related to the net growth in capacity, the replacement of scrapped capacity and the capital output ratio of the new technique implemented. But the fact that construction time extends over four years — the year of decision and the remaining three construction years — complicates matters. The investments observed at year t should refer to all plants under construction, including all projects started during the years (t-3) to t. This can be exemplified by the following formula

$$inv(t) = \sum_{i=0}^{3} b_i \cdot \varepsilon_{t+i,k}\, ycap_{t+i} =$$

$$= \sum_{i=0}^{3} b_i\, \varepsilon_{t+i,k}[\Delta ycap_{t+i} + d(t-3)],$$

where $\varepsilon_{t+i,k}$ is the capital output ratio of the capacity to be installed at year t+i. The term $b_i \cdot \varepsilon_{t+i,k} \cdot ycap_{t+i}$ expresses the amount of investments caused by the construction of vintage t+i during year t.

Different variations of the coefficients in the investment function have been tried, but a simple weight scheme with the same weight on each element seems to work well. We then get

$$inv(t) = b \cdot \sum_{i=0}^{3} \varepsilon_{t+i,k} \; ycap_{t+i}. \qquad (9)$$

3 EMPIRICAL RESULTS

A vintage model of the type used here is a hypothetical construction which cannot compete with studies that use data on actual firms and production units such as Johansen(1972), Førsund and Hjalmarsson (forthcoming) and Fuss (1977, 1978).

However, a special feature of vintage models is recognition of the fact that new production capacity might use technologies quite different from those of the old units. This property makes it possible, e.g., to describe developments which might otherwise seem odd such as the decrease in energy use per unit of output during a period with falling relative energy prices. An aggregate model must either describe energy as a complement to one or more of the other inputs and/or include energy-saving technological change. A vintage model can depict such a situation by adding units which are less energy intensive while in the ex ante production function, energy might still be a substitute for the rest of the inputs and technical change neutral, as in this study.

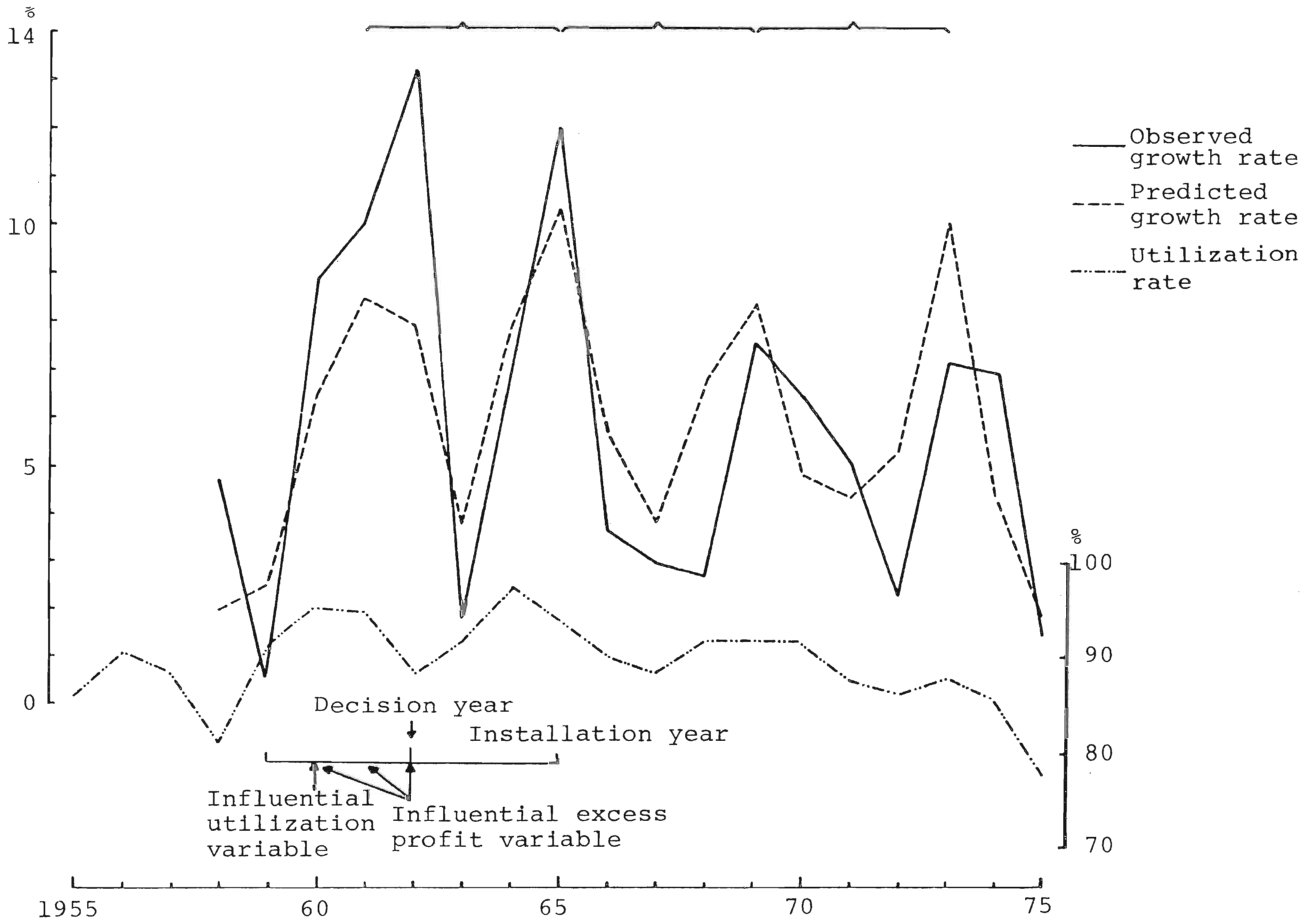
3.1 Past Development of Capacity Explained by the Growth Model

Perhaps the most striking feature of the increase in capacity in the Swedish iron and steel industry is the four-year cycle encountered during the estimation period. Since the utilization rate variable has the same frequency, reflecting the international trade cycle, this variable is important in predicting the swings in capacity growth. As indicated in Figure 2, the time lag between the upward pressure of the business cycle and the responding increase in capacity growth is five years. This response pattern could be interpreted to mean that the decision-makers recognize a trade cycle and take it into account. The reoccurrence of a boom in demand at the expected time confirms the impression of a cycle and triggers the decision to expand capacity to meet the next peak in demand.

Past and current profits and expected demand also explain the short-term swings in growth, but their impact differs over time. Thus, the level of the first and largest peak around 1961 is mostly due to a rapid increase in profitability during the years 1957-59. On the other hand, the size of the second peak is to a large extent explained by an expected increase in demand. Past growth also has a positive effect on the explanation for the two remaining peaks.

The regularity of the growth pattern might, of course, be accidental. The strong correlation with the utilization rate is then spurious and should not be expected to continue in the future.

Figure 2 also indicates a slow decline in the growth trend over time. The average growth rate for the first nine years is 6.2 percent, after which it decreased to 5.5 percent. This drop in average growth is explained mainly by the decrease in profits over time. The average decline in the profit variable alone would have caused growth to


%
14
10
5
0
Observed growth rate
Predicted growth rate
Utilization rate
%
100
90
80
70
Decision year
Installation year
Influential utilization variable
Influential excess profit variable
1955
60
65
70
75

decrease by 1.4 percent. The decline due to a slowdown in expected demand is only .4 percent. However, an increase of 1.1 percent due to a higher average utilization rate counteracts these declining tendencies and in fact limits the decline in capacity growth to .7 percent.

The short-term growth pattern is thus highly dependent on the upswings and downswings of the utilization rate. Profit and growth expectations, however, do have an effect, but in different ways during different time periods. On the other hand, the long-term decline in average growth is due mostly to a fall in profitability.

3.2 Estimated Input Shares and Investments

The price elasticities for the input shares of new vintages, calculated at the mean value of the exogenous variables, are presented in Table 1 along with the Allen partial elasticities of substitution (AES) at the same point. Since the variations in these elasticities over time are slight, the mid-point elasticities give a fair indication of how the model predicts that new techniques will respond to prices during the observation period.

All inputs are estimated to be substitutes and the factor relation most sensitive to changes in relative prices on the margin is energy and labor, which had the highest elasticities of substitution. Capital and labor are estimated to be almost perfect complements on the margin.

It should be emphasized, however, that it is difficult to compare the properties of the ex ante function estimated in this study, which describes how

Table 1 The AES and price elasticities of the ex ante function

	Price elasticities			The Allen elasticities of substitution[a]		
	$\eta_{.,e}$	$\eta_{.,k}$	$\eta_{.,l}$	σ_{ek}	σ_{el}	σ_{kl}
$\eta_{e,.}$	-.98	.43	.55	.82	2.63	.07
$\eta_{k,.}$	.08	-.10	.02			
$\eta_{l,.}$	.35	.06	-.41			

[a] The Allen (partial) elasticity of substitution measures, for a constant output level the percentage change in the input mix between two production factors due to a 1 percent change in their relative prices when all other inputs adjust optimally to the price change.

technique is chosen on the margin, with the production structures usually estimated, where a whole subsector is regarded as a single homogeneous production unit. The reason is that in the latter approach, price changes and other explanatory variables affect the average technique of an entire subsector in exactly the same way. In a vintage model, new vintages are distinguished which generally have different properties than already installed capacity.

The only aspect of changes in technique over time which is not explained by changes in input prices and the implementation of new vintages, is the embodied trend factor in the unit output cost of new vintages. This trend factor, which is the inverse of the neutral technical change factor in the production function, is important in explaining the development of the ex ante function, i.e., the marginal input shares. However, the dominant factor in explaining the development of average input shares is the addition of new production units.

This may be illustrated by separating the effect of adding new production from the embodied technical change and price adjustment of the new vintage. The percentage change in the average input share can be split into two terms accordingly:

$$\frac{\varepsilon_i(t) - \varepsilon_i(t-1)}{\varepsilon_i(t)} = \frac{ycap_t(t)}{ycap(t)} \frac{\left(\varepsilon_{t-1,i} - \varepsilon_i(t-1)\right)}{\varepsilon_i(t)} +$$

$$\frac{ycap_t(t)}{ycap(t)} \cdot \frac{\left(\varepsilon_{t,i}(p,t) - \varepsilon_{t-1,i}\right)^{1,2}}{\varepsilon_i(t)} .$$

The first term describes the effect which results from including a vintage of the optimal technique at time t-1. The second term describes the effect of adjusting the technique of the new plant to today's prices and embodied trend changes. The effects of these two causes of change are listed in Table 2, along with the total predicted and observed percentage change for each input share.

The distinction between vintage and marginal effects is illustrated in Figure 3. For simplicity, embodied technical change is omitted. An assumed positive price substitution moves the input mix of

---

1 $\varepsilon_{t-1,i}$ should be written $\varepsilon_{t-1,i}(p(t-1),t-1)$.

2 If the term $ycap_t(t)/ycap(t)\ \varepsilon_{t-1,i}$ is added and subtracted from $\varepsilon_i(t)$ it can be written:

$$\varepsilon_i(t) = ycap_t(t)/ycap(t) \cdot \varepsilon_{t-1,i} + \left(1-ycap_t(t)/ycap(t)\right) \cdot \varepsilon_i(t-1) + ycap_t(t)/ycap(t)\left(\varepsilon_{t,i}(p,t) - \varepsilon_{t-1,i}\right).$$

Table 2 Changes in input shares, 1960–75

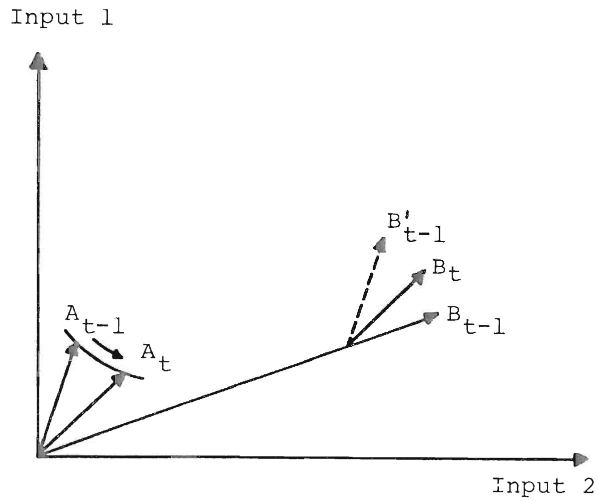
	Energy				Capital				Labor			
	Marginal effect	Vintage effect	Pre-dicted total	Ob-served total	Marginal effect	Vintage effect	Pre-dicted total	Ob-served total	Marginal effect	Vintage effect	Pre-dicted total	Ob-served total
1960	-.6	-5.1	-5.7	1.6	-.4	- .6	-1.0	-	-.3	-5.9	-6.2	-6.7
63	.6	-1.7	-1.1	-5.7	-.4	- .3	- .7	-	-.4	-3.3	-3.7	-8.9
66	.4	-2.0	-1.6	- .9	-.5	- .7	-1.2	-	-.7	-5.6	-6.3	- .2
69	.4	- .3	.1	-1.	-.5	-2.	-2.5	-	-.6	-6.6	-7.2	-6.3
72	-.3	- .0	- .3	-1.	-.2	-1.2	-1.4	-	-.3	-3.8	-4.1	-7.3
75	.8	-1.6	- .8	5.8	-.3	-1.4	-1.7	-	-.4	-4.2	-4.6	8.9

the new vintage from A_{t-1} to A_t. If the vintage with a technique optimal at time t-1 is added to the old production capacity surviving in period t-1, the aggregate input mix will move from B_{t-1} to B'_{t-1}. This illustrates the "vintage effect" in Table 2. The substitution due to a relative price increase for input 1 will then move the aggregate mix from B'_{t-1} to B_t, which illustrates the "marginal effect" in Table 2.

The "vintage" effect explains most of the decrease in the i/o ratios for both energy and labor. The vintage effect of the changes in the capital share depends on the assumed initial capital stock value. The hypothetical average capital input share happens to be similar to that of new vintages. So, in this instance, the two effects are of the same magnitude.

The vintage effect is a function of the differences between the i/o ratios of the new vintage

Figure 3



and the total aggregate. This fact may help to explain (without introduction of elaborous time-dependent nonneutral technical change) why an aggregate input share decreases at the same time as its own price falls, relative to prices of the other input factors. This is illustrated in Figure 3, which shows a positive elasticity of substitution on the margin, i.e., a relative incease in the price of input 1 will cause the ratio of input 1 to input 2 to decrease. But the aggregate effect of adding new production is the opposite, since the intensity of input 1, relative to input 2, increases. In a two-factor input case, a regular production model cannot reflect such an increase without the introduction of nonneutral technical change. In a case with more inputs this situation can be modelled by making the input with the decreasing input share a strong complement to another input with increasing own prices.

The preceding issue of complementarity or substitutability between inputs has lately been discussed a great deal, particularly in connection with energy due to its important policy implications (see Berndt and Field, 1981.) Suppose the aggregate model describes energy and labor to be complements. This would indicate that an increase in energy prices caused, e.g., by an extra tax would lead to a reduction in employment per unit of output. A vintage model, however, can describe the simultaneous decrease in the input share of energy and in the relative energy price by adding a new unit which is less energy intensive than the average. Still, energy might be a substitute for the other inputs in the ex ante production function. Even if the new vintage has a higher energy share than it would have had without a decrease in prices, the average use of energy might well decrease per unit of output, after the introduction of the new plant. This situation occurred for instance during the period 1960-64, where the price of energy relative to output and capital was almost constant, whereas its price relative to labor fell drastically by approximately 9 percent per year. As shown in Figure 4, this leads to an increase in energy intensity per unit of output on the margin, but since the marginal capacity has a lower level of energy use, total energy use still decreases.

The ratio of the labor share of a new vintage to the average value fluctuates between 45 and 50 percent during the estimation period (Figure 5). This high labor productivity, predicted for new production capacity, might well be biased upward because of the rigidity of the model specification, which does not allow for any increase in labor productivity for already installed units.

The model predicts the upswings and downswings of the investments poorly (Figure 6). This is not too troublesome, however, since this study has focused mainly on the model for capacity growth.

Figure 4 Energy output ratio, 1958–75

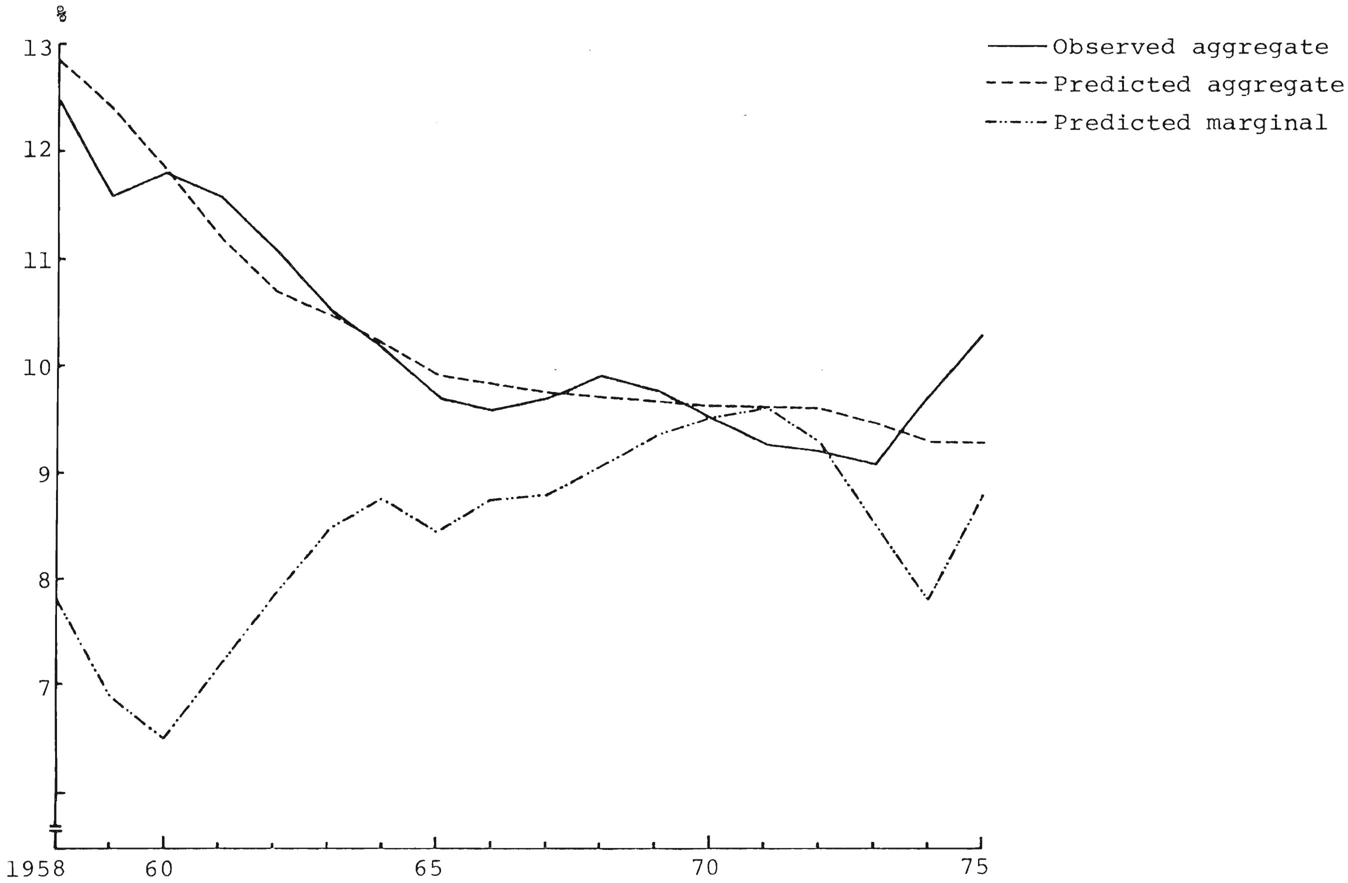
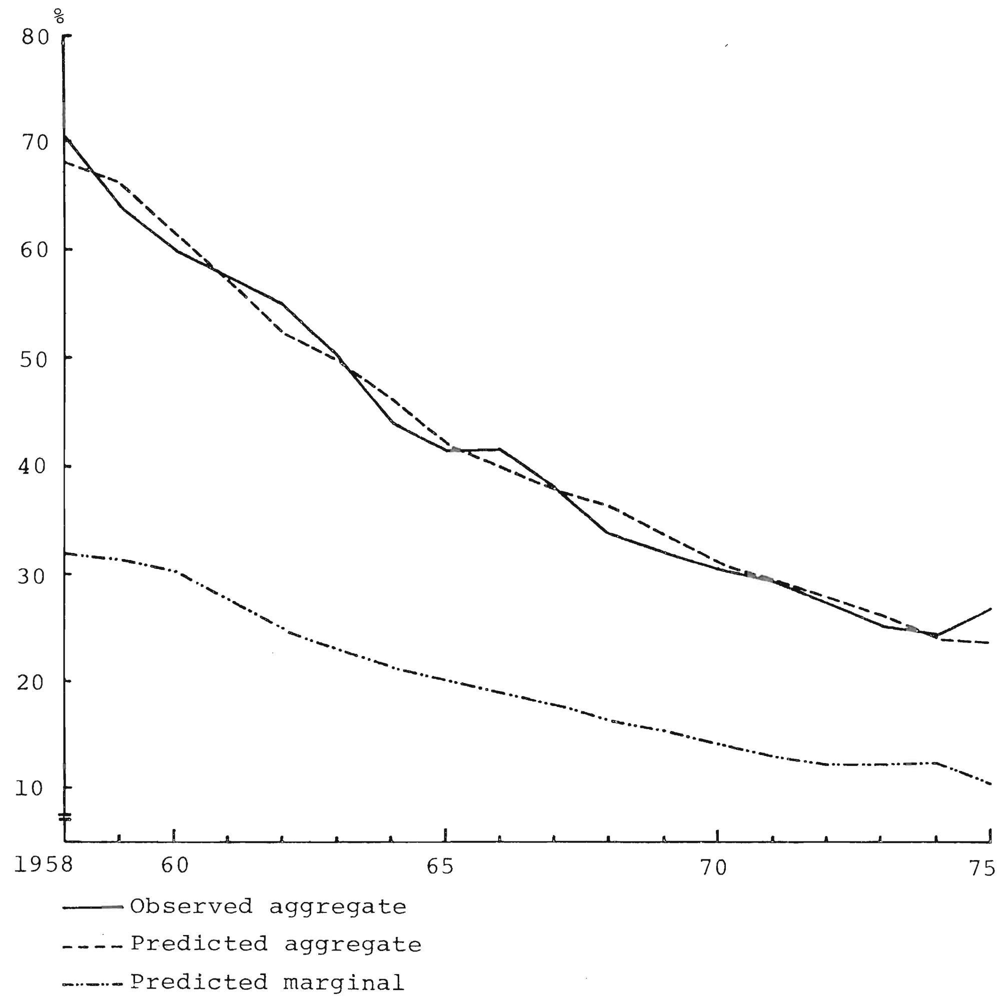
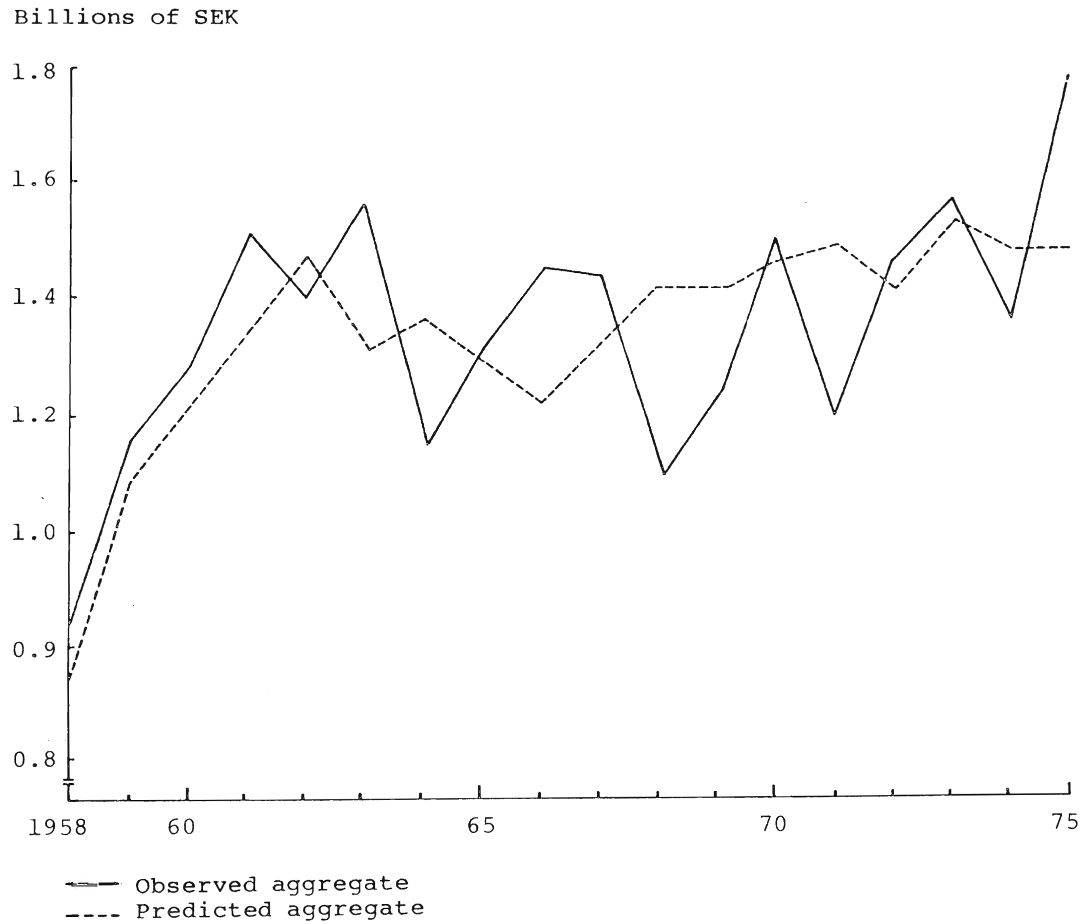


Figure 5 Labor output ratio, 1958-75



Billions of SEK. 1975 prices.



Appendix 1 ESTIMATION PROCEDURE AND PARAMETER ESTIMATES

It is difficult to obtain a proper empirical base for the dynamic structure of the model. The maximum number of observations is 27 and long time lags are to be expected. This is because the construction time for new production units might be several years and the decision to build a new plant is likely to depend on economic results several years in the past. These factors can add up to quite long lags between an event and its impact on the installation of new capacity. Estimation of all the coefficients of all lagged variables without constraints would leave too few degrees of freedom.

One way of reducing the number of parameters is to specify, e.g., a quadratic Almon lag structure. But it is difficult a priori, to believe in a specific lag distribution, since the observed aggregate dynamic structure depends on several economic agents who might well have different reaction patterns. On the other hand, the amount of new production capacity installed by each economic agent is expected to be positivly dependent on the explanatory variables, e.g., an increase in profits should lead to an increase in new capacity. If this is true on the micro level, then the variables will also be positively correlated on the macro level. Since a constant elastic functional form is used, the above reasoning suggests that the coefficients should be estimated under the restriction that they all are greater than or equal to zero. These restrictions are imposed on the estimated elasticities. The following two constraints are also added in order to increase the degrees of freedom further: economic events during the construction period, which is f years long, will not affect either the size or technique of the new production plant, and only the two preceding years plus year t are assumed to influence the construction of a new plant.

The model of capacity growth was then estimated for different construction times of one to four years under the above assumptions and coefficient restrictions. A three-year construction period gives the highest R^2 and the largest number of significant coefficients.

These initial runs were based on the profit variable derived from the capital stock data reported by the SCB.[1] Since a construction time of three years seems reasonable, it has been used throughout the study.

The equations for the input shares of energy and labor and the investment function were estimated simultaneously, using a nonlinear FIML procedure. A new capital cost variable was then calculated using the estimated depreciations. The growth model could then be estimated with a capital cost variable which corresponds to the rest of the model.

The model equations which are explained in Section 2 are listed below, along with the statistical assumptions.

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[1] SCB is the Swedish abbreviation for National Central Bureau of Statistics.

Aggregate input share (see 2.4)

$$\varepsilon_i(t) = ycap_t(t)/ycap(t) \cdot \varepsilon_{t,i}(p,t) + [ycap(t-1)-d(t)]/ycap(t) \cdot \varepsilon_i(t-1)+v_{t,i}, \quad i = 1,2 \qquad \text{(A1)}$$

where

$$\varepsilon_{t,i}(p,t) = p_q(t-3)/p_i(t-3) \cdot [\alpha_i + \Sigma\beta_{i,j} \ln p_j(t-3)]$$

$$d(t) = \delta \cdot oc(t-3) \cdot ycap(t-3)$$

$$p_q(t-3) = e^{\lambda(t'-3)} \Pi p_i^{\alpha_i} \Pi_j p_i^{\beta_{i,j} \ln p_j} \quad {}^{1}$$

Investments (see 2.4)

$$inv(t) = b \cdot \sum_{j=0}^{3} \varepsilon_{t+j,i}\ ycap_{t+j}(t) + v_{t,3} \qquad \text{(A2)}$$

Capacity growth (see 2.1)

$$\ln[ycap(t+3)/ycap(t+2)] = a + \gamma_1 \ln(yp) + \sum_{i=0}^{2} \gamma_{i+2} \ln(ep_{t-i}) + \sum_{i=0}^{2} \gamma_{i+5} \ln(ur_{t-i}) + v_{t,4}. \qquad \text{(A3)}$$

v_t denotes the vector of error terms and is assumed to be normally distributed with zero mean and the following covariance matrix

$v_t \sim N(0,\Omega)$,

where

$$\Omega = \begin{bmatrix} \Sigma & 0 \\ 0 & \sigma \end{bmatrix}$$

[1] t'=t-1975. This transformation is made in order to set the price index p_q equal to unity in the base year 1975.

and

$$E(v_t \; v'_s) = \delta_{ts}$$

and

$$\delta \tau \sigma = \begin{cases} 1 \text{ if } t=s \\ 0 \text{ if } t \neq s \end{cases}$$

where Σ is the covariance matrix corresponding to the equations (1) and σ is the variance of the error term for the growth model.

There are no constraints on the parameters in equation (A3), which connects it to the first three equations for the input shares (A1) and investment (A2). This implies that the estimation of all four equations can be divided into two parts — one which simultaneously estimates the first three equations and one which estimates the single equation for capacity growth. This follows from the structure of the covariance matrix and the fact that no endogenous variables from the upper block of equations appear in the fourth equation. Since depreciation is estimated consistently in the first block of equations, the capital cost derived from these estimates will also be consistent. This ensures that the link between the blocks will not affect the consistency of the single equation estimate of the growth model. Efficiency, however, will be lower than in an estimate which would incorporate all four equations simultaneously.

The estimated parameters are listed in Table 3. The restrictions which constrain the cost function of new vintages to be linear homogeneous are imposed on the estimates.

Table 3

	α_i	β_{i1}	β_{i2}	β_{i3}	b	λ	d^a	R^2	DW
Energy share	.154	-.015*	.045	-.030*				.80	.87
Labor share	.265	.045	.080	-.125				.98	1.40
Investments	.581	-.030*	-.125	.155	.642			.12	2.11
Common parameters						-.0380	.0644		

	α	yp	ep	ep_{-1}	ep_{-2}	ur	ur_{-1}	ur_{-2}	$\bar{R}^2$	DW
Growth equation parameters	.106	.512	.266	.030*	.005*	.0*	.0*	.268	.54	2.01

* Not significantly different from 0 on the 5 percent level.

[a] The d reported is δ multiplied by the average unit cost of production. This implies that the average depreciation rate during the observation period is 6.4 %.

Appendix 2 DESCRIPTION OF THE DATA

One strategic variable was not explained in the text, namely the data used for capacity growth. Observations of production capacity are seldom available, although time series on the development of capacity and production of crude iron were made available through the kind cooperation of the Swedish Ironmasters' Association.

Under the assumption that the utilization rate is the same for the sector as a whole as for crude iron production, a capacity variable for the entire iron and steel industry can be constructed as:

$$(ycap_I / y_I) \cdot y_{IS} = ycap_{IS},$$

where the index I denotes crude iron, IS iron and steel, ycap production capacity and y actual production.

Since all crude iron produced in Sweden is processed further in the domestic steel industry, it is likely that the steel industry has developed in close connection with the crude iron industry. The assumption of the same utilization rate in the two subsectors therefore seems justified. However, if e.g. the amount of special steel produced has increased relative to other steel products, then a trend shift might occur between the output of crude iron and the aggregate measure of steel.

This would also cause the calculated capacity measure to depart from the observed capacity of crude iron production over time. Such a departure has not occurred, as indicated in Figure 7.

All but two of the variables used in this study are the same as those in Dargay (1983), where a further description can be found. The exceptions are the capital cost component in the excess profit variable and the capital price variable used to estimate the input shares. In the first case, the calculated depreciation and rate of return for each year have been inferred, since the excess profit variable might be regarded as an ex post cash flow variable rather than an ex ante planning variable. The capital stock which appears in the profit variable also has to be accumulated using the estimated depreciation rate. The value of the initial stock is not known, however; it is calculated under the assumption that the cost of capital, reported by the SCB, is equal to the cost given by the different depreciation models used in this study, i.e.,

$$(p_{KO}\ K_O)_{SCB} = p_{KO}\ K_O$$

and

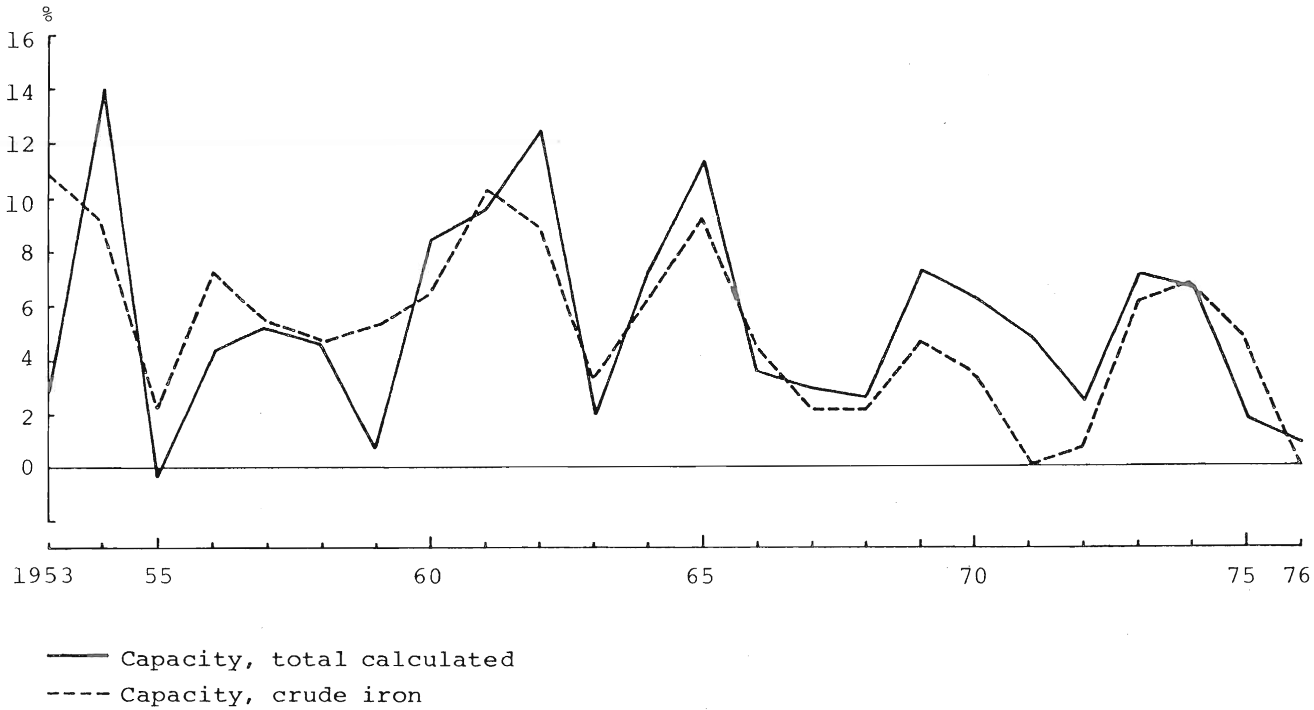
$$K_O = (p_{KO}\ K_O)_{SCB}/p_{KO}.$$

The capital stock series has then been calculated accordingly

$$K_t = I_t + (1-dr_{t-1})K_{t-1}.$$

In the second case, on the other hand, it seems more natural to regard capital price as an ex ante planning variable. Therefore, the depreciation rate and internal rate have been considered as constants. Since all prices are in index form, the capital price will be equal to the investment price index.

Figure 7 Capacity growth, 1953-76



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A Model of Energy Demand in the Swedish Iron and Steel Industry

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Contents

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1 INTRODUCTION

The iron and steel industry is a large user of energy. Iron and steel production accounts for 20 percent of the total energy used for industrial purposes in Sweden. The pulp and paper industry is the only sector which has a larger share and these two industries combined account for almost two-thirds, or 60 percent, of total industrial energy consumption. For energy demand forecasting purposes as well as analysis and evaluation of energy policy in general, it is clearly important to know the flexibility of the energy input in these two industries. Common measures of such flexibility are the partial elasticity of substitution between various inputs or input demand price elasticities. In this paper, estimates of the flexibility of energy input are reported for the iron and steel industry. These estimates are obtained through a model of iron and steel production. The model is of the activity analysis type, based on engineering information on the technological possibilities of producing a certain amount and composition of steel output. This approach has certain advantages as compared to the more traditional method of econometric estimation of time-series or crossection data. Such data are often of rather poor quality due to limited sample variation and multicollinearity. Also, in econometric estimation based on historical data, effects of new technology which has recently come into use or is expected to be used in the near future cannot be taken into consideration.

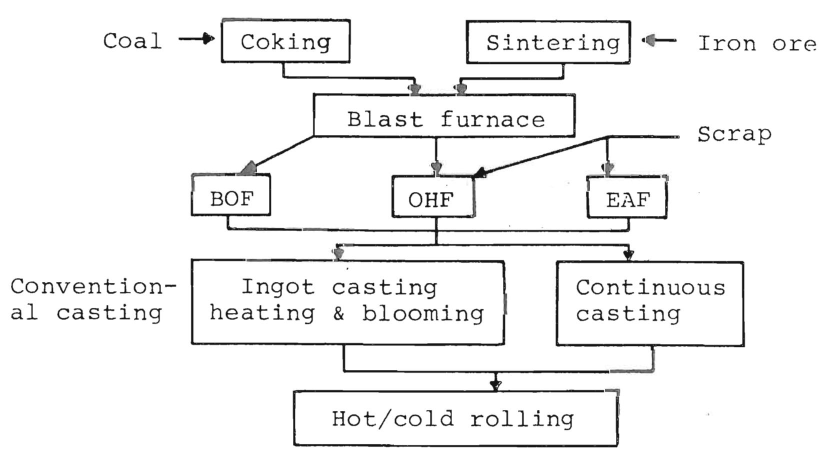
Energy consumption in the Swedish iron and steel industry is about 30 TWh annually. Coal and coke account for 50 percent, oil approximately 30 percent and electricity 15 percent. The coal and coke input in this case is not primarily an energy input but is necessary for metallurgical purposes. The demand for coal and coke, oil and electricity and the interrelations between these demands are estimated from the model. The results are presented in Section 3.

2 THE MODEL

2.1 Iron and Steel Manufacturing

Before presenting the model, a brief introduction to iron and steel manufacturing may be useful to the reader. Steel is produced in a variety of shapes and qualities although the main steps in the production process are quite similar. The flow chart in Figure 1 shows the main technological processes used in steel manufacturing.

Figure 1 A schematic view of iron and steel manufacturing



The dominant technology for producing raw iron is the blast furnace. Coke is required as both a source of energy and a reduction agent in order to reduce iron ore to raw iron in the blast furnace. The coke is usually produced by the ironworks' own coking plants. In addition to coke, the coking plant produces valuable by-products such as tar, ammonia, light oil and coke-oven gas. The coke-oven gas may be reused as a fuel in other parts of the iron and steel mill. Iron ore can be charged directly into the blast furnace if it is of a certain minimum size. Nowadays, however, most ore is enriched and has therefore been crushed into very small particles, so that it has to be agglomerated before charging. Agglomeration is carried out in sinter plants where enriched iron ore, limestone and coke are mixed and then subjected to heating. The result is sinter, a porous mass suitable for charging into the blast furnace. Alternatively, sinter may be purchased in the form of pellets direct from iron mines.

Although the blast furnace is the dominant iron-making technology, other methods — so called direct reduction — exist. The raw iron produced in direct reduction processes, often called sponge iron, is not molten and thus has to be melted in connection with steel refining. This makes sponge iron more of a substitute for scrap than molten raw iron from blast furnaces. There are recent indications of a possible commercial breakthrough for a third type of iron-making technologies. These are smelting reduction methods for producing molten raw iron similar in quality to that manufactured in blast furnaces. This technology uses coal and iron ore directly, without the intermediate coking and sintering processes. Smelting reduction may well become a very important competitor to the blast furnace within the next two decades.

Raw iron is refined into steel in steel furnaces. Three major types of steel furnaces are still in use. The basic oxygen furnace (BOF) is currently the most modern and certainly the most important in terms of installed capacity. The BOF is charged with molten raw iron and oxygen is blown into the furnace as the refining agent. The BOF depends heavily on molten raw iron since melted raw iron supplies most of the energy needed for refining. The maximum cold charge (scrap or sponge iron) is 30 percent of the total charge. In contrast, the older open hearth furnace (OHF) is very flexible in its input mix. It can take molten raw iron only, cold charge only or some combination of the two. Energy is supplied by fuel, often oil, but flexibility is also considerable in the choice of fuel. In spite of these advantages, the OHF is becoming obsolete. The OHF has much lower productivity than the other types of steel furnaces and the energy cost is considerably higher. Furthermore, the environmental impact of the OHF is severe and continued operation of these furnaces would require increased efforts to control emissions. The third type of steel furnace is the electric arc furnace (EAF). It is mainly a smelting device and thus only employed in steel-making with scrap or sponge iron as raw materials. The heat required to melt the cold charge is supplied by high-voltage electricity and refining can take place in either the EAF or an auxiliary refining furnace (so called duplex operation).

The output from steel furnaces, raw steel, is cast into semifinished shapes which are then hot and cold rolled into the various final shapes of the finished steel output. Raw steel is cast into semifinished shapes either through continuous casting, which means that molten raw steel is cast directly into semifinished shapes, or through the older method of first casting the raw steel into ingots, and then, after cooling, rolling the ingots into semifinished shapes.

2.2 The Production Model

The activity analysis model of the iron and steel-making processes described in the preceding section has three elements. The first is a rule of behavior which states the objective the iron and steel industry is assumed to pursue. The second element is a representation of iron and steel-making technology and the third is a representation of the structure of the industry.

The behaviorial assumption of the model is quite simple. The industry is assumed to minimize its costs for an exogenously specified level and mix of final steel output. Thus, the model is concerned only with decisions on input mix and capacity utilization.

In order to model iron and steel-making technology, the complete production cycle is divided into seven processes: coking, sintering, iron-making, steel-making, production of semifinished shapes, hot and cold rolling and the auxiliary process of internal electricity and steam generation. The production technology for each process is modeled by a set of activity vectors, defined at the unit production level of the principal output of the process. Thus, for each process, the possibilities of producing one unit of output are given by a $n \times m_p$ technology matrix, A_p, where n is the total number of commodities in the model and m_p the number of activities in process p, $p = 1,2,\ldots,7$.

There are twenty-seven commodities in the model. Eight of them are primary goods which cannot be produced by the technology included in the model, but must be purchased externally by the industry. There are eleven intermediate goods produced and used by the industry itself (some of the intermediate goods, e.g., scrap, can also be purchased externally). The final steel output of the industry is divided into eight different commodities according to shape and steel quality. This means that a rather crude disaggregation is used in the model. Only two different steel qualities are distinguished: commercial steel and alloyed steel.[1] Three groups of steel shapes are distinguished: plate, strip and other shapes. All three are produced in both qualities. Only strip steel is assumed to be cold rolled, thus making a total of eight $(2\times3+2)$ final steel commodities. All of the primary, intermediate and final commodities in the model are summarized in Table 1.

The total technology matrix is the $n \times m$ matrix

$$A = [A_1, A_2, A_3, A_4, A_5, A_6, A_7], \text{ where } m = \sum_{p=1}^{7} m_p.$$

The technical options for each process in the model are listed in Table 2. Although three iron-

[1] Alloyed steel in the model includes nonalloyed high-carbon steel. This quality corresponds to what is also known as special steel.

Table 1 The commodities of the model

Final steel output:	plate, commercial
	plate, alloyed
	strip, commercial, hot rolled
	strip, alloyed, hot rolled
	strip, commercial, cold rolled
	strip, alloyed, cold rolled
	other, commercial
	other, alloyed
Intermediate goods:	coke
	sinter
	raw iron, molten
	sponge iron
	raw steel, commercial
	raw steel, alloyed
	semifinished shapes, commercial
	semifinished shapes, alloyed
	scrap
	steam
	internally generated fuels (mainly coke-oven and blast furnace gas)
Primary inputs:	labor
	capital
	ferroalloys
	iron ore
	pellets
	coal
	oil
	electricity

Table 2 The technical options in the model technology

P	Process	Available technical options
1	Coking	1. Wet slaking a) choice of fuel 2. Dry slaking a) choice of fuel
2	Sintering	1. Choice of fuel
3	Ironmaking	1. Blast furnace a) choice between sinter and pellets b) choice of auxiliary fuel addition 2. Direct reduction a) two available process designs 3. Smelting reduction a) two available process designs
4	Steelmaking	1. BOF a) choice of amount and type (scrap or sponge iron) of cold material b) choice of fuel c) recovering of waste gas 2. EAF a) choice of charge composition (scrap or sponge iron) b) choice of fuel c) installation of oxyfuel equipment 3. OHF a) choice of charge composition (molten raw iron, scrap or sponge iron) b) choice of fuel c) oxygen addition
5	Production of semifinished shapes	1. Conventional casting a) choice of fuel 2. Continuous casting a) choice of fuel
6	Hot and cold rolling	1. Choice of fuel
7	Generation of electricity and steam	1. Cogeneration of steam and electricity a) choice of fuel 2. Electricity generation only a) choice of fuel 3. Steam generation only a) choice of fuel

making technologies are included, smelting reduction has been omitted from this study. This technology is a future option as there is still uncertainty as to when it can be introduced commercially and what its exact characteristics would be. There are three steel-making technologies, corresponding to the three types of steel furnaces discussed above. The choice between conventional casting and continuous casting is also listed. These are the strategic decision alternatives in the model technology. Other decision alternatives for each technology include the share of scrap in the steel furnace, the amount of pellets in the blast furnace and the fuel mix in heating ovens in the rolling mills.

The third and final element of the model is a representation of the industry structure. The industry in the model consists of two representative plants. Iron and steel is produced in two main types of steel mills. Most of the output is produced in large integrated plants which generally carry out all processes, from coking and sintering through iron reduction and steel furnaces, to rolling mills. About 30 percent of annual production comes from scrap-based mills. Their production facilities are limited to steel-making and hot and cold rolling, and their demand for iron raw materials is satisfied mainly by scrap. In an energy analysis context, it is important to maintain this distinction in the model. The scope for e.g. generation, and thus utilization, of internal energy is much more limited in scrap-based plants.

Of course it can be argued that the model should contain a more realistic industry structure. An ambitious strategy would be to identify the subset of technology in use for each existing plant and distinguish each plant according to its input requirements. This plant structure could then be introduced explicitly into the model. Such data are not readily available, however. Although the Swedish iron and steel industry is not overwhelmingly large in terms of number of plants (around 30), considerable effort would be required to compile this set of data. In addition, the model was constructed to be used on a rather small computer, which also limits the degree of detail in the model. More importantly, the benefits of greater detail with respect to industry structure are unlikely to outweigh its costs. There are two fundamental benefits: energy demand issues could be related to questions of industry structure and computations of energy demand could be based on a richer empirical foundation. As the model is intended to focus on energy demand, questions of industry structure are not of primary concern. Such issues can also be treated in models without the technological detail needed for energy demand purposes.

When industry structure is disregarded in energy demand calculations, two aspects are neglected: First, different plants which use the same technology or the same combination of technologies may differ in efficiency. In the input space, these plants would lie on a common ray through origo. The less efficient a plant is, the further from origo it would lie. Thus the average unit input coefficients of a technology, or a combination of technologies, would be an increasing function of the level of production in that technology. This aspect is not captured in the present model of the version.

The second aspect is that plants which use the same technology, or combination of technologies, may not lie exactly on the same ray extending from origo. The ratio of e.g. electricity input to fuel input for a certain kind of steel oven may vary across plants which use this particular steel oven. At constant outputs, some flexibility in the input mix could be achieved by reallocating production among these ovens. This is not captured in the present model. This loss of information, however, seems less important as compared to the first aspect.

As mentioned above, the number of plants in the Swedish iron and steel industry is comparatively small, around 30. The industry is dominated by three large integrated plants which belong to the SSAB, a state-owned company. These plants produce mainly commercial steel. There are also a few small, scrap-based plants which produce commercial steel. The remaining plants produce special steel; they are mostly scrap-based and comparatively small.

In order to introduce the plant structure into the model, the technology matrix A is taken to represent the technology of the integrated plant. For the scrap-based plant, a second technology matrix is defined as

$$B = [A_3', A_4', A_5', A_6', A_7'],$$

where A_p' contains a subset of the activities in A_p, $p = 3,4,\ldots,7$. In general, the technical alternatives are fewer in the scrap-based plant, which makes the number of columns fewer in A_p' than in A_p. The numerical values of the elements of B may differ from their corresponding element in the initial A matrix.

The problem analyzed in this model can be stated formally using the following notation:

Index sets:

I_1 = set of final goods
I_2 = set of intermediate and primary goods
J_A = set of production activities in the integrated plant
J_B = set of production activities in the scrap-based plant
S = set of initial capacities
R = set of delivery activities.

Variables and parameters:

X_j = level of production activity j
M_r = level of delivery activity r
K_s = initial capacity type s
P_i = price of commodity i
E_i = exogenous production requirement on commodity i
b_{ij} = output of commodity i in activity j
a_{ij} = input of commodity i in activity j
m_{ir} = delivery of commodity i by delivery activity r
g_{sj} = amount of capacity s utilized when production activity j is operated at unit level.

The problem is as follows: given the production technology matrix [A, B], a set of initial capacities, a set of input prices and the level and mix of final output, find the combination of activities that minimizes the costs of the industry.

This combination is found by solving the linear programming problem:

$$\text{Min} \sum_{r \in R} P_i \, m_{ir} \, M_r,$$

subject to

Commodity balances:

Final output:

$$\sum_{j \in J_A \cup J_B} (b_{ij} - a_{ij}) X_j \geq E_i \qquad i \in I_1$$

Intermediate and primary goods:

$$\sum_{j \in J_A \cup J_B} (b_{ij} - a_{ij}) X_j + \sum_{r \in R} m_{ir} M_r \geq 0 \qquad i \in I_2$$

Capacity constraints:

$$\sum_{j \in J_A \cup J_B} g_{sj} X_j \leq K_s \qquad s \in S$$

$$X_j \geq 0 \quad \forall j \qquad M_r \geq 0 \quad \forall r$$

The capacity constraints are, of course, introduced to account for the fact that at a given point in time, the feasible activity levels are bounded from above due to historically inherited capacities. Over time these upper bounds can be relaxed through investments in additional capacity. This is taken into account by solving the model in two versions. In the first, which corresponds to a short-run situation, there is no possibility of relaxing the upper bounds on any activity level and the relevant choice criterion is operating costs exclusive of capital costs.

The second version allows for capacity additions. This is achieved by expanding the technology matrix. For each activity which is constrained by an initial capacity, a second activity is introduced. This second activity is unconstrained but its utilization cost includes a capital cost. In all other respects it is identical to the constrained activity. Thus, utilization of the second type of activity implicitly assumes, through capital costs, investments in additional capacity. This is the long-run version of the model. The formal structure of the linear programming problem is, of course, identical in both cases. The only difference between the two cases is in the content of the technology matrices A and B.

Through delivery activities, the iron and steel industry purchases the inputs it cannot produce itself, or cannot produce in adequate quantities. Each delivery activity supplies a single commodity or service and at a constant price.

The data required in the model are the coefficients of the technology matrices, initial capacities, production of final output and input prices. Production of final output and input prices are, of course, varied exogenously to obtain different solutions, but the basic solution uses production data, input prices and initial capacities from 1975 (in the following referred to as "basic levels").

The technological coefficients are based on engineering information obtained from various sources. The data have been chosen to represent efficient process designs. One reason is that such data are often more easily available in the engineering literature and perhaps more reliable than figures on average industry performance at specific process levels. Second, average data are affected by changes in the industry structure, but data on best-practice performance are not. The iron and steel industry is undergoing rapid and drastic structural change, so that average data have to be revised frequently. Of course, best-practice data introduce a bias in the results. Input requirements and production costs are underestimated. But at least the direction of the bias is known. Best-practice data could not be obtained for every aspect of the model, however, so that in some cases data are more or less of the average-practice type. On the whole, it is valid to say that the model technology represents best-practice technology. The concept of best-practice is not always clear-cut, however, since the technology in this case contains old and obsolete technologies such as the OHF.

3 RESULTS

The two versions of the model were solved for different sets of energy prices. The variations in the optimal solutions of the model provide information about the impact on the choice of production technique and on production costs. So as to limit the number of computer runs, each price was varied sequentially by the following multiples, while other prices were held at their levels in the basic solutions.

$$\Theta = \begin{bmatrix} 2.0 \\ 1.5 \\ 0.5 \end{bmatrix}$$

The grid of price variation ranges from 50 percent below to 100 percent above basic levels. The span of this variation is certainly wide enough to include most possible price changes, although it could be argued that a finer grid in the most likely interval for price changes, say 75 percent below to 50 percent above the basic levels, would be more suitable. This particular choice of Θ is due primarily to the aim of limiting the number of computer runs.[1]

The impact of changes in the energy price in both the short and long run, is discussed below. The results are summarized in input demand elasticities. The analysis is preceded by brief comments on the basic solutions.

3.1 The Basic Solution in the Short Run

The basic solution of the model uses 1975 data for the level and mix of steel output, the prices of primary inputs and the levels of capacities. The capacities impose upper bounds on the production activities, thereby limiting the choice of production technique.

The results for the short-run basic solution are summarized in Tables 3-6. As indicated by Table 3, the production levels of the processes are some 20 percent below actual data, except for sintering,

[1] Unfortunately, the software used to solve the LP-problems is somewhat primitive. More sophisticated software can e.g. identify the price range in which a particular solution is optimal. Such information would, of course, be extremely valuable in assessing the impact of price changes and choosing reasonable values in Θ.

which is somewhat above. The result for sinter is explained mainly by the fact that a 100 percent sinter charge in the blast furnaces was chosen in the model, whereas about 1/3 of the charge actually consisted of pellets. The lower raw steel production required in the model for the given output level is due to more efficient yields in the hot and cold treatment of the steel than appears to be the case in actual performance. This reflects the fact that model data have generally been calculated to correspond to potential performance of an activity when modern equipment is utilized. This also explains the lower level of raw iron production in the model. It should be pointed out, however, that the data on actual production in Table 3 may not be fully comparable with the model results. The reason is that in the actual data, the amounts produced of, say, raw iron differ from the amounts consumed in subsequent processes, the difference is used for other purposes or held in stock. Thus, according to one source (SOU 1977:16, pp.136-137), actual input of raw iron in steel-manufacturing processes was 2.774 million tons in 1975, which is considerably closer to the model figure.

The steel technologies chosen are shown in Table 4. The general conclusion is that the model uses the OHF to a much lesser extent and instead places more emphasis on the BOF as compared to the actual distribution of steel production. The use of the EAF in the model is quite similar to the actual levels, except for alloyed steel production, where the model utilizes the EAF more and the OHF less. These are very reasonable results, since the OHF is more expensive to operate than both the BOF and the EAF. The clear-cut optimization in the model

Table 3 Production in various processes of iron and steel manufacturing

	Model production Mill.tons	Actual production Mill.tons	Difference Percent
Coking	1.2	n.a	-
Sintering	3.7	3.37	9.8
Ironmaking	2.39	3.38	29.2
Steelmaking	5.081	6.448[a]	21.2
Casting of semi-finished shapes	4.472	5.548	19.4

[a] estimated using model yield data.

Sources: SOS Bergshantering; Svensk Järnstatistik.

Table 4 Distribution of steel production according to types of steel furnaces
Percent

	BOF	EAF	OHF	Σ
Model:				
total	59	40	1	100
commercial steel	72	28	-	100
alloyed steel	-	95	5	100
Actual:				
total	39	42	19	100
commercial steel	54	32	14	100
alloyed steel	9	61	30	100

Sources: SOS Bergshantering; Svensk Järnstatistik.

Table 5 Distribution of production of semifinished shapes according to continuous and conventional casting

Percent

	Continuous casting	Conventional casting
Model:		
total	45	55
commercial steel	42	58
alloyed steel	50	50
Actual:		
total	24	76
commercial steel	30	70
alloyed steel	4	96

Sources: SOS Bergshantering; Svensk Järnstatistik.

Table 6 Energy use

Millions of tons except where stated otherwise

	Model	Actual
Coal	1.68	2.59
Oil	.304	.8
Internally generated fuels (PJ)[a]	10.56	5.56
Electricity (TWh)	3.2	4.3
internally generated	-	-
bought externally	3.2	4.3

[a] Net of recycled blast-furnace gas used in the blast furnaces themselves.

Source: SOS Industri.

cannot take all the complexities of reality into account. This may make it worthwhile to continue, at least in the short run, to use the OHF. Table 5 shows that continuous casting is used to a larger extent in the model than in reality. This is mainly because a larger share of alloyed steel is continuously cast in the model than in actual production. In the model, it is assumed that at most 50 percent of the alloyed steel production can be continuously cast. For quality reasons the remainder has to undergo the older and more costly method of conventional casting. This assumption may exaggerate the 1975 possibilities.

The total energy input per tonne of final steel output in the basic solution is 21.7 GJ. The actual energy input according to the figures of Table 6, was 28.7 GJ. Part of the discrepancy can be attributed to the higher energy efficiency of the model technology as compared to average actual performance. But the model also disregards some minor aspects of energy use in the industry. The model treats only the energy required directly in the production processes. Energy for space heating, lighting and similar purposes is neglected, which implies underestimation of the energy input. But as 90 percent of the total energy input is used directly for production purposes, this underestimation should not be too serious.

3.2 The Basic Solution in the Long Run

Some results from the long-run basic solution are listed in Tables 7-10. The long-run basic solution uses the same final output requirements, input prices and initial capacities as the short-run

Table 7 Production levels in main production processes of iron and steel manufacturing Long-run version

	Mill.tons	Change from short-run version, %
Coking	1.2	-
Sintering	3.7	-
Ironmaking	2.39	-
Steelmaking	4.8	-6
Casting of semi-finished shapes	4.48	-

Table 8 Distribution of steel production according to types of steel furnaces
Percent

	BOF	EAF	OHF
Total	72	28	-
Commercial	59	41	-
Alloyed	100	-	-

Table 9 Additions to initially given capacities

	Mill.tons	Percent of initial capacity
BOF (integrated plant)	.465	15.5
Conti-cast (integrated plant)	1.805	116

basic solution. In the long-run case, however, production in excess of the initial capacities could be achieved by utilizing activities related to capital costs.

According to Table 7, the production levels of the various production steps do not, in general, exhibit any change. Only raw steel production diminishes somewhat, because conventional casting is abandoned almost completely, thereby reducing scrap losses. Table 9 reveals a very large increase in the capacity of continuous casting. In fact, conventional casting is not used to any large extent and then only for the share of alloyed steel which, for quality reasons, is constrained in the sense that it cannot be continuously cast. The only other investment made is in the BOFs. The increase in BOF capacity is quite modest, but it enables the model industry to completely close down the OHFs. The share of steel produced in the BOFs increases, as compared to the short-run case, but almost a third of the raw steel is still produced in the EAFs. Table 8 also shows that the EAFs are only used to produce commercial steel.

The energy input configuration for the long-run basic solution is given in Table 10. The difference from the short-run version is largely explained by the change from conventional to continuous casting. Fuel and electricity requirements are decreased because continuous casting is more efficient in these respects. Continuous casting also reduces scrap losses and thus requires lower raw steel production. Lower scrap losses imply lower internal scrap generation and the reduction in raw steel production is accomplished by reducing scrap-based production.

Table 10 Energy use. Long-run version
Millions of tons except where stated otherwise

		Difference from short-run version
Coal	1.68	-
Oil	.247	- .061
Internally generated fuels (PJ)	6.95	-3.61
Total fuel (PJ)	17.24	-6.0
Electricity (TWh)	3.03	- .17
internally generated	-	-
bought externally	3.03	- .17

3.3 Production Costs in the Basic Solutions

The dual variables associated with the commodity balance constraints of the linear programming problem have a straightforward economic interpretation. The dual variable associated with the i'th commodity constraint represents the marginal cost of producing that commodity. This marginal cost includes, as the case may be, the shadow values of initial capacity directly or indirectly employed in the production of this commodity. The marginal cost is also net of the shadow value of by-products. The marginal costs of the final steel output and some intermediate commodities are listed in Table 11. The long-run costs are generally lower because the two expensive technologies, OHF and conventional casting, are no longer used.

The cost shares of labor, materials and energy are given in Table 12. The model underestimates the

Table 11 Model production costs for final steel output and certain intermediate products
SEK/ton. 1975 prices

		Short-run basic solution	Long-run basic solution
Plate	commercial	646	604
	alloyed	1404	1362
Strip	commercial	623	580
hot rolled	alloyed	1383	1342
Strip	commercial	790	737
cold rolled	alloyed	1855	1795
Other	commercial	604	564
	alloyed	1379	1336
Coke		320	314
Sinter		97	119
Raw iron		300	330
Sponge iron		309	309
Raw steel	commercial	421[a]; 400	400[a]; 400
	alloyed	911[a]; 890	888[a]; 890
Semifinished	commercial	504[a]; 488	469[a]; 450
shapes	alloyed	1058[a]; 1042	1025[a]; 1023

[a] The first figure is the production cost of the integrated plant, the second figure the production cost of the scrap-based plant.

Table 12 Cost shares in the basic solutions

	Short-run version	Long-run version	Actual[a]
Labor	16	15	21
Ferroalloys	29	30	
Iron ore	9	9	
Pellets	-	-	
Scrap	17	16	
Total materials	55	55	63
Coal and coke	14	15	13 (coal and coke, and oil)
Oil	5	4	
Electricity	10	9	3
Total energy	29	28	16

[a] from SOS Bergshantering 1975; Table 3.

labor cost share. It overestimates the energy cost share and, in particular, that of electricity. As this study focuses on the impact of energy price changes, the higher energy cost share of the model technology means that the model is also more sensitive to changing energy prices. For this reason, the model adjustments to price changes may be exaggerated.

3.4 The Impact of Energy Price Changes

The mix of final steel output is kept constant in all of the model solutions, so the minimum cost input requirements per unit of final output can be computed unambiguously. The impact of price changes on the energy input requirements, per unit of output, is shown in Tables 13 and 14 for the short-run and long-run versions, respectively.

Table 13 Energy input requirements[a] per unit of finished steel output with constant output mix. Short-run version

	Price regime	Input: Coal	Oil	Internal fuels	Elec-tricity
Basic solution		.45	.08	.68	.86
Electricity	.5	.46	.08	.68	.88
	1.5	.43	.10	.65	.77
	2.0	.43	.11	.65	.74
Oil	.5	.43	.11	.65	.74
	1.5	.54	.04	.95	.87
	2.0	.54	.04	.94	.87
Coal	.5	.65	.03	.98	.89
	1.5	.39	.09	.60	.85
	2.0	.17	.12	.26	.92

[a] tonne input per tonne steel output except for:
electricity: MWh per tonne steel output
internal fuels: Gcal per tonne steel output

Table 14 Energy input requirements[a] per unit of finished steel output with constant output mix. Long-run version

	Price regime	Input: Coal	Oil	Internal fuels	Elec-tricity
Basic solution		.45	.067	.45	.82
Electricity	.5	.46	.067	.47	.84
	1.5	.58	.070	.50	.67
	2.0	.57	.080	.49	.64
Oil	.5	.45	.089	.46	.72
	1.5	.68	.005	1.02	.74
	2.0	.69	.0008	1.04	.73
Coal	.5	.68	.0018	1.09	.95
	1.5	.39	.072	.43	.71
	2.0	.14	.106	.19	.71

[a] for units of measurement, see Table 13.

The sensitivity of the energy input requirements to price changes was calculated in terms of arc price elasticities; see Tables 15 and 16 for the short-run and long-run versions, respectively. The elasticities are defined as

$$e_{ij} \equiv \frac{q_i^2 - q_i^1}{p_j^2 - p_j^1} \cdot \frac{p_j^1 + p_j^2}{q_i^1 + q_i^2},$$

where e_{ij} = elasticity of factor demand of good i with respect to the price of good j.

p_j = price of good j, where superscript 1 indicates original price, superscript 2 the price after the change.

q_i = quantity of good i demanded, where the superscripts denote the same as for prices.

It should be pointed out that the computed values of these elasticities are not unique. This is because the solutions, and thus the q_i's, are typically optimal for an interval of prices. A range of elasticities can therefore be computed for a given solution to the LP-problem using the different prices for which this solution is optimal.

Tables 15 and 16 confirm that all own-price elasticities are negative, as they should be, and — perhaps more interesting — they are all distinctly different from zero. There is one exception, however. A decrease in the price of electricity gives a value very close to zero in both the short and long-run versions. This implies that a substantial increase in the electricity intensity of

Table 15 Arc price elasticities of energy demand Short-run version

	Price regime	Input: Coal	Oil	Electricity
Electricity	.5	- .03	0	-.03
	1.5	- .11	.56	-.28
	2.0	- .07	.47	-.23
Oil	.5	.07	- .47	.23
	1.5	.45	-1.67	.03
	2.0	.27	-1.0	.02
Coal	.5	- .55	1.37	-.05
	1.5	- .36	.29	-.03
	2.0	-1.35	.60	-.12

Table 16 Arc price elasticities of energy demand Long-run version

	Price regime	Input: Coal	Oil	Electricity
Electricity	.5	- .03	0	-.4
	1.5	.63	.11	-.5
	2.0	.35	.27	-.37
Oil	.5	0	- .42	.19
	1.5	1.02	-4.3	-.26
	2.0	.63	-2.93	-.17
Coal	.5	- .61	2.84	.24
	1.5	- .36	.18	.12
	2.0	-1.58	.68	.22

steel production is not very likely and could only arise through a large reduction (more than 50 percent) in the price of electricity. Any substantial increase in electricity intensity can take place in the model only by producing a larger share of raw steel in the EAF. But in spite of some excess EAF capacity in the basic solution, its share in raw steel production is more or less unaffected by the decrease in electricity price. This is because most of the raw steel is produced in the BOF, which also retains its strong cost advantage after the decrease in electricity price.

In general, the long-run elasticities also have a higher numerical value than the corresponding short-run elasticities. This is normal since the long-run version imposes fewer constraints on production decisions.

When comparing the energy own-price elasticities, it is clear that electricity is the least flexible energy input, whereas oil input, especially in the long run, is very flexible. From Tables 15 and 16, it seems reasonable to conclude that for electricity and a price increase, the own-price elasticity is -.25 to -.30 in the short run and -.35 to -.50 in the long run. For a price decrease, on the other hand, the elasticity is around -.05 in both the long and short-run versions.

There is also a marked difference in the elasticity values for oil, according to the direction of the price change. For a decrease in the oil price, the own-price elasticity lies around -.45 (the short-run value is in fact somewhat higher than the long-run value). With a price increase, the elasticity is -1.0 to -1.7 in the short run and rises to values as high as -3.0 to -4.0 in the long run. These high elasticities for an increase in the oil price may be somewhat exaggerated, however. Internally generated fuels, mainly coke-oven and blast-furnace gas, can be used in the model, as a substitute for oil in many areas of the iron and steel works. This substitution is costless in the model, which implies that the iron and steel works are equipped for both types of fuels. This is clearly not the case in reality. Some retrofitting of furnace equipment, etc. has to take place in order to substitute for oil. The model exaggerates the ease with which oil consumption can be diminished. Consequently, the oil price elasticities should be revised downwards.

The assymetry in the elasticity values, according to whether there is an increase or a decrease in the oil price, follows from the fact that, in the basic solution, relatively more oil-intensive activities in the various processes are generally chosen. Thus, when the oil price increases, there is a rather rich set of possibilities for substituting away from oil, while there are fewer opportunities for using more oil when it becomes cheaper.

The values of coal price elasticities are intermediate between the electricity and oil elasticities. For a price decrease, the elasticity is -.55 to -.60 in both the short and long-run versions. The interval widens as the coal price increases. The elasticity is -.36 in both the short and long-run versions for a 50 percent increase and rises to -1.6 in both cases when coal prices are doubled.

A negative cross elasticity indicates complementarity between the two inputs, while a positive cross elasticity means that they are substitutes.

In order to characterize any pair of inputs unambiguously as either complements or substitutes, the signs of the cross elasticities should be symmetric, that is, $\mathrm{sgn}|e_{ij}| = \mathrm{sgn}|e_{ji}|$. This also seems generally to be the case. There are, however, some exceptions. Thus, in the long-run version, the symmetry does not hold between coal and electricity, nor between electricity and oil. Coal and oil are clearly substitutes in both the short and long-run versions. This is also what would be expected a priori. Lower oil consumption, for instance, is achieved by increased utilization of internally generated fuels. This means that the blast furnace-BOF steel-making process has to be used more intensively, leading to an increased demand for coal.

Coal and electricity are complements in the short run but substitutes in the long run, even though the sign reversal in the two computed elasticities for the long-run solution elicits some ambiguity concerning the latter relation. A priori, coal and electricity would be expected to be substitutes since the blast furnace-BOF and scrap-EAF processes are alternatives. The complementary relation in the short run is due to the capacity constraints. When the price of electricity increases, or the price of coal decreases, the EAF becomes less competitive. This tends to diminish the demand for scrap. On the other hand, as sinter capacity is fully utilized, the model finds it too expensive to increase raw iron production by buying pellets. Instead, the scrap released from the EAFs is used to increase the use of scrap in both the OHF and BOF and, in the latter case, actually decreases the demand for raw iron and thus coal. This gives rise to the complementary relation in the short run. This does not happen in the long run when the EAF becomes less competitive. Instead the model then chooses to expand both sinter and BOF capacity, thereby increasing the use of coal.

Oil and electricity seem to be substitutes in both the short and long run, even if some ambiguity is again introduced by the sign reversal for $e_{electricity;\ oil}$ in the long-run version. The relations between oil and electricity are more complex than when coal is involved. Coal has a few, limited uses, while oil and electricity are used throughout the iron and steel works. However, the competitive relation between the OHF, mainly oil-fired, and the EAF should mean that oil and electricity becomes substitutes. In the long-run solutions, as was apparent in the discussion of the basic solutions, the OHF is not used at all, or only to a limited extent, which could explain the more ambiguous relation in the long-run version.

It should be emphasized that these results are based on a partial analysis. Only one price is changed at the time, while other prices and the amount of final output are kept constant. Of course, in equilibrium, a change in one price induces changes in other prices, i.e., input prices as well as output prices. Changes in output prices, in turn, lead to changing amounts of final output, which implies further changes in the input mix. In order to ascertain the extent to which changes in the input price are likely to induce changes in output, it is instructive to study the effects on the marginal production costs of final steel output. This is shown in Tables 17 and 18 for the short and long-run versions, respectively.

Table 17 The impact of price changes on production costs
Percentage change from the short-run basic solution

		Electricity			Oil			Coal		
		.5	1.5	2.0	.5	1.5	2.0	.5	1.5	2.0
Plate	commercial	-6.7	6.5	13.3	-4.8	4.6	9.3	-.1	.1	3.2
	alloyed	-4.7	3.7	7.3	-2.3	2.4	4.6	-	-.6	1.4
Strip hot rolled	commercial	-7.0	6.6	13.8	-4.8	4.5	9.1	-	-	3.2
	alloyed	-3.9	3.8	7.7	-2.2	2.2	4.4	-	-.5	1.6
Strip cold rolled	commercial	-8.6	8.4	17.0	-5.7	5.6	11.3	-.1	.1	3.8
	alloyed	-4.6	4.6	9.1	-2.7	2.6	5.3	-	-.7	1.4
Other	commercial	-7.3	7.1	14.6	-3.4	3.6	7.3	-	.1	3.8
	alloyed	-3.9	3.9	7.9	-1.8	1.9	3.8	-	-.8	1.4

Table 18 The impact of price changes on production costs
Percentage change from the long-run basic solution

		Electricity			Oil			Coal		
		.5	1.5	2.0	.5	1.5	2.0	.5	1.5	2.
Plate	commercial	-6.8	4.1	8.1	-3.6	2.8	6.5	-10.6	3.5	4.
	alloyed	-3.3	2.1	4.2	-2.0	1.5	3.5	- 4.6	1.3	2.
Strip hot rolled	commercial	-7.2	4.3	8.6	-4.6	2.6	6.0	-10.5	3.6	4.
	alloyed	-5.4	2.3	4.5	-2.3	1.5	3.4	- 4.5	1.3	2.
Strip cold rolled	commercial	-8.7	6.1	12.1	-3.4	3.7	8.4	-10.3	3.5	5.
	alloyed	-4.2	3.1	6.0	-1.8	1.9	4.3	- 4.3	1.3	3.
Other	commercial	-7.4	4.8	9.4	-2.3	2.0	4.4	-10.5	3.5	5.
	alloyed	-5.6	2.3	4.6	-1.6	1.2	2.7	- 4.4	1.3	3.

A doubling of the electricity price raises the marginal production cost by 7-17 percent in the short run and 4-12 percent in the long run, depending on shape and steel quality. Similarly, when the oil price is doubled, the cost increases by 4-11 percent and 3-8 percent in the short and long run, respectively.

The impact of changes in the coal price is of similar magnitude in the long run but negligible in the short run. This latter effect is due to the fact that the increase in the coal price is almost completely absorbed by a corresponding drop in the shadow value of the BOF capacity. In the short-run version, all existing capacity in the three types of steel furnaces in the integrated plant is utilized and the marginal cost is determined by scrap-based steel production in the OHF. A change in the coal price affects only BOF-produced steel, but since all plant capacity is utilized, there is no scope for reallocating steel production from or to the BOF. Consequently, an increase in e.g. the coal price only decreases the rent or shadow value of installed BOF capacity.

These marginal cost changes are certainly large enough to be likely to induce output adjustments and, as a result, further adjustments in the input mix.

4 CONCLUSIONS

A quantitative analysis of the energy demand for one sector of the economy, e.g. the iron and steel industry, could be pursued using two alternative approaches. The first is based on a sample of past data on energy use, energy prices, production levels and the use and prices of other inputs in production. It is postulated that the data are derived from a particular mode of behavior in the industry, usually cost minimization, and the data set is subjected to statistical analysis. Hopefully, it is then possible to obtain a set of energy demand relations with good explanatory power.

The second alternative is based on a model of the production technology in the sector. Such a model can rely on engineering information and, in principle, be very detailed. An activity analysis framework is perhaps the most straightforward and analytically tractable way of organizing engineering information. By combining the production technology model with a behavioral assumption such as cost minimization, results can then be derived with respect to how production is organized and, consequently, the demand for various inputs, including energy.

The latter approach was illustrated in this paper for the iron and steel industry. It has certain advantages as compared to the first alternative of econometric estimation, where it may be difficult to obtain good statistical results due to e.g. limited sample variation and multicollinearity in the available data. Moreover, in econometric estimation based on historical data the effects of new technology, which has recently or is soon expected to come into use cannot be taken into account. On the other hand, the requirements in terms of technological information and computational capacity can easily become quite large for a model of the type illustrated in this paper. Its data base should be continually maintained and revised. Furthermore, the user has to be well acquainted with technological details in order to understand the results of the model.

The outcome of some simple energy price change experiments were summarized by price elasticities in Tables 15 and 16. Electricity was found to be the least flexible, and oil the most flexible, energy input. Coal and oil as well as oil and electricity were found to be substitutes in both the short and long run. There seems to be a complementary relation between coal and electricity in the short run, although they are substitutes in the long run.

The computed values of the elasticities should, however, be used with great caution. They are not unique, since the various input requirements will generally be chosen for a range of prices, i.e., not only those used in calculating the elasticity values. Moreover, the estimates would probably change, perhaps substantially, if another basic solution were used, thereby changing e.g. the level and mix of final steel output, available capacities, etc.

Energy Substitution in the Forest Industry

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Contents

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1 INTRODUCTION

The pulp and paper industry is a major consumer of electricity and heat in Sweden. A large share of this energy is produced within the industry through the burning of spent liquids, bark, etc. The industry refines raw materials which have a potential alternative use as fuel.

The sensitivity of net energy consumption, i.e., the use of oil and externally produced electricity, to relative prices of oil, electricity, and labor, and investments was studied by means of two linear programming (LP) models of the pulp and paper industry in northern Sweden. The outcome of the study is reported in this paper.

The results from the LP models have a number of advantages as compared to the information which can be gathered from historical data. The models focus on current and blueprint technology. Production technologies which are adapted to relative prices outside the ranges of the prices observed in the past are included. The LP models utilize fairly informative data bases and therefore provide more detailed results than those usually obtained in studies of historical reaction patterns. The LP approach also has some drawbacks, however. One is the linearity imposed on the model structure. Another is the practical limitation on the inclusion of all potential substitution alternatives. In this case, only energy substitution related to changes in production levels and output composition within a plant and within the industry is considered. Thus, "disembodied" energy saving and substitution are disregarded.

2 THE MODELS

The models used were developed for a study of the optimal allocation of wood resources in northern Sweden.[1] They are outlined and discussed in Hultkrantz (1982 and 1983).

The models maximize the quasi-rents to industrial capacity (gross profits net of the capital costs of new investments) and quasi-rents to forest owners (price of stumpage), subject to the constraints set by industrial capacity, investment possibilities and available volumes of wood in different cost classes. The world market prices of forest industry products and domestic prices of various inputs (except wood resources) are exogenous. A model solution is, in principle, equivalent to the (partial equilibrium) outcome of a market for wood resources with perfect competition.

A major part of the data was collected from official statistics for the Swedish manufacturing industry in 1979, based on figures provided by the companies themselves. Input-output data were calculated for separate production lines within the plants. Plants which produce both pulp and paper, make use of different processes for the production of semi-finished pulp, market pulp and paper, etc. In most cases there are several options to the composition of different kinds of pulp in a specific paper product.

The models comprehend the pulp, paper and board industry and wood-based, large-scale heating sta-

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[1] The districts of Norrbotten, Västerbotten, Västernorrland, and Jämtland.

tions (blueprint technology). The sawmill industry's net demand for wood material (timber less waste products used by the pulp and/or board industry) is exogenous to the model.

Wood (conifer and deciduous) is supplied by five (one large intramarginal and four marginal or near-marginal) capacity-constrained supply activities. In this way, the short-run exploitation cost distribution of the allowable cut[1] is represented in the models. The main data source here is the cost accounts for government-owned forests.

The possibility of a minor transfer of softwood from southern Sweden is also allowed for.

The first model, the "1984"-model, includes the investment alternatives that were actually considered by the companies in the region in the fall of 1980. The data on the projects were supplied by the corporations. The wood market in some future year, say 1984, is thus described in terms relevant for planning and investment decisions made in 1980. This means e.g. that capital costs (annuities) are only taken into account with regard to investments.

Energy substitution in industry is a dynamic process. The "1984"-model is a static model, however, although investment activities are included. The second model, the "1979-1993"-model, comprises three periods. The first five-year period is constrained by the capacities in 1979. Capacities in

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[1] Hence, the forest owners are assumed to face only the static problem of whether or not to cut a permissible volume of trees. The dynamic problem of when to harvest the growing resource is solved by government regulation.

the second period can be expanded by the same investments as those available in the "1984"-model. Further investments can be made for utilization in the last period.[1] The costs of these investments are modified to compensate for their shorter lifetime. A solution is chosen which maximizes the sum of the discounted quasi-rents of the three periods.

In the three-period model, unlike the case in the "1984"-model, a single production line corresponds to each final or semifinished product, and the industry as a whole is described as if it consisted of only one multiproduct plant. The size of the model is kept from becoming too extensive at the expense of the scope for substitution.

2.1 Energy Substitution in the "1984"-Model

The solutions to the "1984"-model are based on the prices of outputs and inputs in 1979. Different solutions have been calculated by varying the prices of electricity, oil and labor and the level of the capital cost of new investments. These prices are successively set at a "low" and a "high" level (in the case of oil, there are two "high" prices). These price assumptions are specified in Table 1.

Price (arc) elasticities for the industry's demand

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[1] The shadow prices of the volume constraints on investment possibilities can be interpreted as quasi-rents imputed to scarce business organization, land, etc., i.e., resources which are necessary for an investment. This interpretation is valid for the second period, but more ambiguous in the third period, since the constraints for this period are more arbitrary.

Table 1 Alternative price assumptions

	Basic case	Low level	High level	
Oil	800 SEK/m^3	50%	(i) 150%	(ii) 200%
Electricity	0.10 SEK/kWh	50%	200%	
Labor	59 SEK/h	80%	120%	
Investment costs	100%[a]	75%	125%	

[a] Annuity index based on a 10 % interest rate and an investment lifetime of 10 years.

for these inputs have been calculated[1] from the results of the model. It should be noted that the exact levels are somewhat arbitrary; because of the linearity, a specific model solution can be valid for a whole interval of prices.

The own-price elasticities of electricity and oil are shown in Table 2. For electricity consumption, the sensitivity to own price is fairly low. This is due to the rather minor role electricity costs play in the total economy of the industry, even though the consumption of electricity is considerable. The sensitivity to an increase in the price of electrical power, however, becomes more significant when the price of oil is high.

Oil consumption in the industry is hardly affected by a decrease in the price of oil. The elasticity is higher if the price is increased to 150 % and

[1] The following formula is used:

$$\frac{X - X_0}{X + X_0} : \frac{P - P_0}{P + P_0},$$

where X, P are quantity and price of the input in a specific solution and X_0, P_0 represent the corresponding measures for the basic solution.

Table 2 Own-price elasticities

Electricity consumption

Oil price	Electricity price 50%	Electricity price 200%
100%	-0.07	0
150%	-0.01	-0.25

Oil consumption

	Oil price 50%		Oil price 150%		Oil price 200%	
Investment cost level	Pulp, paper and board industry	Total, incl. heating stations	Pulp, paper and board industry	Total, incl. heating stations	Pulp, paper and board industry	Total, incl. heating stations
75%	-0.04	(-0.04)	-0.36	(-1.15)	-1.72	(-6.74)
100%	0	(0)	-0.46	(-4.82)	-2.00	(-5.75)
125%	0	(0)	-0.71	(-10.93)	-2.30	(-5.36)

rises to 2 when the price is doubled. This high elasticity is the result of two kinds of substitution. One consists of the direct effects within the industry; the other comprises the effects from the increase in competition on the wood market as the use of wood fuels becomes more attractive.

The figures in parentheses in Table 2 show the own-price "pseudoelasticities" for oil when the quantity of oil replaced by wood in heating stations is included in computing the elasticities. Calculated in this way, the elasticities rise considerably.

Somewhat surprisingly, when the price of oil is doubled, this "pseudoelasticity" decreases with increasing investment costs, whereas the opposite can be observed in the case of the industry's oil consumption. This, however, is due to difficulties in paying for the wood used in heating stations as the investment cost level rises. This rise does not affect the existing industrial capacity. Thus, less wood is used as a substitute for oil when investment costs are high.

The substitution between industrial use and use in heating stations can be studied in Table 3 which shows total wood consumption and the share thereof used directly for heating purposes. The table indicates that a 200 percent increase in the oil price (ceteris paribus) decreases wood consumption in the industry by close to half. In this case, industry's consumption of oil is reduced by as much as 80 percent.

This reveals two important features of the industry's sensitivity to rising oil prices. First, the competitiveness of the pulp, paper and board industry against large-scale wood based heating stations is clearly greater than has been feared in the public debate on this issue during the past few years. This is even more evident from the effects of a 50 percent increase in the oil price.

Table 3 Total wood consumption and use of wood fuels

Electricity price %	Oil price %	Total wood consumption Mill. m^3	Consumption in industry Mill. m^3	Conifer wood used as fuel Mill. m^3	Leaf wood used as fuel Mill. m^3
100	100	12.564	12.564	0	0
100	150	13.130	11.340	1.230	0.560
100	200	14.400	6.714	6.576	1.110
200	100	13.130	10.170	2.400	0.560

This decreases industrial wood consumption by only 10 percent (see Table 3). Second, even when the "disembodied" oil-saving possibilities are excluded, there is wide scope for oil substitution in the industry.

Table 4 shows the cross-price elasticities of oil and electricity. Since all elasticities are negative, the results indicate that oil and electricity are complementary. The same conclusion was implied by simulations using an earlier version of the model where some "disembodied" energy substi-

Table 4 Cross-price elasticities between electricity and oil

Oil consumption

	Electricity price			
	50%		200%	
Oil price	Industry	(Total)	Industry	(Total)
100%	-0.05	(-0.05)	0	(0)
150%	-0.01	(-2.07)	-0.25	(-3.19)

Electricity consumption

	Oil price		
	50 %	150 %	200 %
Electricity price			
50%		-0.17	
100%	0	-0.08	-0.84
200%		-0.49	
Investment cost level			
75%	-0.01	-0.04	-0.68
100%	0	-0.08	-0.84
125%	0	-0.22	-1.06

tution possibilities within the plants, in particular changes in the internal production of electricity (where oil is required), were included (Hultkrantz, 1980).

The most noteworthy result in this table is the significant impact of electricity prices on total oil consumption. At the high (150 %) oil price the use of conifer wood as fuel is doubled (whereas the use of deciduous wood for heating purposes remains unchanged) when the price of electricity is doubled (cf Table 3).

Table 5 shows the cross-price elasticities between

Table 5 Cross-price elasticities, electricity vs. labor and investments

Electricity consumption

	Investment cost level	
Oil price	75 %	125%
50%	-0.05	-0.02
100%	-0.04	-0.02
150%	-0.01	-0.28
200%	-0.45	-0.75

Wages	
80%	120%
0	-0.075

Investments (value)

	Electricity price	
Oil price	50%	200%
100%	0	0
150%	-0.11	-0.17

Employed labor

	Electricity price	
Oil price	50%	200%
100%	-0.05	0
150%	-0.05	-0.24

electricity and labor and between electricity and investments. The figures show rather weak complementarity between electricity and the two other inputs. The impact of electricity prices on employment is shown to be considerably less than was sometimes claimed in the debate which preceded the Swedish referendum on the use of nuclear power in 1980.[1]

Table 6 Cross-price elasticities, oil vs. labor and investments

Oil consumption

Oil price	Investment cost level 75%	Investment cost level 125%
50%	-0.255	-0.033
100%	-0.163	-0.033
150%	-0.304	-0.493
200%	-1.196	-1.903

	Wages 80%	Wages 120%
	0	-0.33

Investment costs

Investment cost level	Oil price 50%	Oil price 150%	Oil price 200%
75%	-0.252	-0.326	-1.318
100%	0	-0.183	-0.773
125%	0	-0.153	-1.877

Employed labor

Investment cost level	Oil price 50%	Oil price 150%	Oil price 200%
75%	-0.041	-0.085	-0.873
100%	0	-0.281	-1.022
125%	0	-0.437	-1.039

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[1] For an extreme, but influential example, see Facht, Sjöberg and Svensson (1979).

In the same manner, the cross-price elasticities between oil and the other two inputs are shown in Table 6. Both labor and investments are strictly complementary to oil. The relative impact of rising oil prices is gradually increasing, due to the accelerating use of wood fuels. In both cases, the cross-price elasticities for a 200 percent rise in oil prices approach or exceed unity. Inversely, oil consumption is very sensitive to the investment cost level when the oil price is high.

2.2 Energy Substitution in the Three-Period Model

The simulations using the three-period model are based on a specific price scenario. During the first period, all prices are the actual 1979 prices. In the second and third periods, the output price level (the weighted sum of output prices) is approximately equal to the price level in 1979, but the price relations among different outputs correspond to long-term (average 1955-1979) price relations. The prices of electricity, oil and labor are also changed, as shown in Table 7.

Table 7 Basic price assumptions

	Per. 1	Per. 2	Per. 3
Oil (SEK/m^3)	800	900	1013
Electricity (SEK/kWh)	0.10	0.11	0.12
Labor (SEK/h)	63	66	77

The results from the basic solution can now be compared with the outcomes from four cases where the price of oil or the investment cost level in the second and third periods is changed (oil price to 1200 or 1600 SEK/m^3; investment cost level to 75 or 125 percent).

The effects of the increases in the price of oil are summarized as price elasticities in Table 8.

Table 8 Oil price elasticities

Oil consumption

	Oil price			
	150%		200%	
Period	Industry	(Total)	Industry	(Total)
2	-0.15	(-0.31)	-1.31	(-10.30)
3	-0.49	(-0.30)	-1.88	(-12.84)

Electricity consumption

	Oil price	
Period	150%	200%
2	-0.18	-0.97
3	-0.72	-1.67

Employed labor

	Oil price	
Period	150%	200%
2	-0.08	-1.27
3	-0.29	-1.74

Investment costs

	Oil price	
Period	150%	200%
2	-2.63	-1.34
3	-0.57	-4.45

The signs of these elasticities and in most cases their magnitudes are the same as the estimates from the "1984"-model. The exceptions are mainly due to the absence of substitution between plants with the same output, but with different efficiency, in the three-period model. For instance, wood fuel users have to compete with the average and not the marginal efficiency plant in the industry, so that the introduction of wood-based heating requires a somewhat higher oil price than in the "1984"-model.

The closest similarity between the second period results and the "1984"-model is found in the cases of electricity and labor. The own-price industrial oil consumption elasticities are somewhat low as compared to the results from the one-period model. On the contrary, the effects on investments are greater in the three-period model.

Generally, the elasticities increase from period 2 to period 3. Thus, after an oil price hike the use of oil, electricity, labor and investments are gradually reduced over time as the scope for adjustments grows wider. This result lends further support to the previous conclusion about complementarity between oil and the other inputs.

The results of a change in the investment cost level with respect to oil and electricity consumption are shown in Table 9. The elasticities correspond quite well to the results from the "1984"-model.

Table 9 Investment cost level elasticities

Oil consumption

	Investment cost level			
	75%		125%	
Period	Industry	(Total)	Industry	(Total)
2	-0.11	(-0.11)	-0.27	(-0.27)
3	-0.20	(-0.20)	-0.38	(-0.24)

Electricity consumption

	Investment cost level	
Period	75 %	125 %
2	-0.03	-0.26
3	-0.08	-0.55

3 OIL PRICES AND NET RETURNS FROM FOREST SECTOR PRODUCTION

A rising oil price affects the net income of the forest sector in two opposing ways. First of all, if the increased price, as in the model simulations under study, is not compensated by higher output prices, net returns decrease. Second, the opportunity cost of wood, derived from the possibility of using the wood in heating stations, increases. Hence, net income can be expected to be high when oil prices are either low or high, but low inbetween. This is confirmed by the results from the two models reported here, as shown in Table 10. Both the 1979 oil price and the 200 percent level give wood suppliers and industry owners a higher total net income than a price on the 150 percent level.

Table 10 Optimal solution values
Index

Oil price %	"1984" %	"1979-1993" %
50	116	
100	107	104
150	100	100
200	114	104

4 CONCLUSIONS

Several policy implications can be drawn from the results presented in this paper. Two of the most important conclusions are as follows.

In discussions of policy measures which may affect the price of electricity (energy taxes, restrictions on the construction of hydropower stations based on environmental considerations, etc.), reference is often made to the employment effects in manufacturing. In the case of the pulp and paper industry, which accounts for a third of total industrial electricity consumption, these effects seem to be small.

Second, free competition between heating stations which use wood as fuel and the forest industry will have only marginal effects on production in the forest industry, unless the price of oil relative to the prices of the forest industry products is raised very substantially. The introduction in Sweden of regulation concerning the use of wood fuels in large-scale heating was obviously based on misleading informaton in this regard.

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PART III

ENERGY IN THE FUTURE

Energy in Swedish Manufacturing 1980–2000

A Simulation Study of the Impact of Energy Prices and Capital Structure on Energy Use in Swedish Industry

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Contents

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Energy Prices and Industrial Development

The experience of the 70s demonstrated the importance of energy prices for industrial development. More particularly it focused attention on two major reasons for looking well ahead in matters of energy policy.

One such reason is the inherent uncertainty and instability of the international oil markets. Whatever the fundamental causes of the drawn-out stagflation in the 70s, the two oil price hikes certainly had a decisive importance by triggering off spirals of price increases and severely affecting the external balances of small open economies like the Swedish.[1] The experience of the 70s also provided many instances of the political and economic difficulties of adjusting open economies to major shifts in the world markets and the consequent need to provide "hedges" against the risk of repeated upheavals in the coming decades. We have elsewhere tried to deal with this stability aspect of Swedish energy policy by exploring various means — including that of oil taxation — of "insuring" energy supply and price stability, using for these policy analyses a dynamic macro-model for the Swedish economy (Nordström-Ysander, 1983).

Our aim in this paper is to provide a starting point for the study of the second kind of long-term policy problem, which has to do with the drawn-out industrial adjustment to a new energy price structure.

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1 For a more extensive discussion of the relation between oil price hikes and the stagflation syndrome, cf. Eliasson-Sharefkin-Ysander (1983b).

The oil price hikes and their repercussions on other energy prices meant i.a. that a great part of industry was left with a built-in technology that was ill-adjusted to the new level and structure of energy prices. By reducing the quasi-rent earned and thus the economic value of older, less energy-efficient plants, the oil price hikes "eroded" or "exploded" part of the "capital stock" of industry.[1] The added costs of higher energy prices were thus translated into major, although hard to measure, "capital losses" for industry. These losses can by definition only be replaced by a technical change of capital equipment embodied through successive investments. This part of the adjustment to new relative prices is therefore a long-term proposition, which will in most cases continue into the next century, even without new changes in relative energy prices.

These adjustment needs are further compounded by long-term shifts in domestic energy supply schedules, due to decisions already made in Swedish energy policy. A heavily subsidized development of domestic fuels and other "alternative" energy resources and an almost complete veto against further expansion of Swedish hydro-power are two such instances. Of even greater importance is the decision taken some years ago not to replace the nuclear plants, which means that an electricity glut in the 80s may be replaced by a growing scarcity in the 90s.

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[1] These dramatic formulations are really based on some elementary facts about the way economic aggregates are formed. What we call the "capital stock" is simply an aggregate measure of miscellaneous production means weighted with their economic values. For a stringent discussion of this measurement problem, cf. Berndt-Wood (1983).

Even with a surprise-free future there are thus needs for long-term adjustment and reasons for looking well ahead in planning energy policy. To the direct effect on energy demand of industrial capital adjustment will successively be added the effect of a restructuring of the manufacturing sector due to world market trends including the shifts in energy price levels. To discern future trends in industrial energy demand one must therefore study the dynamics of industrial investment and growth not only with regard to specific energy use but also for tracing the changing branch composition.

This we have in the following tried to do by simulations on a dynamic macro-model for the Swedish economy, incorporating a vintage approach to industrial capital and a relatively detailed description of the different mechanisms for energy substitution. Many of these mechanisms have been modeled using the estimates for price elasticities derived by Dargay (1983b) and Jansson (1983) and reported in the preceding chapters in this volume. The model which differentiates between 26 types of "energy consumers" — 14 manufacturing branches, 9 other industrial sectors, households and central and local governments, respectively — has been documented elsewhere (Jansson-Nordström-Ysander, 1982) and has also been used earlier for studies of energy policy (Nordström-Ysander, 1983).

While referring to this documentation, we shall here merely summarize the main assumptions for the reference case used in the following simulations. Some aspects of the energy substitution mechanisms in the model will, however, be touched on later in discussing the simulation results.

Table 1 Assumptions for the eighties and nineties
Reference case

World trade development

	Annual increase, %			
	1980/1990		1990/2000	
	Volume	Price[a]	Volume	Price[a]
Raw materials and semifinished goods[b]	2.3	5.5	2.6	4.1
Finished goods	5.7	6.4	5.0	6.0
Services	4.5	7.0	5.0	6.0

[a] In international currency.

[b] Includes the following branches: agriculture, forestry and fishing; mining and quarrying; manufacture of wood products, pulp and paper; basic metal industries.

Labor supply development

	Annual increase, %	
	1980/1990	1990/2000
Number of persons[a]	32.3	14.2
Number of persons[b]	0.7	0.3
Hours worked per employee[b]	-1.0	-0.2
Labor supply, number of hours[b]	-0.3	0.1

[a] Yearly change in thousands of persons.

[b] Yearly percentage growth.

We assume that the rate of increase in the volume of international trade will be stable but somewhat lower than in previous postwar decades. For raw materials and semi-finished goods this will mean an annual rate of increase of 2.3 and 2.6 percent, respectively, during the 80s and 90s, while the trading in finished goods is supposed to increase annually 5.7 and 5.0 percent, respectively, and that of services 4.5 and 5.0 percent. A stagnating supply of labor is expected in the next two decades.

A model simulation also requires a number of policy variables to be given exogenously in order to reach announced targets of economic policy.

We have employed three main policy instruments: wage policy, income tax and public consumption. These instruments are used to determine the rate of unemployment, the balance of payment and the growth rate of public consumption.

The policies adopted in the reference case have had the following main targets. The current balance of payment deficit should be eliminated by 1990 and stay close to zero for the rest of the period. Unemployment should be kept around what is considered a "normal" rate of frictional unemployment — 2 percent of the labor force. The assumed strategy for public consumption has been to let it grow at a slightly faster rate than private consumption during the 80s but evening out the accounts in the 90s, thus attaining on the average a roughly proportionate increase over the two decades of public and private consumption.

Table 2 shows the simulated development of the economy in the reference case. The need to restore the external balance before 1990 is reflected in the gap between the growth of exports and imports during the 80s with repercussions primarily on private consumption growth. In the 90s a faster consumption growth compensates for the meager previous decade.

Table 2 Real GDP by expenditure 1980-2000
Reference case

	Annual increase, %	
	1980/1990	1990/2000
Consumption	1.3	2.4
Investments[a]	1.8	2.1
Exports	4.6	3.8
Imports	2.9	4.3
GDP	2.1	2.3

[a] Including changes in stocks.

The Future Supply of Energy

Primary fuels from domestic (wood, peat) and foreign (oil, coal) sources are assumed to be supplied in any quantity at given prices. The assumed price development for primary fuels in the reference case is given in Table 3. Oil prices are assumed to increase by 8% per year throughout the simulation period. This implies, that the real price of oil is assumed to grow by 1.5% per year during the eighties and some half percentage point faster during the nineties relative to the world market price for finished goods. Coal prices are assumed to be proportional or follow oil prices.

Table 3 Prices of primary fuels
Reference case

	Growth rate, %	
	1980/1990	1990/2000
Oil	8.0	8.0
Coal	8.9	8.0
Domestic fuels	6.0	5.0
CPI	6.2	6.5
GDP-deflator	6.7	7.2
World market price for finished goods	6.4	6.0

The difference in the rate of price increase during the 80s shown in Table 3 simply reflects the way the coal price after a certain time lag "catches up" with the oil price hike in 1978/80. This "catching up" is assumed to take place during the first years of the 80s. Prices for domestic primary fuels grow with costs in the forestry branch. Some allowance is made for improvements in the extraction technology, assuming a slight increase in productivity growth during the 90s. The price of domestic fuels relative to oil is therefore decreasing at an accelerating rate — from minus 2% per year during the first half of the period to minus 3% per year during the second half.

Since assumptions about future oil prices might be of key importance for the simulation we have throughout used for comparison an "alternative case" where the real price of oil is kept constant up till the turn of the century.

Turning to the supply of electricity and distant heating we noted already above the political restrictions imposed on the use of nuclear and hydro power in Sweden. Total gross production of nuclear and hydro power (i.e., including internal use in the power stations) is assumed to increase by almost 4 TWh per year during the 80s and then to decline at approximately the same rate from 1995 due to the gradual closing of nuclear power stations. Adding further exogenous assumptions on industrial production of backpressure power, wind power development, possible combined production of electricity and distant heating, etc., the production system shown in Figure 1 emerges. Although the assumptions made and the resulting supply structure may well be disputed, it seems necessary to account for the rather strong shifts imposed on the electricity-distant heating production system during the simulation period by political decisions. This will have strong implications i.a. on the use of fuels — domestic and imported.

As shown in Figure 1 production of electricity is assumed to increase fast during the 80s with the nuclear power still building up. Although direct use of electricity for heating purposes will also increase, there will still be capacity left to replace fuels in the distant heating system. However, when demand for electricity catches up with the stagnating production in the 90s, the use of electric power to boil water for distant heating will have to end.

The assumed decrease of fuel input in the distant heating system in the 80s may very well be reversed in the 90s. The same holds for the fuel input in electric power production. Part of the gradually reduced nuclear capacity may have to be replaced by condensed steam or combined power

Figure 1 Production of electricity and distant heating
Reference case

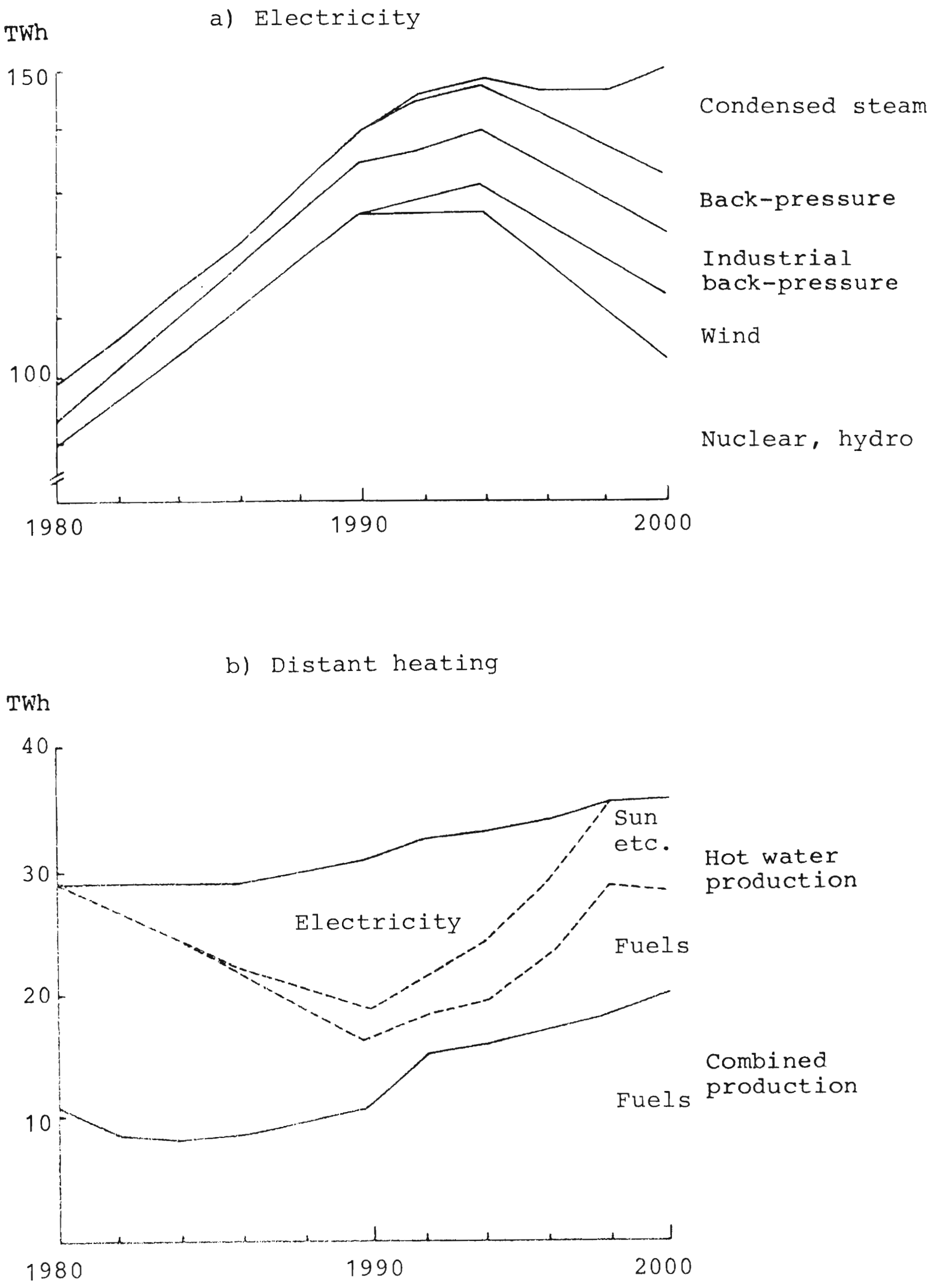
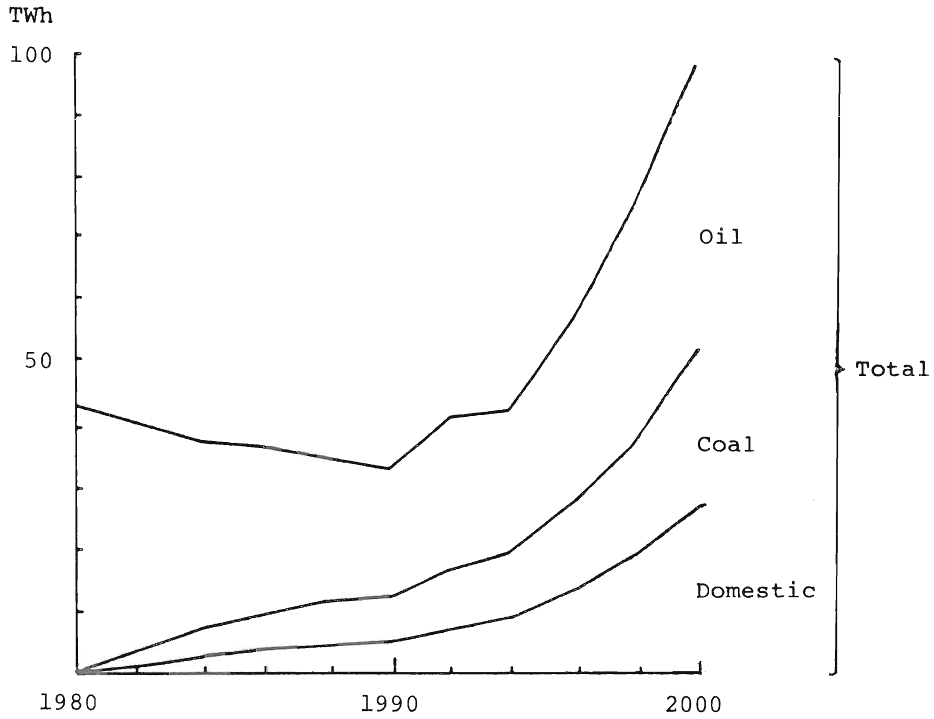


Figure 2 Use of fuel in the electric power/ distant heating production system Reference case

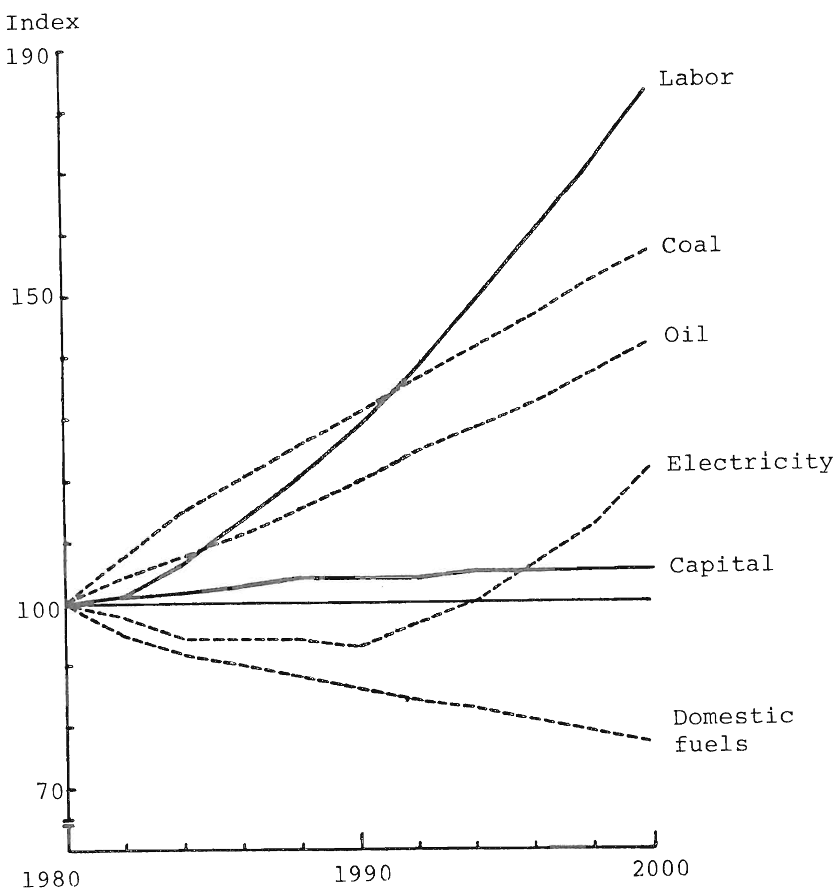


plants using domestic or imported fuels. The reference case development of fuel use in electric power/distant heating production is summed up in Figure 2. With the assumptions made, the figures show a very fast increase in fuel input and even a slight increase in the use of oil towards the end of the 90s. Increased use of imported fuels with rising relative prices will make the real price of electricity and distant heating rise in the 90s. This will slow down demand growth but — according to the model — not enough to prevent large increase in the use of fossil fuels in power plants.

Changing Factor Prices and Factor Mix

The changing structure of factor prices that emerges in the reference case is shown in Figure 3. Relative labor costs continue to rise annually on the average with 2.5% during the 80s and with 3.6% in the 90s, while user cost of capital stays almost constant. The oil and coal prices climb slowly but steadily as assumed, while productivity gains are reflected in an equally steady decline

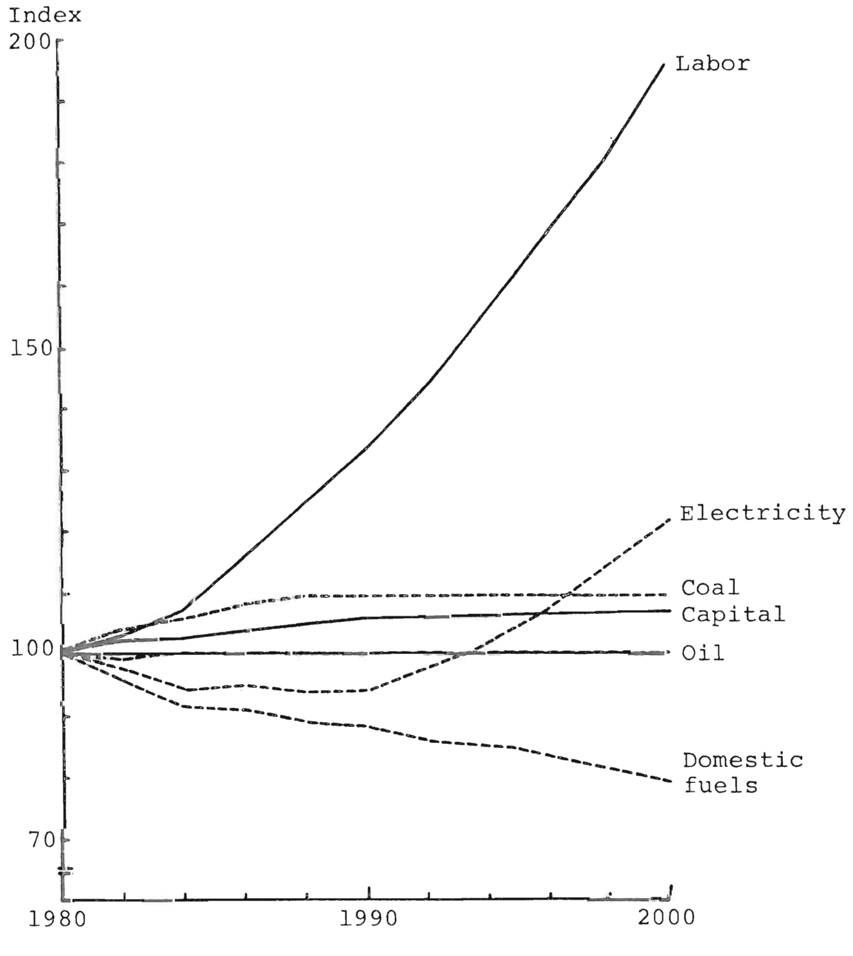
Figure 3 Relative factor prices in manufacturing, 1980-2000. Reference case.
Producer price = 100



of the cost or domestic fuels. The electricity glut in the 80s causes the price to dip in the 80s but electricity costs then rises fast during the following decade.

Figure 4 demonstrates that keeping the relative oil price constant — the alternative case — affects factor prices other than the coal price only marginally.

Figure 4 **Relative factor prices in manufacturing, 1980–2000. Alternative case**
Producer price = 100. Constant real oil price



Changing factor prices affect the factor use in manufacturing in three main ways in the model. Firstly, by changing the relative profitability — and plant utilization — of the different branches, it influences the relative rate of scrapping and investing and thus the branch composition with structural effects on the use of the various production factors. Secondly, for each vintage of investment in each branch, it determines the choice of technology, i.e., the cost-minimizing factor mix of new plants. This technological decision is modeled in terms of five types of factors: labor, capital, fuels, electricity and intermediate goods. Lastly, changes in the relative prices for different fuels will give rise to ex post substitution between different fuels within plants of all vintages.

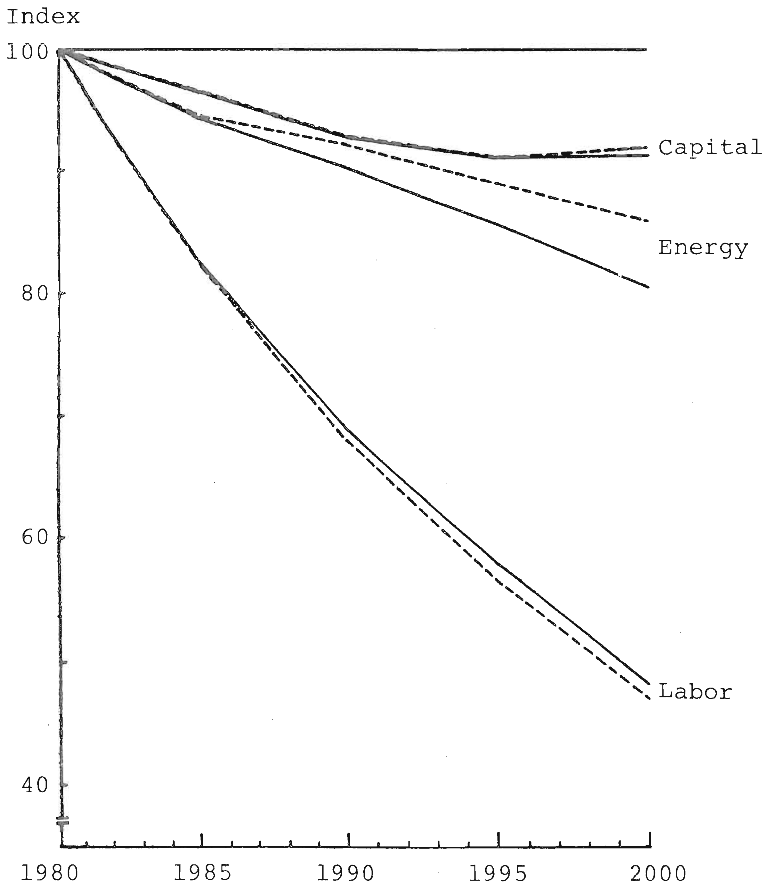
Let us begin by looking at the change in specific use of capital, labor and energy in manufacturing, as depicted in Figure 5. We see, both in the reference case and in the alternative case, a continuing mechanization which is far more labor-saving than energy-saving. However, if we compare this with the corresponding developments during the first three postwar decades (see Dargay, 1983a, in this volume) there are still noticeable differences. Since the capital-labor price relation developed even more favorably in earlier decades, the increase in capital-labor ratio was then faster. The lower relative level of energy prices then meant less interest in energy saving and an almost parallel development of the specific use of capital and energy, up to the time of the oil price hikes. For the coming decades the ongoing adjustment to higher energy prices will be reflected — according to the simulation results —

Figure 5 **Input coefficients in manufacturing, 1980-2000**

Index 1980 = 100; constant 1980 prices

—— = Reference case

---- = Alternative case



Capital: Capital stock/Production

Energy: KWh electricity, petroleum products and solid fuels/Production

Labor: Hours worked/Production

in a faster decrease of specific energy use relative to the use of capital. This is also true, although to a much smaller extent, in the alternative case with approximately constant relative oil prices.

Substitution between Energy Inputs

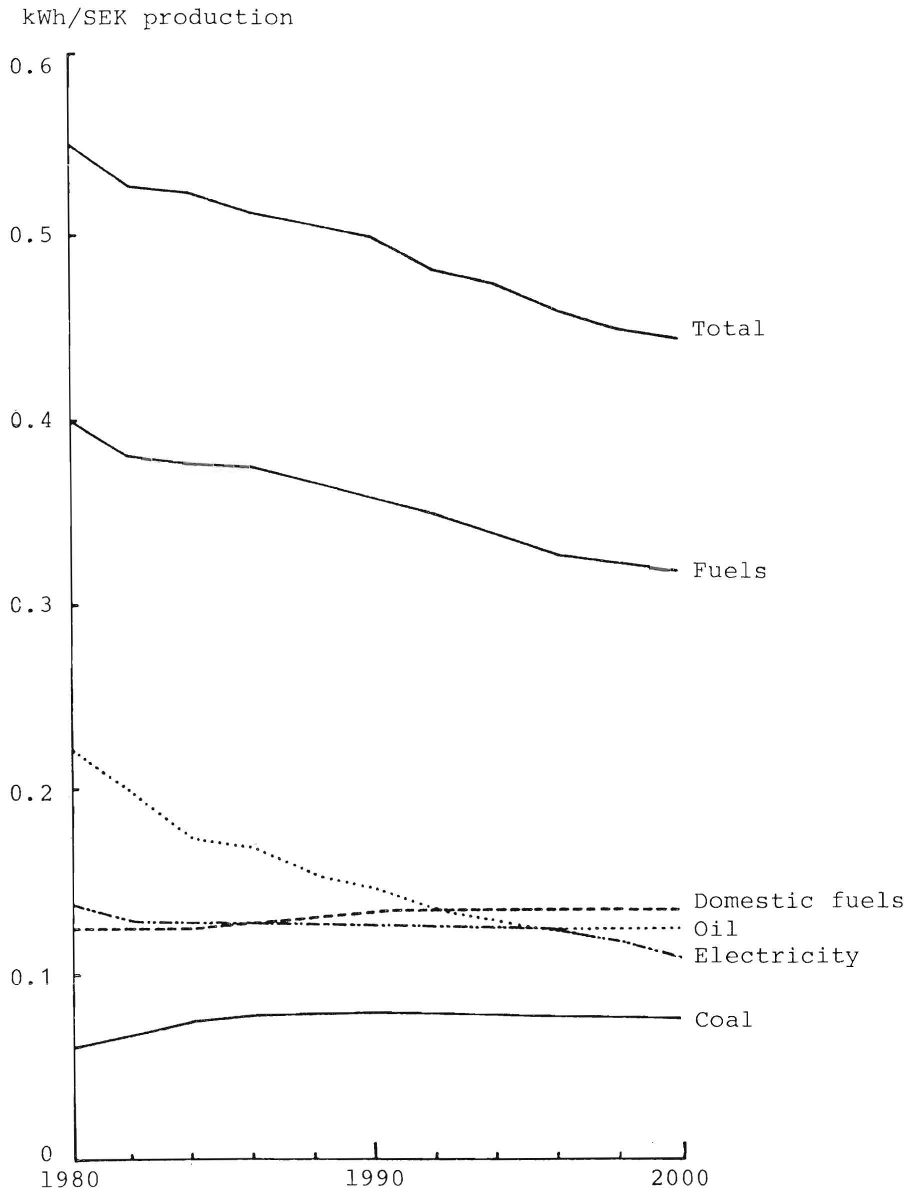
The changing price structure will not only affect the use of energy in manufacturing but also the choice between different forms of primary energy. As already noted above, such substitution within the sector is determined in the model by three mechanisms: the vintage or investment effect, the ex ante substitution between aggregate inputs due to choice of technology and finally the ex post substitution between fuels.

Before reporting the simulation results we should however note that there are deficiencies in the econometric estimates on which our modeling of the two first mechanisms are based. This probably implies that our results concerning the future possibilities of saving energy are biased in a downward direction, i.e., are too low.

The main problem with the original estimates (cf. Dargay, 1983b) is that they are based on data which are too aggregate in several respect. Aggregating machinery and buildings probably means, e.g., that you tend to underestimate that part of medium-term possibilities of energy substitution, which depend on investment in machinery and equipment. Of even greater importance is the fact that the estimates concern observed substitution within total branch capacity, instead of just measuring changes in the marginal or new capacity. Using the estimates as a description of the ex ante technological choice in a vintage model then means introducing two kinds of biases. The estimated energy price elasticities will throughout be too low. We have however tried to correct for this by a scaling-up procedure. Secondly, treating today's average input coefficients as technically optimal for new plants will certainly mean underestimating future factor productivity in general and energy-efficiency in particular. We have used other data to correct for this in respect to labor productivity but we have not had access to the kind of blueprint technological data needed to make similar corrections for energy and capital. This means that all our projections will tend to underestimate the level of future energy savings in manufacturing. The importance of this bias can be illustrated by noting that if you had used instead the ad hoc assumption that today's marginal input coefficient is only 60% of the average, the average coefficient at the turn of the century would have decreased about 50% more than in the reference case reported here.

Let us with these reservations in mind look at the simulation results as illustrated in Figures 6-8. Figure 6 shows the development of energy input coefficients in the reference case. We see that the decrease of the total energy coefficient is mainly due to fuel saving while the electricity coefficient remains relatively stable up to the middle of the 90s. The sharp rise in electricity prices from then on means however that electricity use — and related to that productivity gains in capital use — will decline somewhat. This in turn will to some extent be compensated by use of oil, putting an end to the decline in specific oil usage.

Figure 6 Energy coefficients in manufacturing 1980-2000
Reference case
KWh/SEK production; constant 1980 prices



As for substitution between different fuels we see that only a smaller part of the overall saving in oil use will be compensated for by increased use of coal and domestic fuels. There will not be any major technological switch towards coal.

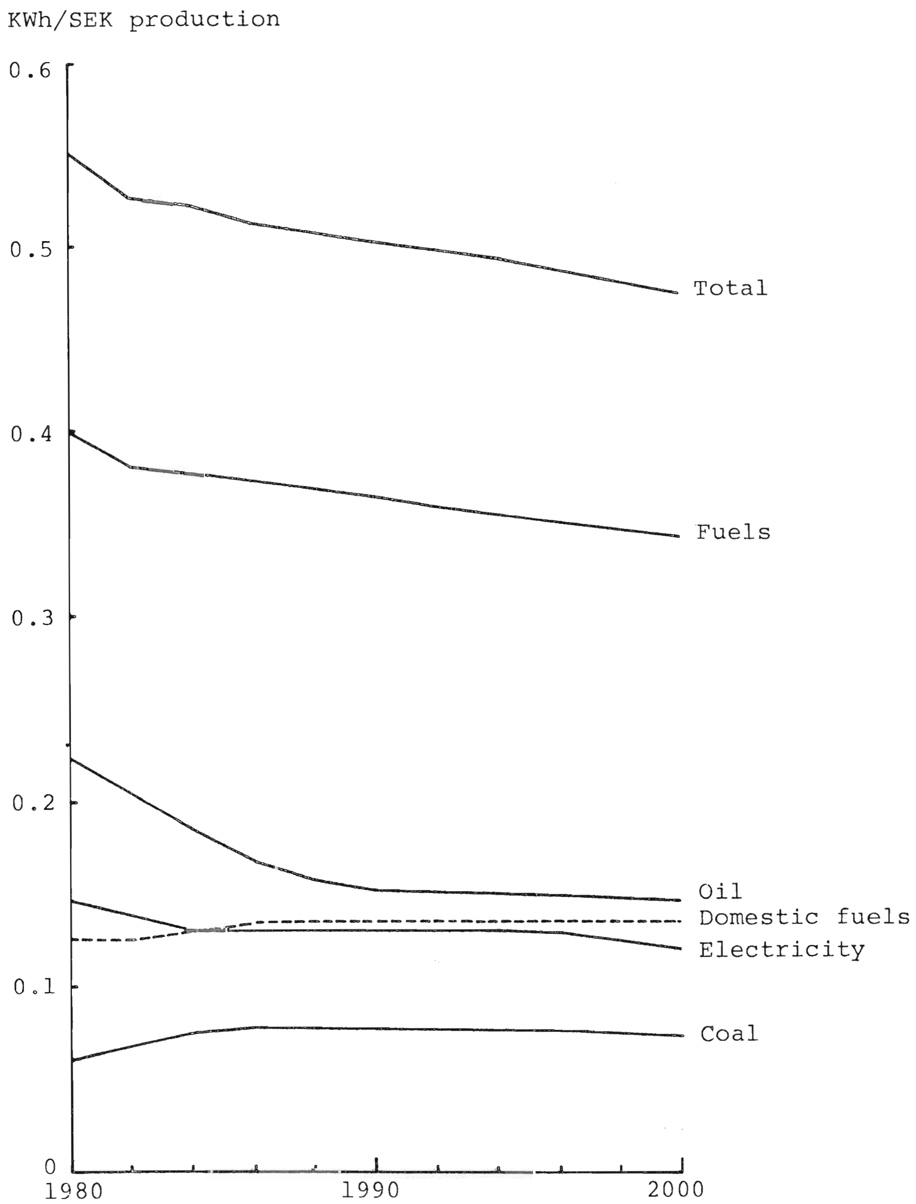
From Figure 7 we learn that a complete stagnant oil price, as in the alternative case, will not only break the decrease in oil usage but will also somewhat modify the decline in electricity use foreseen in the reference case. Apart from this the overall picture of energy usage, will not be markedly affected.

If we multiply the energy coefficients with the projected growth of production in the manufacturing sector we get the development of total use of energy as depicted in Figure 8. The figure reminds us of the fact that total oil saving within manufacturing will be rather moderate despite the sharp decline in oil coefficient. The use of fuels will increase about a quarter while electricity use at the turn of the century will be more than a third larger than today in spite of the high relative price of electricity.

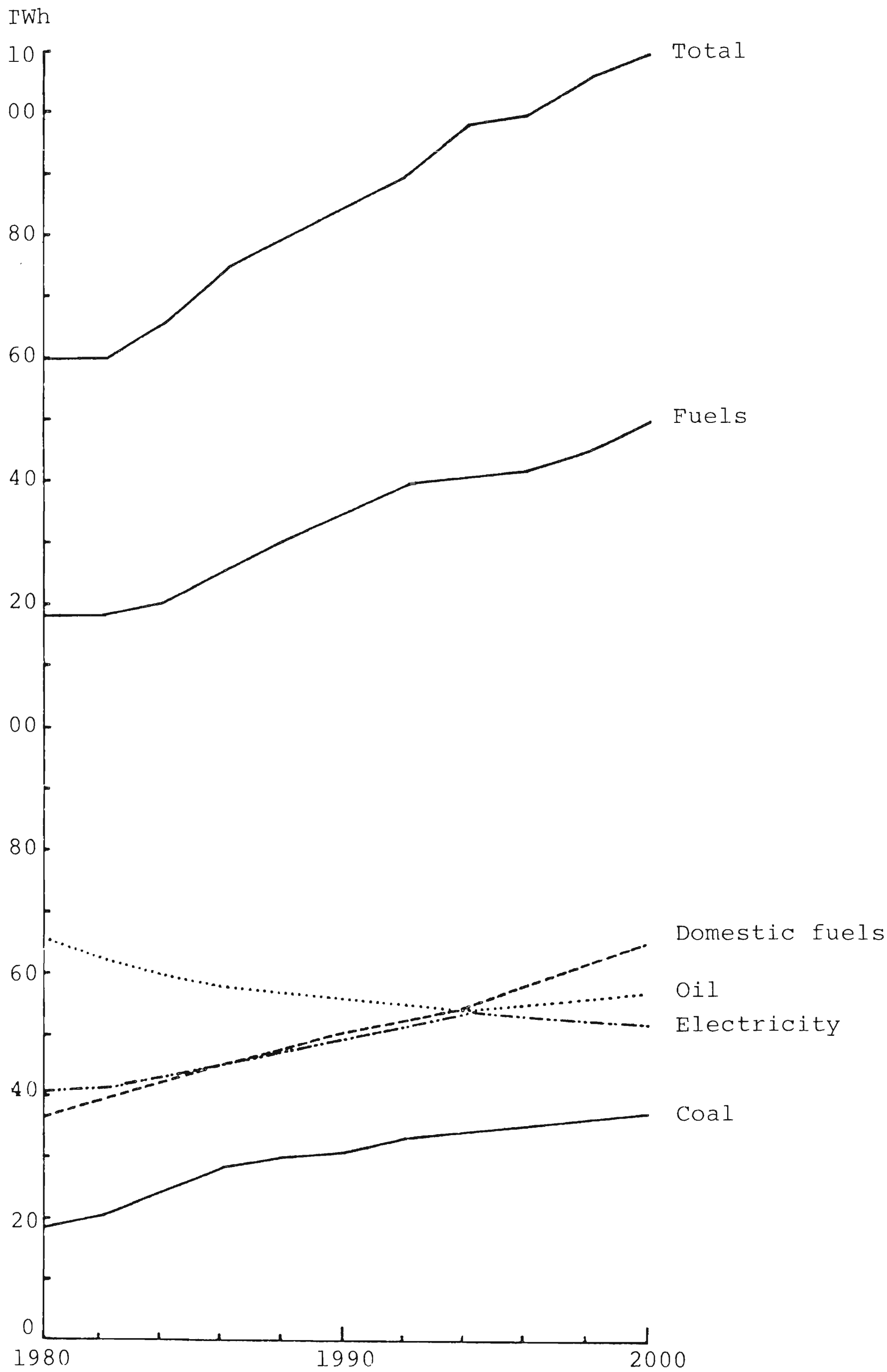
Structural Change and Energy Use

Our discussion so far has dealt with the aggregate manufacturing sector. Part of the total change in energy use during the period studied is however simply due to a changing branch structure within manufacturing. For interpreting and understanding the projected energy substitutions it is vital to separate the structural effect from the change within branches. It should however be noted that

Figure 7 Energy coefficients in manufacturing 1980-2000
Alternative case
Constant real oil prices



igure 8 Energy use in manufacturing 1980–2000
Reference case

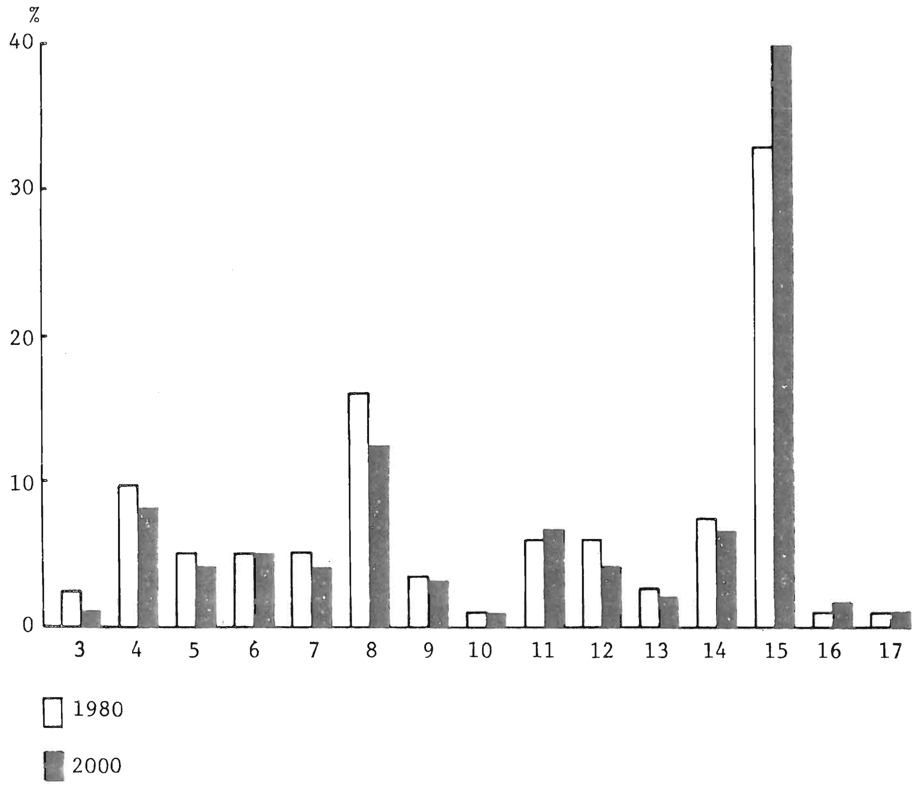


these two factors affecting total energy use are not independent of each other. Large possibilities of energy saving within a certain branch will affect its overall profitability and by that also its rate of capacity expansion. A fast expansion will in turn make possible a rapid exploitation of the saving potential which will be reflected in the change of the average energy coefficients for the branch.

The projected change of branch structure within the manufacturing sector is described in Figure 9. Among the big "losers" are those basic industries, which are also energy-intensive like mining, pulp and paper, and iron and steel. In these cases rising energy costs are of course only one marginal factor adding to the dominant effects of changing international market conditions and of domestic restrictions on raw materials. A continued decrease in production shares is also registered for food and textiles. On the "winning" side is first and foremost the engineering industry but also an energy-intensive branch like chemicals will have an increased share of production.

How these structural changes affect aggregate energy use is shown in Table 4. For each form of energy the change of total use in manufacturing during the projection period is recounted as the change in production volume multiplied first by the change in energy coefficients (structure being held constant) and then by the change in energy use structure (energy coefficients being kept constant). Depending on whether we use a Laspeyre or Paasche kind of index, we get the results with or without brackets in Table 4.

Figure 9 Branch shares (%) of gross production of manufacturing 1980 and 2000 Reference case



3. Mining and quarrying
4. Manufacture of food (sheltered)
5. Ditto (exposed)
6. Manufacture of beverages and tobacco
7. Textile, wearing apparel
8. Manufacture of wood, pulp and paper
9. Printing and publishing industries
10. Manufacture of rubber products
11. Manufacture of non-metallic and other chemicals, and plastic products
12. Petroleum and coal refineries
13. Manufacture of non-metallic products (except products of petroleum and coal)
14. Basic metal industries
15. Manufacture of fabricated metal products, machinery and equipment, excl. shipbuilding
16. Shipbuilding
17. Other manufacturing industries

Table 4 Factors determining change of energy use in manufacturing, 1980-2000

	Relative change 2000/1980 in:			
	total production volume •	specific energy usage[a] •	use structure[b] =	energy use
Oil	1.65	0.52 (0.56)	0.93 (0.85)	0.79
Coal	1.65	1.46 (1.54)	0.86 (0.81)	2.07
Domestic fuel	1.65	1.29 (1.23)	0.83 (0.88)	1.77
Total fuel	1.65	0.90 (0.91)	0.87 (0.85)	1.29
Electricity	1.65	0.92 (0.92)	0.91 (0.90)	1.38
Total energy	1.65	0.90 (0.91)	0.88 (0.87)	1.31

[a] Weighted average of specific energy usage with 1980 production shares as weights. The result of using instead production shares for 2000 is shown in brackets.

[b] Weighted average of production shares with specific energy usage in 2000 as weights. The result of using instead specific energy usage in 1980 is shown in brackets.

Note

The construction of Table 4 can be explained by a simple formula.

Let us use the following symbols.

E_j^t = Energy use (TWh) in manufacturing branch j at time t. (t=1 denotes 1980 and t=2 stands for 2000)

$$E^t = \sum_j E_j^t$$

Note to Table 4, cont.

V_j^t = Production volume (1980 prices) in manufacturing branch j at time t.

$$V^t = \sum_j V_j^t$$

$$e_j^t = \frac{E_j^t}{V_j^t} = \text{Specific energy usage.}$$

$$v_j^t = \frac{V_j^t}{V^t} = \text{Production share.}$$

From this definition it follows that:

$$\frac{E^2}{E^1} = \frac{V^2}{V^1} \frac{\sum_j v_j^2 e_j^2}{\sum_j v_j^1 e_j^1} =$$

$$= \frac{V^2}{V^1} \cdot \frac{\sum_j v_j^1 e_j^2}{\sum_j v_j^1 e_j^1} \cdot \frac{\sum_j v_j^2 e_j^2}{\sum_j v_j^1 e_j^2} = \qquad (1)$$

$$= \frac{V^2}{V^1} \cdot \frac{\sum_j v_j^2 e_j^2}{\sum_j v_j^2 e_j^1} \cdot \frac{\sum_j v_j^2 e_j^1}{\sum_j v_j^1 e_j^1} \qquad (2)$$

The figures without brackets in the first three columns in the table represent the three consecutive terms in (1), while figures for the corresponding but different terms in (2) are given in brackets. The first term measures the change in production volume. The second represents the change in specific energy usage, employing as weights the production shares for the year 1980 (1) or 2000 (2). The third term shows the change in "use structure", computed by averaging the production shares using as weights the specific energy usage in the year 2000 (1) or 1980 (2). The fourth column finally, shows the product of the figures in the preceding three columns, measuring the change in energy use.

We see that for total energy the structural effect is of the same magnitude as the change in specific energy usage. The same is true for total fuels and for electricity. We find however, not surprisingly, that the change in specific usage varies between the fuels both as to sign and magnitude. While specific usage is halved in the case of oil it increases almost half a time for coal and some thirty percent for domestic fuels. Counted for the whole fuel group these divergencies, however, tend largely to cancel out, leaving only a ten percent reduction in specific usage for total fuels or about the same as the concomitant structural change.

One way of summarizing these findings would be to note that half the total energy savings up to the turn of the century would be realized even if the average energy-efficiency remained unchanged within each manufacturing branch.

The Vintage Effect

To gain a better understanding of the energy substitution process on a more "micro" level, one should go also below the branch structure and look at the development of energy use for succeeding vintages within a branch.

We will here illustrate the substitution embodied in capacity renewal and expansion by looking, for the year 2000, at the energy coefficients for the different vintages of an energy intensive branch — the wood, pulp and paper industry.

As shown in Figure 10 the renewal of this industry is not expected to proceed very rapidly. About a third of the operative capacity in the year 2000 will have been built before 1980. For this industry, as for most of others, we unfortunately lack data on the initial vintage distribution. This has forced us to let the initial marginal energy coefficients be equal to the average, introducing an upward bias in the estimates of future energy use.

For the successive new vintages Figure 10 however shows a relatively rapid decrease in the coefficients for both fuels and electricity. If we should disaggregate the vintages further into the low energy wood industry and the energy-intensive pulp and paper industry, one would suspect the decrease in energy coefficients to be even faster for the pulp and paper part. With the sharply increasing electricity prices in the 90s there is also a tendency reflected in the figure to substitute fuels consuming processes for electricity consuming processes.

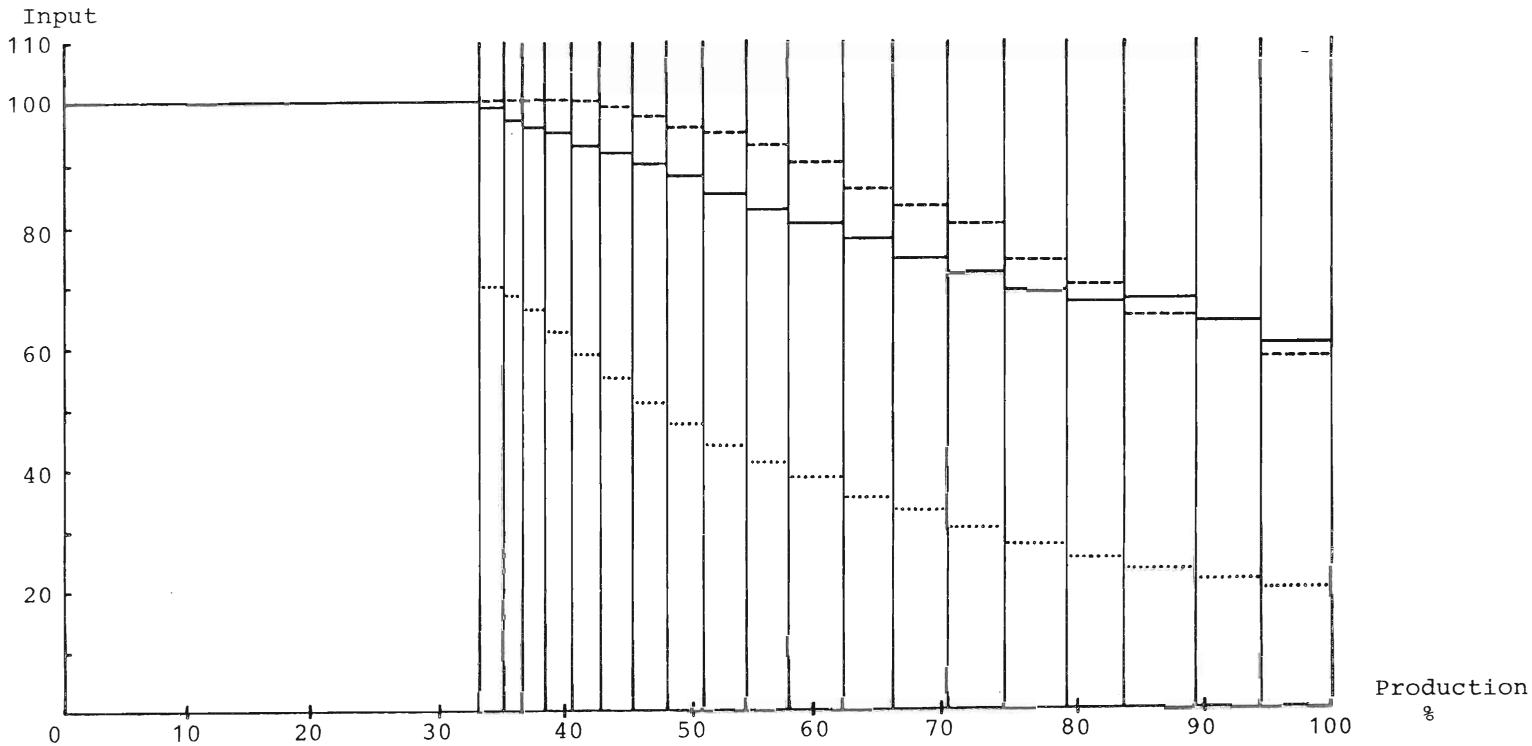
Summing Up

Telling the story of energy use in Swedish manufacturing over the next two decades means tracing the interwoven paths of structural adjustment and energy substitution. The structural change emerges from our study as a strategic factor in determining future energy use in two ways. First, half the total saving both of fuels and of electricity was seen to stem from the change of branch structure. Second, the rate of industrial renewal and expansion will to a great extent determine the amount of potential energy savings that can be realized before the turn of the century.

Figure 10 Inputs of labor, electricity and fuels per unit output for different vintages in the pulp and paper industry in 2000. Reference case

1980 average = 100

.... Labor --- Electricity —— Fuels



The closing down of nuclear reactors beginning in the 90s, will mean higher electricity prices, and can be expected to cause a certain slow down both of mechanization and electrification and of oil savings in manufacturing.

The continued decrease of oil use was mainly realized by saving fuels and was only to a minor extent due to substitution between fuels. The specific usage of coal in manufacturing was thus not projected to increase further during the 90s.

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