A list of Working Papers on
the last pages

No. 98

TECHNICAL PROGRESS AND STRUCTURAL CHANGE IN THE SWEDISH CEMENT INDUSTRY 1955-1979

by

Finn R. Førsund and Lennart Hjalmarsson

June 1983

First draft August 1980
Revised draft January 1982
" " August 1982

TECHNICAL PROGRESS AND STRUCTURAL CHANGE IN THE SWEDISH CEMENT INDUSTRY 1955-1979

by

Finn R. Førsund, University of Oslo, Oslo, Norway

and

Lennart Hjalmarsson, University of Gothenburg, Gothenburg, Sweden

Paper presented at the Econometric Society World Meeting in Aix-en-Provence, September 1980.

We wish to thank G. Svahn and K.G. Fredenberg at Cementa AB for valuable assistance with data and H.J. Bakke for valuable programming assistance.

Financial support from the Swedish Council for Social Science Research and the Industrial Institute for Economic and Social Research is gratefully acknowledged.

Summary

The purpose of this article is to provide a deeper empirical insight into the structural change of an industry which is more relevant than that obtained by an analysis based on the traditionally estimated average production function. The main contribution is a long run analysis of technical progress and structural change by means of the short-run industry production function introduced by Johansen [13], and based on micro data for individual production units. For that purpose we have developed Johansens approach into an operational framework for discrete capacity distributions including a special algorithm for the computation of the short-run industry production function.

Adress of authors: Finn R. Førsund
Institute of Economics, University of Oslo
Box 1095, Blindern
OSLO 3, Norway

and Lennart Hjalmarsson
Department of Economics, University of Gothenburg
Box 3091
S-400 10 GOTHENBURG, Sweden

1. INTRODUCTION

In recent years production theory has developed in a more realistic direction with greater emphasis on the choice of technology for new capacity and the structure of the existing capacity of an industry consisting of a number of micro units (see e.g. Salter [16], Johansen [13] and W. Hildenbrand [12]. Studies of *frontier* and *short-run industry* production functions based on data for micro units have, to some extent, replaced the traditional *average* production function estimations usually carried out on highly aggregated data.

The traditional assumptions in production theory of smooth (costless) substitution possibilities and choice of scale make it difficult to comprehend the structural development of several important industries characterized by quite limited substitution possibilities after the time of investment. The crucial difference between substitution possibilities before and after the actual construction of plants is most clearly captured by the vintage (putty-clay) approach assuming smooth substitution possibilities *ex ante* and fixed coefficients for current inputs and capacity determined by the initial investment *ex post*. The integration of these properties into a formal framework of production theory is found in Johansen [13]. Within this framework it is necessary, at the micro level (the unit of production), to distinguish between the production possibilities existing before the time of investment - the *ex ante production function* - and those existing after the investment - the *ex post production function*. Aggregating the ex post functions of the micro units, at a certain point of time, yields the *short-run industry production function*.

The purpose of this article is to provide a deeper empirical insight into the structural change of an industry which is more relevant than that obtained by an analysis based on the traditionally estimated average production function. The main contribution is a long run analysis of technical progress and structural change by means of the short-run industry production function and it represents a further development and extension of an approach first used in Førsund & Hjalmarsson [7] and Førsund et.al [5]. For that purpose we have developed Johansen's approach into an operational framework for discrete capacity distributions including a special algorithm for the computation of the short-run industry production function.

Considering now an industry consisting of a certain number of micro units, the short-run industry production function is established by maximizing output for given levels of current inputs. Thus, it corresponds to the basic definition of a production function when the industry is regarded as *one* production unit as opposed to the traditionally estimated function for an industry. The latter approach is based on the notion of the representative firm, i.e. it is assumed that *all* micro units have the same underlying production technology, except for a random error term, when estimating an average industry function. In contrast, the short-run function explicitly recognizes that the technology of the individual micro units differs, and utilizes all these technologies when establishing, by explicit optimization, the relationships between the aggregate industry output and inputs. Thus in a putty-clay world the short-run function is the true function for the *industry* as a whole. Due to the unique relationship between actual technologies and the short-run function the latter and its derived relationships provide us with a well-defined concept of industrial structure.

The connection between a series of short-run industry production functions over time goes through the ex ante production functions. The ex ante function can be regarded as a choice of technique function for the construction of an *individual* unit. The short-run industry production function reflects both the history of ex ante functions over time and the actual choices made from these ex ante functions. Production at any point of time must be compatible with the short-run function.

In order to develop a comprehensive long run analysis of technical progress and structural change information about both the short-run function and the ex ante micro function is required. The ex ante function can be derived from engineering knowledge, or estimated as a frontier production function (see e.g. Eide [2] and Førsund & Hjalmarsson [8] respectively). In the latter case the requirement for information about technical relationships are much higher than for the short-run function and we have not been able to perform such a complete analysis in connection with the present study.

However, since a study of the dynamics of the production of a sector requires a study of how the short-run production function changes over time (Johansen [13, p. 26]), establishing a time series of short-run functions will provide valuable information on the long-run structural development of an industry, even though the underlying ex ante micro function is not completely revealed.

In particular the following three aspects of technical change can be studied empirically on the basis of a succession of short-run production functions:

i) factor bias, i.e. shift of the substitution region,

ii) productivity change, i.e. shift of the isoquants towards the origin,

iii) changes in the shape of the isoquants, i.e. change in substitution properties.

To further elucidate the process of technical advance we have generalized, inspired by Farrell, Salter's measure of technical advance for this type of production function. See Førsund & Hjalmarsson [6] and [9] and Salter [16, chap. 3].

In this article we have applied the short-run function approach to an empirical analysis of technical progress and structural change in the Swedish cement industry during a twenty five year period, i.e. 1955-1979. Due to the rising fuel prices in the 1970s, the cement industry has drawn a great deal of attention as a very fuel intensive consumer, see e.g. [18]. The analysis is based on micro data for individual kilns. The technology of the cement industry has previously been investigated in the economic literature. However, these studies were mainly concentrated on economies of scale in cement production yielding estimates of minimum efficient scale at the *plant* level on the basis of engineering information, or statistical data from plants in operation. See e.g. McBride [14] and Norman [15]. Thus, these studies provide some insight about the scale properties of the *ex ante* production function for cement plants.

2. THE CONSTRUCTION OF THE SHORT-RUN INDUSTRY PRODUCTION FUNCTION

When establishing a production unit on the basis of an ex ante production function the full capacity values $\bar{x}$, $\bar{v}_j$ $(j = 1,\ldots,n)$ of output x, and the current inputs v_j, $(j = 1,\ldots,n)$ respectively are determined. The ex post function at the micro level, following Johansen [13], a limimitational law is assumed to hold:

$$(1) \qquad x = \text{Min}\left[\frac{v_1}{\xi_1},\ldots,\frac{v_n}{\xi_n},\bar{x}\right]$$

where the input coefficients $\xi_j = \frac{\bar{v}_j}{\bar{x}}$ $(j = 1,\ldots,n)$ are constant i.e. independent of the rate of capacity utilization.

In the following we assume that all cement kilns have the simple structure given by (1) with, but of course, different production capacities and different input coefficients. (We shall return to the empirical basis for these assumptions in Section 3.) The input coefficients, ξ_j, are estimated by the observed coefficients.

The short-run industry function $X = F(V_1, \ldots, V_n)$ is obtained by solving the following problem:

(2a) $$\max_{x^i} \quad X = \sum_{i=1}^{N} x^i \quad \text{subject to}$$

(2b) $$\sum_{i=1}^{N} \xi_j^i x^i \leq V_j \qquad j = 1, \ldots, n$$

(2c) $$x^i \in [0, \bar{x}^i]$$

where X denotes output and $V_1, \ldots, V_n$ current inputs for the industry as a whole and where $i = 1, \ldots, N$ refers to plants with a capacity of $\bar{x}^i$. Since for our purpose, we are only interested in the economic region, it has been natural to assume free disposal of inputs as expressed by Equation (26).

The optimization problem raised above is a linear programming (LP) problem when the input coefficients are assumed to be constant.

The necessary first order conditions are:

(3) $$1 - \sum_{j=1}^{n} q_j \xi_j^i \left\{ \begin{matrix} \geq \\ = \\ < \end{matrix} \right\} 0 \text{ when } \left\{ \begin{matrix} x^i = \bar{x}^i \\ x^i \in [0, \bar{x}^i] \\ x^i = 0 \end{matrix} \right\}, \quad i = 1, \ldots, N.$$

The variables, $q_1, \ldots, q_n$, are shadow prices of the current inputs in terms of units of output. It follows directly then, that $q_1, \ldots, q_n$ represent the marginal productivities of the inputs of the macro function. Whether a production unit is to be operated or not is then, according to (3), decided by current operating "costs" (dimensionless), calculated at these shadow prices, being either lower than, or exceeding unity. This corresponds to utilizing units with non-negative quasi rents. An equality sign in (3) defines the zero quasi rent, thus giving the boundary of utilization of the set of production units. When operation costs equal unity we have a marginal production unit in the sense that it may or may not be operated in the optimal solution. For a more detailed exposition, see Johansen [13, pp. 13-19].

Since the short-run production function is on a non-parametric form, the question of how the function should be represented now arises. This must, of course, depend on the use to which the function is to be put. In order to analyse long run technical progress and structural change we need the complete representation of each isoquant of the set found suitable for analysing the three aspects: Factor bias, productivity change and change in substitution properties.

Due to the linear structure of the problem (2a-c), the isoquants will be piece-wise linear in the two-factor case considered here. In principle, the short-run function (2) can be derived by solving a number of LP-problems. However, when the aim is to establish a reasonably interesting number of isoquants, in order to reveal all the corners of the piece-wise linear isoquants, solving the LP-problems (2a-c) is not a practical procedure.

If one is satisfied with the information given by a *limited* number of isoclines these are readily obtained by utilizing a simple ranking of the micro units according to unit production costs for given input prices. Such a cost minimization procedure is utilized by Johansen [13], K. Hildenbrand [11] and W. Hildenbrand [12].

Our approach yields, for the two-factor case, a *complete* description of the isoquants by locating all the corner points geometrically, providing the whole set of isoclines and, in addition, thus enabling us to provide a full characterization of the production function via marginal productivities, marginal rates of substitution, elasticities of substitution and elasticities of scale. Even for problems with a large number of production units the computation of isoquants is performed within a very reasonable amount of computer time. (Although addressed to other aspects of the short-run function, this geometric approach was inspired by unpublished work by Seip [17].)

Briefly, the algorithm works in the following way.[1)]

The boundaries of the substitution region are found by ranking the units according to increasing input coefficients for each input separately. This corresponds to ranking units according to unit costs when one input at a time has a zero price. We know that the isoquant must be piece-wise linear, downward sloping and convex to the origin and minimizing costs for every factor price ratio. The essential idea is to substitute production units successively along the isoquant so that all the above mentioned properties are fulfilled. This is obtained by the following geometric procedure:

Starting from an arbitrarily chosen output level on the upper boundary, the last unit entered on the boundary is partially utilized. The problem is to find the next corner point on the isoquant. The algorithm, then, compares the slopes in the input coefficient space, of the connecting lines between the starting unit and all units. Thus two units are always partially utilized along an isoquant segment.

In the case of increased utilization of the starting unit, when moving from the boundary along the isoquant segment, the first isoquant corner point is reached either when the capacity of the starting unit is exhausted, or when the capacity utilization of the decreasing unit reaches zero. When the capacity utilization of the starting unit decreases, the corner point is reached when the utilization of this unit reaches zero, or the utilization of the increasing unit reaches 100 per cent. At each corner only one unit is partly utilized.

The first segment can, at most, be vertical because the boundary units are sorted according to increasing input coefficients of that input which is increasing along the isoquant towards the lower boundary. The actual length of the segment depends on the capacity of the activated units.

The next step is to compare the angles of all other units in the input coefficient space with the partly activated unit at the previously found corner point. The angle of the next line segment is then determined by the unit giving the second-steepest angle *compared* to the angle of the previous line segment, and so on, until the lower boundary is reached.

The successive angles, in the input coefficient space, between the units activated along the isoquant are the same as the slopes of the line segments in the input space. Intuitively this can be grasped by considering the shadow price interpretations of the dual variables (q_1 and q_2).

3. DATA

The Cement Manufacturing Process

The raw material for cement production consists mainly of limestone which is crushed and then ground into a fine powder. In the dry cement manufacturing process, the powder is fed directly into a kiln where it is calcined (burned) to form clinker. In the wet process, water is added to form a slurry which is then fed into the kiln. The basic principle of the semi-dry process is to use the exhaust gases from the kiln for drying and preheating the raw materials before inserting them into the kiln. Thus, the main advantage is energy saving.

The kiln is essentially a huge cylindrical steel rotary tube lined with firebrick. The raw material (either slurry or dry) is fed into the upper end. At the lower end is an intensely hot flame which provides a temperature zone of about 1500° C by the precisely controlled burning of coal, oil or natural gas under forced draft conditions. After the clinker is cooled, it is ground with 4-6 % gypsum into cement.

The Data

The micro units in this study are the individual kilns of the Swedish cement industry. Cement production is usually studied on the plant level. Since the putty-clay assumptions are crucial to our approach,the kiln is the most suitable unit. The kiln is the largest and most expensive piece of equipment in the cement plant, the only consumer of fuel and responsible for two thirds of the total energy consumption of the plant.

The data covers a time period between 1955 and 1979, but since our purpose is to study the long run development of the short-run industry production function we have chosen to illustrate the results for the typical years 1955, 1960, 1965, 1970, 1974 and 1979. We have obtained all data directly from the only existing Swedish producer. The data comprises energy, labour input, capacity and actual output. Since the raw material input is strictly proportional to output, independent of vintage and size, this input is not included explicitly.

Energy consumption is measured in calories and relates to the direct use of energy for drying, calcining and burning the cement in the kiln. When different types of energy have been used we have aggregated to one energy measure based upon the raw energy content of the different energy types (primarily oil and coal). Burning coal means a small decrease in energy efficiency which means that for the same amount of output, up to 5 per cent more raw energy is required from coal than from oil.

While energy consumption is kiln specific with fixed input coefficients in the short run, labour input is not. Labour input is determined by the aggregate kiln capacity for each plant. Sticking to the kiln as the micro unit it is a natural assumption to allocate labour in proportions to the production of each kiln.

Since our purpose is to study the *long run* structural change in the use of energy and labour this procedure should yield a relevant picture of substitution and productivity changes, even if the short run function for individual years must be regarded as an approximation of the actual production possibilities.

Capacity and output is measured in tonnes of cement on the individual kilns. According to the industry practice, annual capacity is defined as maximum daily capacity during 310 days. The industry capacity, annual output (in ktonnes), percentage capacity utilization and the number of kilns operated during the selected years are presented in Table I. Note that it is possible to produce more than capacity if the number of lay-off days is lower than expected.

Table I

The relatively low degree of capacity utilization in the Seventies even during boom years is due to the sharp decrease in building activity in Sweden; this also explains the decrease in output between 1970 and 1979. The industry still maintains old kilns as reserve capacity for peak periods.

In 1955 the whole capacity was wet processes, except for one semi-dry kiln, but no wet kiln has been installed since 1967. In 1974 five kilns were dry, two semi-dry and thirteen wet and in 1979 only three wet kilns remained. (For a thorough description of Swedish cement industry and its developments see Carlsson [1].)

Our time unit is one year. There is empirical evidence for a certain amount of disembodied technical change in the form of input saving progress going on more or less continuously. Alternatively these input savings could be explained by capital substitution in the form of small scale investments additive to the basic kiln structure.

Moreover the input coefficients do, to a certain degree, depend on the rate of capacity utilization. Both coefficients tend to increase with decreasing rate of utilization. Due to our method of estimating the coefficients by current observations this especially affects energy coefficients for kilns with a very low rate of capacity utilization. Stops and restarts have a negative effect on energy effeciency. Since slump years are avoided labour hoarding should not affect the labour coefficients unduly. These qualifications underline the fact that the assumption of fixed coefficients within each year must be looked upon as a convenient approximation.

The relative prices between labour and energy have changed considerably during the period. In Table II we have calculated the factor price development of the basis of actual costs for the cement industry.

Table II

The sharp rise in energy prices in 1974 has to some degree been mitigated by an increase in coal burning from 13 per cent of the thermal energy input in 1974 to 34 per cent in 1979.

In the sequel the following notation will be employed:

L = labour (hours)

E = energy (cal)

X = output (tonnes)

L/X, E/X = input coefficients for labour and energy respectively.

D, S-D and W stand for dry, semi-dry and wet processes respectively.

4. THE CAPACITY DISTRIBUTION

The capacity distributions in 1955, 1974 and 1979 are shown in Figure 1.

Figure 1. The capacity distribution has moved considerably between 1955 and 1974, and somewhat further between 1974 and 1979, especially in the labour saving, but also in the energy saving direction. The average value of the input coefficient for labour, for the industry as a whole, has, from 1955 to 1979, decreased by 67 per cent and by 17 per cent for energy.

While energy input coefficients are largely embodied in the kilns, labour is not. Decreasing labour input coefficients partly reflect the increases in the size of the kilns (a larger unit does not require more labour than a smaller one), partly a rationalization in other parts of the plant. The shape of the distribution has changed somewhat due to the large bulk of new dry kiln capacity and particularly in 1979 it is highly concentrated in labour input coefficients. Except for the largest wet kiln in 1974, the largest units are also the most efficient. The dry process makes it possible to exploit economies of scale, resulting in labour saving technical progress.

On the basis of actually average paid input prices we can construct a zero quasi rent line. (See Section 2 above.) In Figure 1 quasi rent lines are drawn through the "marginal" kilns in 1955, 1974 and 1979. Thus, we have started from actual output and calculated the cost-minimizing sequence of kilns up to this output. The last kiln in this sequence is the "marginal" kiln. Two kilns were above this line in 1955, five in 1974, and five kilns in 1979.

As regards the actual situation, all kilns were in use these years with varying degrees of capacity utilization. This might be an indication of imperfect optimization. However, one must take into consideration that a full optimization of the cement industry must include the transport costs between the various plants and the consumers.

5. THE SHORT-RUN INDUSTRY PRODUCTION FUNCTION AND TECHNICAL CHANGE

Region of Substitution

The region of substitution and isoquant map of the short-run industry production function is presented in Figure 2 with five year intervals.

Figure 2

Comparing different years for the same isoquant level, the region of substitution is rather narrow in 1955, 1960 and 1965 and increases considerably between 1965 and 1970 when the dry process was introduced and capacity increased. An indication of this is that for the isoquant level of 2000 ktonnes the reduction in labour input by moving from the starting point to the end point of the isoquant was about 20 per cent in 1970-74 compared to only about 3 per cent in 1955-60, and for energy reduction the values were below 3 per cent in 1955-60 as compared to about 10 per cent in 1970-74. Due to the extremely small differences in labour coefficients there is very little scope for substitution in 1979 and the substitution region is extremely narrow.

The development of the short-run function is determined by investments in new capacity and scrapping. The investment decision is based on the expected future development of input prices, the ex ante technology and the demand. All these factors influence the timing, factor proportions and the scale of investments. According to the earlier studies there are considerable scale economies for both labour and capital in the ex ante production function. while all other inputs are proportional to output (see e.g. [14] and [15]).

Against this background the steady shift of the substitution region towards the energy axis should be expected due to the simultaneous influence of the development of relative prices, shown in Table II, the scale properties of the ex ante function, and the shift in technology from wet to dry process. It is particularly important to note the reduction in labour input coefficients due to increased scale of new kilns.

Figure 1 clearly reveals that there is a technical limit to the decrease in energy coefficients, while this is not the case for labour. The development of the substitution region has been most rapid between 1960 and 1970 parallel to the vary rapid increase in the relative price of labour. During this period the average factor ratio between energy and labour doubled (see Table V below), and capacity increased by 68 per cent. Four relatively large, energy-economized, dry kilns were installed together with three wet kilns, while two rather energy consuming wet kilns were closed.

Productivity change

For all years the distance between the isoquants in Figure 2 is 500 ktonnes and the scale on the axis is the same during the entire period. The productivity improvements can be seen by following any isoquant representing the same output level from year to year. In Figure 2 three isoquant levels are indicated by arrows, 500, 1500 and 2500 ktonnes respectively.

For all levels there is a marked movement towards the energy axis. There is also a substantial shift towards the origin , which is somewhat stronger the higher the levels of output. The long run effect of ex ante substitution possibilities, especially between capital and labour, through exploitation of economies of scale, and energy saving by the introduction of new dry processes has resulted in west-south-west movements of the isoquants.

Another informative visualisation when studying the change of the short-run function is to look at the development of the transformed isoquant map of the short-run function into the input coefficient space. Such a transformation of the isoquant maps in Figure 2 (except for 1960) is shown in Figure 3.

Figure 3 The transformed isoquant map of the short-run function, called the capacity region, shows the region of feasible input coefficients of the industry production function as a whole. Thus, this region must necessarily be narrower than the capacity distribution region portraying the individual units. The boundary towards the origin of the feasible region is called the efficiency frontier. (See Førsund and Hjalmarsson [6]).

The west-south-west movement of the feasible region is clearly exhibited. In 1979 the region almost collapses into two lines. The right hand outgrowth in general represents the least efficient kiln and in 1979 the right hand branch represents the remaining wet capacity.

Substitution properties

Figure 2 reveals a general tendency for the isoquants to become steeper over the years, i.e. the scope for labour substitution diminishes relative to the scope for energy substitution. However, since the isoquants consist of piece-wise linear segments it is difficult to find numerical measures confirming this visual impression.

The conventional measure of substitution properties, the elasticity of substitution, is zero at the corner points and infinity along the segments. One possibility is to approximate the isoquant with a smooth curve, see Førsund and Hjalmarsson [7]. Another possibility is to compute an arc elasticity directly by calculating the ratio between the percentage change in the factor ratio and the percentage change in the slope for two consecutive isoquant segments.

Table III The arc elasticities of substitution for the output level of 1500 ktonnes for all years are shown in Table III. The number of isoquant segments varies from year to year, and the number of arc elasticities is equal to this number less one. Hildenbrand [12] claims that as a "general empirical fact" (his quotation marks) the values of this elasticity are quite low. However, although there are many very low values in Table III, the values vary considerably up to quite high values, and it is difficult to read off any systematic pattern. There does not seem to be any easy way of summarizing all the substitution properties of the whole isoquant since the arc elasticity is as detailed as the isoquant itself. If very detailed information about the substitution properties of limited parts of the isoquant are needed the arc elasticity of substitution fits quite well. If we are interested in summary information there is no obvious way of either fitting a smooth isoquant or parameterizing an elasticity of substitution function.

Technical Advance and Bias Measures

Figures 2 and 3 give a picture of significant change of the short-run production function. As regards numerical measures of the changes, we shall here adopt Salter's measures of techical advance and factor bias (see Salter [16, Ch. 3] and Førsund and Hjalmarsson [8]).

We have chosen to utilize 1979 prices (Paasche index) and have calcualted the degree of technical progress and the factor bias for the three output levels marked out in Figures 2 and 3, 500, 1500 and 2500 ktonnes in addition to 3500 ktonnes and the frontier of the capacity region shown in Figure 3. The short-run industry function program provides us with the current unit costs, $\bar{C}$, along the expansion path, corresponding to the 1979 prices.

Table IV The current unit cost reduction from 1955 to 1979 has been around 60 per cent, and increasing from 59 to 64 per cent when moving from the frontier (i.e. the boundary towards the origin and the axes in Figure 3) to higher output levels. This way of measuring technical advance confirms and quantifies the impressions from Figure 2 that technical progress has been rapid between 1960 and 1965, especially on the frontier with a unit cost reduction of 26 per cent due to the introduction of new kilns. Between 1970 and 1974 and 1974 and 1979 the technical advance slowed down markedly on the frontier, and, during these periods, technical advance steems from increases in labour productivity. The advance measures for 1974-79 show the gain for the industry of the rest of the kilns catching up with the best practice. There are substantial cost reductions for higher total output levels.

Generally the factor bias measures show a strong labour saving bias. (Except at the frontier 1965/60 due to the north-west - south-east extension of the frontier and the 500 ktonnes isoquant in 1960, and on the

2500 ktonnes isoquant in 1974/70 due to the changed slope of the isoquants). The optimal energy/labour ratio has increased three to four times between 1955 and 1979. The results vary somewhat between different pairs of years and for different isoquant levels. The change between 1974 and 1970 has been the smallest.

Both the advance and the bias measures depend on the prices chosen. In order to check the sensitivity of the results the measures have also been calculated for 1955 prices (i.e. Laspeyre index). The same pattern for technical advance results, but on a somewhat lower level (cost reduction 1979/55 0,50 - 0,42) which is to be expected, since relatively the price of labour and labour productivity has increased the most between 1955 and 1979. The overall picture for the bias measure is the same as for 1979 prices.

7. STRUCTURAL FEATURES

The Current Cost Function

The Salter technical advance measure utilizes just a few points on the current average cost curves. The complete average and marginal cost curves provide us with a comprehensive picture of the change of the variable cost structure over time. The average and marginal cost curves are shown in Figure 4.

Figure 4 The difference in absolute cost levels reflects the values of the Salter technical advance measure in Table IV. The average cost curves increase very slowly and smoothly, in all years and are almost flat in 1979. It is clearly shown in the diagram that the Salter measure will be fairly independent of the output levels chosen.

The marginal cost curves provide us with a more detailed and richer structural description. In 1955 there is a marked J-shaped tail of the marginal cost curve reflecting the upward pointing protuberance of the capacity region in 1955 shown in Figure 3. In 1974 the marginal cost curve is characterized by a marked step after 30 per cent of the capacity has been exhausted. After this level, the marginal cost curve develops almost parallell to the average cost curve without any upward turning tail at the end. The first flat part of the curve reflects the location of the three most efficient plants shown in the capacity distribution, Figure 1. In 1979 the two best practice plants constitute about 60 per cent of the capacity reflected in the flat part of the marginal cost curve almost identical to the average cost curve. The upward pointing tail of the marginal cost curve for the last 40 per cent of the capacity corresponds to the distribution of energy input coefficients shown in Figure 1.

Elasticity of Scale

The evenness of the structure can also be illustrated by the spacing of the isoquants,measured, for instance, by the development of the elasticity of scale along a factor ray. (Note that the elasticity of cost, calculated as the ratio between the marginal and average costs shown in Figure 4 as done in W. Hildenbrand [12] can no longer be interpreted as the inverse of the elasticity of scale, since elasticity of scale does not exist uniquely at the isoquant corners and the isocline consist only of corner points; we must therefore choose another basis for calculating the scale elasticity.)

From the classical theory of production it is well known that we have the following relationship:

$$(4) \qquad \varepsilon X = \frac{\partial X}{\partial V_1} V_1 + \frac{\partial X}{\partial V_2} V_2 = q_1 V_1 + q_2 V_2$$

The first equation is the *passus equation* in the terminology of Frisch [4]. ε is the elasticity of scale function which is discontinuous at all corner points. The second equation follows directly from the shadow price interpretation of the variables q_1 and q_2.

Thus, to be able to calculate the scale elasticity it is necessary to find q_1 and q_2. This is done by utilizing the fact that Eq: (3) holds with an equality sign for marginal units. In the two-factor cases there must be two marginal units on every isoquant segment; the utilization rate of one is increasing and that of the other decreasing. On each segment we then have two equations (3) in the two unknowns q_1, q_2. Obviously the scale elasticity is constant along an isoquant segment.

Table V In Table V the development of the elasticity of scale is shown for the average factor ratio for each isoquant level. When the factor ray is outside the substitution region we have chosen the values of the scale elasticity of the bordering isoquant segment in question.

The maximal value of the elasticity of scale is 1. Intuitively, one should expect the highest values for the first part of the substitution region and then decreasing values as less and less technically efficient units have to be employed. However, Johansen ([13], p. 67), analyzing continuous capacity distributions, points out that "not much can be said in general about the variations in ε. In particular ε does not necessarily decrease monotonically with increasing output. It is easy to conceive of [capacity]distributions....which are such that ε first decreases but later on passes through both increasing and decreasing phases as output....increases, although this may perhaps not be very realistic in practice". However, even though the general tendency is for values to decrease, we observe also increasing phases of the scale elasticity for all years except 1979. Thus, this may be the general case and not the exception, at least for discrete distributions.

Even if the elasticity of scale is calculated along a factor ray it turns out that the values shift downwards at the same output levels at which the corresponding marginal cost curves shift upwards in Figure 4. The impact of the best practice units in 1979 for the industry performance is clearly exhibited by the almost unity values of the scale elasticity corresponding to the flat part of the average cost curve in Figure 4.

As regards the variation of the scale elasticity along isoquants our results indicate that it is fairly limited. Thus, the general tendency of the results in Table V is fairly independent of the chosen factor ray.

Efficiency

As measures of structural efficiency we can compute the utilization of observed total input in relation to potential input on the short-run function and also the adjustment of input proportions to relative prices. We must again remember that important factors in the real industry optimization are excluded here,especially transport costs.

By comparing "actual" costs (i.e. costs imputed by the observed average input prices for the respective years) with the costs of producing the same output with the same observed factor ratio on the short-run function, a measure, analogous to Farrell's measure of technical efficiency, is obtained. By further comparing these last costs with the minimal cost along the isoquant corresponding to actual observed output we obtain a measure analogous to Farrell's measure of price, or allocative efficiency. The product of these measures yields Farrell's overall efficiency measure. (See Farrell [3] and Førsund and Hjalmarsson [6 and 9]). The values of the efficiency measures are shown in Table VI.

Table VI In all years except 1979 the efficiency values are very high, particularly in view of the fact that transport costs are excluded. This is most surprising in 1974 where the low degree of capacity utilization should affect the technical efficiency value downwards. The adjustment to relative prices was almost perfect even in 1974 with its considerably wider region of substitution. The overall efficiency measure indicates that a "perfect" optimization should yield less that 3 per cent cost reduction in 1974, in spite of a very low capacity utilization. One reason for this high efficiency level is that in 1974 the Swedish cement industry became a monopoly with an elaborate production model for short-run optimization. In 1979 the relatively low value of technical efficiency was due to the very low degree of capacity utilization of the largest unit which came on stream that year.

8. CONCLUDING REMARKS

In this article we have performed an analysis of industrial structure and structural change for an industry consisting of well defined production units. As an alternative to a traditional production function analysis we have developed Johansen's [13] approach into an operational framework for our purpose. In comparison with highbrow econometrics of empirical production theory this approach may seem less sophisticated. (Cf, Johansen [13] p. 1.) On the other hand it yields a deeper insight into the nature of the development of an industry.

The empirical results show that the process of structural change of the Swedish cement industry has been characterized by a substitution process from labour towards energy in combination with a rather rapid cost reducing technical progress. This development is due to long run ex ante substitution possibilities and increasing returns to scale between capital and labour/energy when introducing new techniques, and disembodied improvements especially as regards labour saving.

TABLE I

THE SWEDISH CEMENT INDUSTRY 1955-1979

Year	Capacity ktonnes	Output ktonnes	Capacity utilization per cent	No of kilns
1955	2507	2502	100	18
1960	2962	2797	94	20
1965	3744	3846	103	23
1970	4967	3968	80	25
1974	4579	3738	82	20
1979	3561	2099	59	9

TABLE II

FACTOR PRICE DEVELOPMENT BETWEEN 1955 AND 1979

1955 INDEX = 100

Year	Labour	Energy	Relative price
1955	100	100	1
1960	142	110	1.29
1965	213	95	2.24
1970	294	84	3.50
1974	510	364	1.40
1979	963	540	1.78

TABLE III

ARC ELASTICITIES OF SUBSTITUTION. OUTPUT LEVEL 1500 KTONNES

$$\sigma^s = \frac{\left(\frac{V_2^s}{V_1^s} - \frac{V_2^{s+2}}{V_1^{s+2}}\right)\left(\frac{V_2^s - V_2^{s+1}}{V_1^{s+1} - V_1^s} + \frac{V_2^{s+1} - V_2^{s+2}}{V_1^{s+2} - V_1^{s+1}}\right)}{\left(\frac{V_2^s}{V_1^s} + \frac{V_2^{s+2}}{V_1^{s+2}}\right)\left(\frac{V_2^s - V_2^{s+1}}{V_1^{s+1} - V_1^s} - \frac{V_2^{s+1} - V_2^{s+2}}{V_1^{s+2} - V_1^{s+1}}\right)} \qquad s = 1,\dots,S-2$$

where V_1^s, V_2^s are the coordinate values at corner point No s where S is the number of corner points along the isoquant.

Isoquant segment pair No[1)]	1955	1960	1965	1970	1974	1979
1	—[2)]	—[2)]	0.21	0.06	5.75	0.05
2	0.03	—[2)]	32.45	8.31	0.10	
3	0.01	0.05	0.48	1.96	0.75	
4		0.03	0.12	0.85	0.06	
5		9.43	0.69	0.04	0.31	
6		0.10	14.46	0.11		
7		0.05	0.07	0.52		
8		0.08	1.53	247.47		
9		0.04	2.12			
10		0.26	0.05			
11			3.23			

1) From upper boundary

2) Virtually vertical isoquant segment

TABLE IV

THE SALTER TECHNICAL ADVANCE MEASURE T, AND THE SALTER FACTOR BIAS MEASURE, D_{EL}, IN 1979 PRICES

$$T = \left(\frac{\bar{C}_{t_2}}{\bar{C}_{t_1}}\right)_{X=X^o}, \quad \bar{C}_t = \text{MINIMIZED COST IN YEAR } t,$$

$$D_{EL} = \left(\frac{E_{t_2}}{E_{t_1}} \; \frac{L_{t_1}}{L_{t_2}}\right)_{X=X^o}, \quad t_1 < t_2$$

	Output levels, X, in 1000 tonnes									
	Frontier		500		1500		2500		3500	
Year	T	D_{EL}	T	D_{EL}	T	D_{EL}	T	D_{EL}	T	D_{EL}
1960/55	0.84	2.01	0.82	1.58	0.83	1.13	0.82	1.15	-	-
1965/60	0.74	0.88	0.79	0.85	0.80	1.43	0.78	1.51	-	-
1970/65	0.82	1.82	0.78	1.65	0.78	1.33	0.82	1.38	0.83	1.32
1974/70	0.90	1.04	0.89	1.20	0.91	1.02	0.93	0.90	0.94	1.03
1979/74	0.90	1.31	0.89	1.30	0.82	1.46	0.74	1.55	0.76	1.58
1979/55	0.41	4.41	0.40	3.41	0.38	3.19	0.36	3.36	-	-

TABLE V

THE DEVELOPMENT OF THE SCALE ELASTICITY ALONG THE AVERAGE FACTOR RAYS

Year	Output levels in 1000 tonnes									Average factor ratio
	500	1000	1500	2000	2500	3000	3500	4000	4500	
1955	0.99	0.95	0.96	0.84	0.85	-	-	-	-	0.087
1960	1.00	0.96	0.97	0.90	0.88	-	-	-	-	0.098
1965	0.99	0.96	0.97	0.92	0.92	0.84	0.83	-	-	0.147
1970	0.96	0.92	0.93	0.84	0.86	0.83	0.83	0.83	0.83	0.197
1974	0.93	0.88	0.91	0.81	0.83	0.84	0.84	0.83	0.79	0.210
1979	1.00	0.99	0.99	0.99	0.99	0.92	0.81	-	-	0.315

TABLE VI

ESTIMATES OF EFFICIENCY

Year	Technical efficiency	Allocative efficiency	Overall efficiency
1960*)	0.98	1.00	0.98
1970	0.95	0.998	0.95
1974	0.97	0.99	0.97
1979	0.88**)	0.97***)	—

*) In 1955 output is equal capacity and the efficiency measures are equal to one and in 1965 observed output exceeds capacity.

**) Since the observed average factor ratio lies outside and above the isoquant for the observed output level, we have compared observed costs with the computed costs at the boundary corresponding to the observed output level. Thus this measure is not a true Farrell measure of technical efficiency.

***) The minimum costs are compared with the costs at the border of the same isoquant.

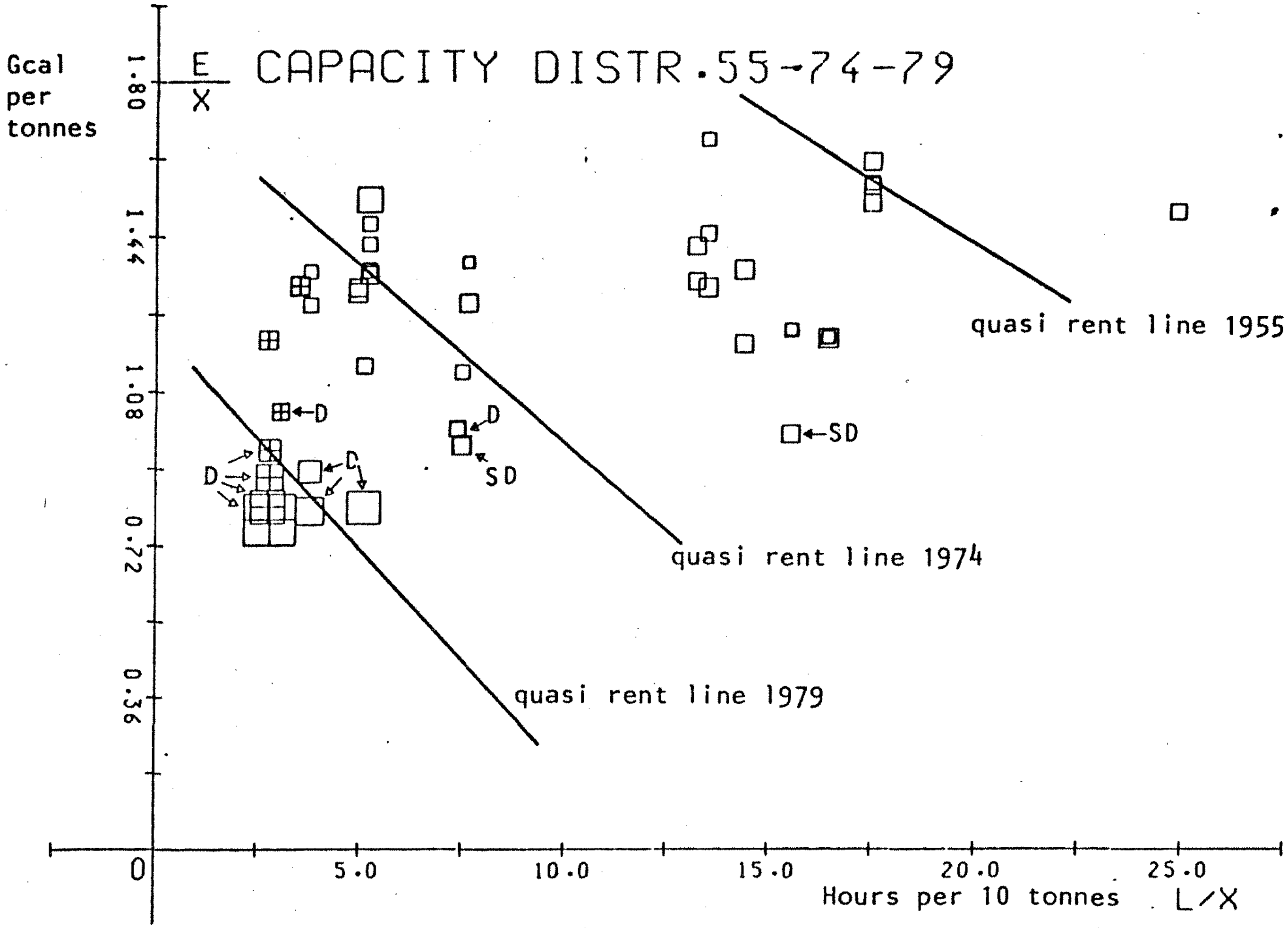

FIGURE 1 The capacity distributions in 1955 (empty squares), 1974 (empty squares) and 1979 (cross squares). The capacity of the kilns is proportionate to the size of the squares.

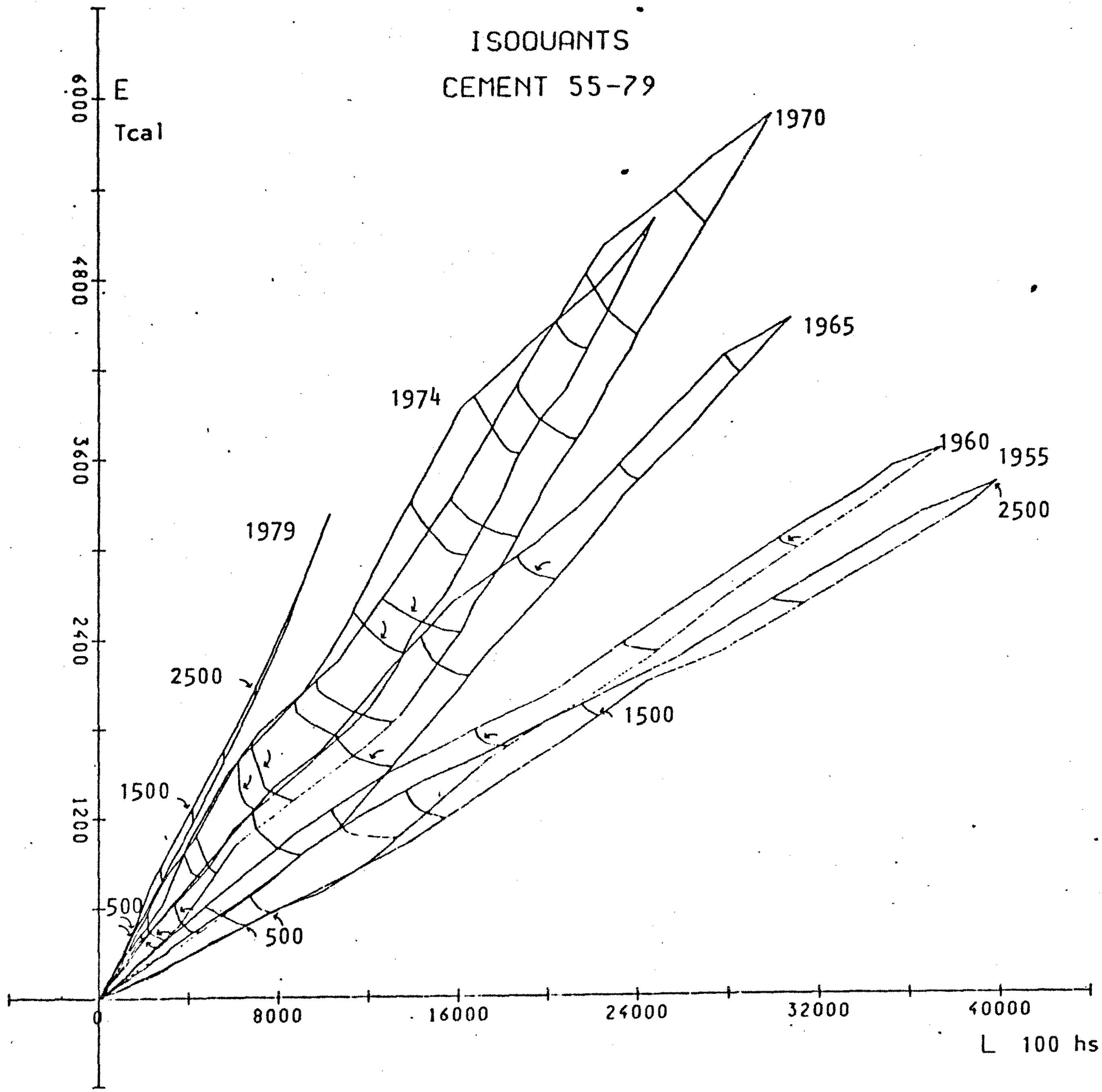

FIGURE 2 — The development of the short-run industry production function between 1955 and 1979.

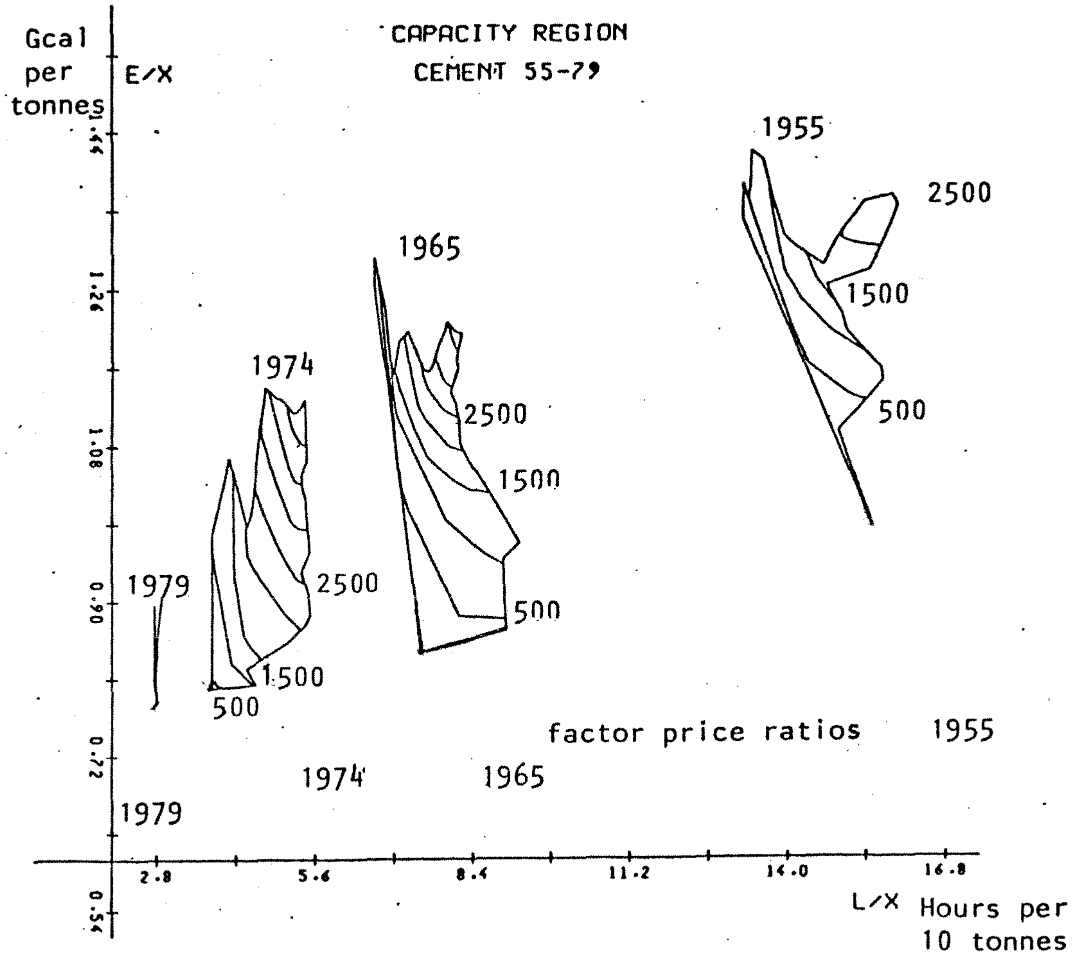

FIGURE 3 —The development of the capacity region of the short-run industry production function and the factor price ratios respective years.

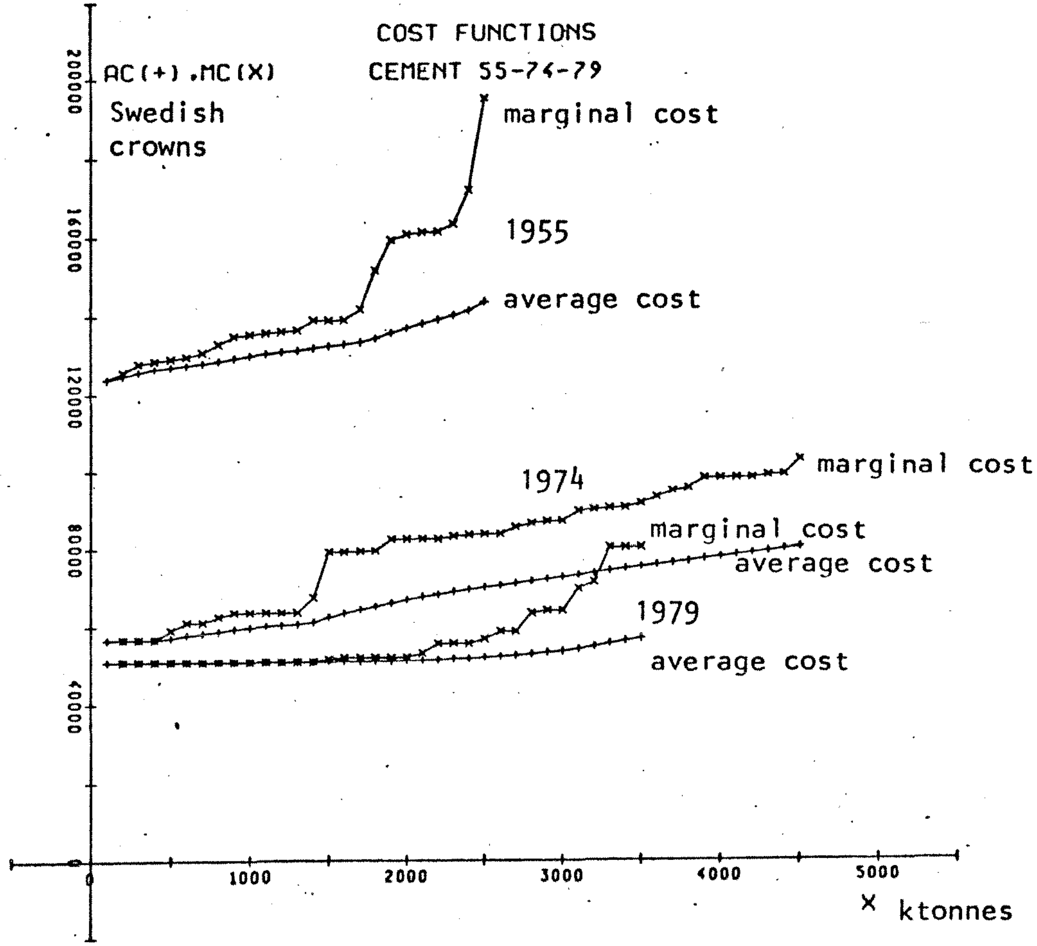

FIGURE 4 — The marginal and average cost functions, along the expansion paths, for 1955, 1974 and 1979 in 1979 prices.

Abstract

The purpose of this article is to provide a deeper empirical insight into the structural change of an industry which is more relevant than that obtained by an analysis based on the traditionally estimated average production function. The main contribution is a long run analysis of technical progress and structural change by means of the short-run industry production function introduced by Johansen, and based on micro data for individual production units. For that purpose we have developed Johansens approach into an operational framework for discrete capacity distributions including a special algorithm for the computation of the short-run industry production function.

Notes:

1) A full description of the algortihm with 1974 as a complete numerical example is available and can be obtained upon request.

REFERENCES

[1] CARLSSON, B.: "Choice of Technology in the Cement Industry - A Comparison of the United States and Sweden," in *The Importance of Technology and the Permanence of Structure in Industrial Growth*, ed by B. Carlsson, G. Eliasson, and I. Nadiri, Stockholm: The Industrial Institute for Economic and Social Research, 1978.

[2] EIDE, E.: *Engineering Production and Cost Functions for Tankers.* Amsterdam-Oxford-New York: Elsevier, 1979.

[3] FARRELL, M.J.: "The Measurement of Productive Efficiency," in *Journal of the Royal Statistical Society A 120* (1957), 253-290.

[4] FRISCH, R.: *Theory of Production.* Dordrecht: E. Reidel Publishing Co., 1965.

[5] FØRSUND, F.R., GAUNITZ, S., HJALMARSSON, L., and S. WIBE: "Technical Progress and Structural Change in the Swedish Pulp Industry 1920-74" in *The Economics of Technological Progress*, ed. by T. Puu, and S. Wibe, London: MacMillan, 1980.

[6] FØRSUND, F.R., and L. HJALMARSSON: "On the Measurement of Productive Efficiency," in *Swedish Journal of Economics*, 76 (1974), 141-154.

[7] ———: "Production Functions in Swedish Particle Board Industry" in *Capital in the Production Function*, Paris X, Nanterre: Institut de Recherches en Economic de la Production, 1978.

[8] ———: "Frontier Production Functions and Technical Progress: A Study of General Milk Processing in Swedish Dairy Plants," in *Econometrica*, 47 (1979), 883-900.

[9] ———: "Generalised Farrell Measures of Efficiency: An Application to Milk Processing in Swedish Dairy Plants," in *Economic Journal*, 89 (1979), 294-315.

[10] ———: "Analysis of Industrial Structure: A Production Function Approach," 1980, Oslo and Gothenburg, mimographed, 1978.

[11] HILDENBRAND, K.: "Numerical Computation of Short-run Production Functions", in *Quantitative Studies on Production and Prices*, ed. by W. Eichhorn, R. Henn, K. Neumann and, R.W. Shepard, Vienna: *Physica-Verlag*, 1982, forthcoming.

[12] HILDENBRAND, W.: "Short-run Production Functions based on Microdata", in *Econometrica*, 49 (1981), 1095-1124.

[13] JOHANSEN, L.: *Production Functions*, Amsterdam: North-Holland, 1972.

[14] MCBRIDE, M.E.: "The Nature and Source of Economies of Scale in Cement Production," in *Southern Economic Journal*, 48 (1981), 105-115.

[15] NORMAN, G.: "Economies of Scale in the Cement Industry," in *Journal of Industrial Economics*, 27 (1979), 317-337.

[16] SALTER, W.E.G.: *Productivity and Technical Change*, Cambridge: Cambridge University Press, 1960.

[17] SEIP, D.: "A Geometrical Approach to Aggregation from Micro to Macro in Putty-Clay Aggregated Production Functions", Memorandum from the Institute of Economics, University of Oslo, 1974.

[18] SRINIVASAN, G. and M.R. FRY, "Energy Savings in the Cement Industry", in *Process Economics International*, 11 (1981), 30-32.

WORKING PAPERS (Missing numbers indicate publication elsewhere)

1976

1. Corporate and Personal Taxation and the Growing Firm
by Ulf Jakobsson

7. A Micro Macro Interactive Simulation Model of the Swedish Economy.
Preliminary model specification
by Gunnar Eliasson in collaboration with Gösta Olavi

8. Estimation and Analysis with a WDI Production Function
by Göran Eriksson, Ulf Jakobsson and Leif Jansson

1977

12. The Linear Expenditure System and Demand for Housing under Rent Control
by Per Högberg and N Anders Klevmarken

14. Rates of Depreciation of Human Capital Due to Nonuse
by Siv Gustafsson

15. Pay Differentials between Government and Private Sector Employees in Sweden
by Siv Gustafsson

1979

20. A Putty-Clay Model of Demand Uncertainty and Investment
by James W. Albrecht and Albert G. Hart

1980

25. On Unexplained Price Differences
by Bo Axell

26. The West European Steel Industry - Structure and Competitiveness in Historical Perspective
by Bo Carlsson

33. The Demand for Energy in Swedish Manufacturing
by Joyce M. Dargay

34. Imperfect Information Equilibrium, Existence, Configuration and Stability
by Bo Axell

<u>1981</u>

35. Value Added Tax: Experience in Sweden
by Göran Normann

36. Energi, stabilitet och tillväxt i svensk ekonomi (Energy, Stability and Growth in the Swedish Economy)
by Bengt-Christer Ysander

37. Picking Winners or Bailing out Losers? A study of the Swedish state holding company and its role in the new Swedish industrial policy
by Gunnar Eliasson and Bengt-Christer Ysander

40. Wage Earners Funds and Rational Expectations
by Bo Axell

41. A Vintage Model for the Swedish Iron and Steel Industry
by Leif Jansson

43. An Econometric Model of Local Government and Budgeting
by Bengt-Christer Ysander

44. Local Authorities, Economic Stability and the Efficiency of Fiscal Policy
by Tomas Nordström and Bengt-Christer Ysander

45. Growth, Exit and Entry of Firms
by Göran Eriksson

52. Swedish Export Performance 1963-1979. A Constant Market Shares Analysis
by Eva Christina Horwitz

56. Central Control of the Local Government Sector in Sweden
by Richard Murray

58. Industrial Subsidies in Sweden: Macro-economic Effects and an International Comparison
by Bo Carlsson

59. Longitudinal Lessons from the Panel Study of Income Dynamics
by Greg J. Duncan and James N. Morgan

1982

61. Var står den nationalekonomiska centralteorin idag?
av Bo Axell

63. General Search Market Equilibrium
by James W. Albrecht and Bo Axell

64. The Structure and Working of the Isac Model
by Leif Jansson, Thomas Nordström and Bengt-Christer Ysander

65. Comparative Advantage and Development Policy Twenty Years Later
by Anne O. Krueger

67. Computable Multi-Country Models of Production and Trade
by James M. Henderson

68. Payroll Taxes and Wage Inflation: The Swedish Experiences
by Bertil Holmlund (Revised, September 1982).

69. Relative Competitiveness of Foreign Subsidiary Operations of a Multinational Company 1962-77
by Anders Grufman

70. Optimization under nonlinear constraints
by Leif Jansson and Erik Mellander

71. Technology, Pricing and Investment in Telecommunications
by Tomas Pousette

72. The Micro Initialization of MOSES
by James W Albrecht and Thomas Lindberg

73. Measuring the Duration of Unemployment: A Note
by Anders Björklund

74. On the Optimal Rate of Structural Adjustment
by Gunnar Eliasson

75. The MOSES Manual
by Fredrik Bergholm

76. Differential patterns of Unemployment in Sweden
by Linda Leighton and Siv Gustafsson

77. Household Market and a Nonmarket Activities (HUS)
- A Pilot Study
by Anders Klevmarken

78. Arbetslöshetsersättningen i Sverige
- motiv, regler och effekter
av Anders Björklund och Bertil Holmlund

1983

79. Energy Prices, Industrial Structure and Choice of Technology; An International Comparison with Special Emphasis on the Cement Industry
by Bo Carlsson

80. Energy Usage and Energy Prices in Swedish Manufacturing
by Joyce Dargay

81. ELIAS - A Model of Multisectoral Economic Growth in a Small Open Economy
by Lars Bergman

82. Oil Prices and Economic Stability - Simulation Experiments with a Macroeconomic Model
by Tomas Nordström and Bengt-Christer Ysander

83. Statlig kontroll av kommunerna
En översikt av svenska erfarenheter under efterkrigstiden
av Richard Murray och Bengt-Christer Ysander

84. Monopoly and Allocative Efficiency with Stochastic Demand
by Tomas Pousette

85. Export Performance of the Nordic Countries 1965-80
A Constant-Market-Shares Analysis
by Eva Christina Horwitz.

86. The Micro (Firm) Foundations of Industrial Policy
by Gunnar Eliasson

87. Excessive Government Spending in the U.S.: Facts and Theories
by Edward M. Gramlich.

88. Control of Local Authority Expenditure - The Use of Cash Limits
by Noel Hepworth

89. Fiscal Containment and Local Government Finance in The U.K.
by Peter Jackson

90. Fiscal Limitations: An Assessment of the U.S. Experience
by Wallace E. Oates

91. Pricing and Privatization of Public Services
by George E. Peterson

92. Export Performance of the Nordic Countries 1965-80
by Eva Christina Horwitz

93. Was Adam Smith Right, After All? Another Test of the Theory of Compensating Wage Differentials
by Greg J. Duncan and Bertil Holmlund

94. Job Mobility and Wage Growth: A Study of Selection Rules and Rewards
by Bertil Holmlund

95. Sweden's Laffer Curve: Taxation and the Unobserved Economy
by Edgar L. Feige and Robert T. McGee

96. The Machine Tool Industry - Problems and Prospects in an International Perspective
by Bo Carlsson

97. The Microeconomics of Organization and Productivity Change - the Use of Machine Tools in Historical Perspective
by Bo Carlsson

98. Technical Progress and Structural Change in the Swedish Cement Industry 1955-1979
by Finn R. Førsund and Lennart Hjalmarsson