



## TECHNOLOGICAL PROGRESS AND STRUCTURAL CHANGE IN THE SWEDISH PAPER INDUSTRY 1972–1990

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### ABSTRACT

*Short run macro production functions for the years 1972, 1980 and 1990 are constructed and used to analyse technological progress during the period. The use of energy and labour per unit of output fell by 40% for Average and 50% for Best Practice technology. Average Practice was estimated to lack 5 years behind Best Practice. Technological progress was largely labour-saving despite the drastic increase in energy price. Ex post substitution possibilities were very small with an elasticity value around 0.1.*

*Keywords: Paper industry, technological progress, short run production functions, Sweden.*



### INTRODUCTION

Recent developments in macroeconomics have caused a renewed interest in the determinants of productivity and productivity change. Due to increased international competition and the growth of world trade, the industrial competitiveness of countries is a matter of prime concern to policymakers. The core questions concern whether or not the productivity development of the export sector can match that in competing countries, and whether or not industry is flexible enough to adjust to the rapidly changing factor prices of the world today.

This paper analyses the development of an important Swedish export industry — the paper industry. In particular, we have focused on the making of newsprint and printing paper with virgin fibres.<sup>1</sup> The time period is 1972–1990,

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<sup>1</sup> The alternative is to produce paper with (mainly) waste paper. About 90 per cent of the total paper production in Sweden is made with virgin wood fibres as raw material.

which is a period with dramatically changing factor prices. During the first half (1975–1982) there was a general stagnation in demand, whereas the second half (1982–1990) was a period of rapid growth.

The theoretical tool of analysis is the short run macro production function introduced by Leif Johansen (1972).<sup>2</sup> This function allows a representation not only of Best Practice and/or Average Practice technology, but also of the total industrial structure. The construction of the function requires plant production data. Two special aspects of technical progress can be analysed with the help of short-run functions — factor bias and productivity change. In graphical terms this is equivalent to the study of (i) the direction of isoquant movement and (ii) the speed of isoquant movement.

The paper is structured as follows. In the second section we outline the theoretical model, i.e. the theory of short run production functions, their construction and various quantitative characteristics. The data are presented in the third section. The empirical results are presented in fourth section. The paper ends with the conclusions.

### SHORT RUN MACRO PRODUCTION FUNCTIONS

The macro production function is based on short-run micro functions, i.e. the production functions of the various plants in the industry. The Leif Johansen production model differs between *ex ante* (before investment) and *ex post* (after investment) functions. Before the investment, capital is a variable factor; afterwards it is fixed. The *ex post* micro function is characterised by a fixed capacity ceiling and fixed input coefficients, i.e. if  $q_i$  is the production volume at plant  $i$  and  $\bar{q}_i$  the capacity at plant  $i$ , then:

$$0 \leq q_i \leq \bar{q}_i \quad i = 1, 2, \dots, N \quad (1)$$

If  $v_{ij}$  is current input of factor  $j$  and  $\bar{v}_{ij}$  its full capacity value, then

<sup>2</sup> See also Hildebrand W. (1981).

$$v_{ij} = \frac{\bar{v}_{ij}}{\bar{q}_{ij}} \cdot q_i = \xi_{ij} q_i \quad (2)$$

The assumption is that current inputs are directly proportional to output, i.e. that ex post micro production is characterised by fixed input coefficients,  $\xi_j$ . In the economic literature, this is also called a "Leontief technology". We shall assume that paper plants have this simple technological structure though we are aware that this is not exactly in accordance with empirical evidence.<sup>3</sup> The input coefficients are estimated by the observed coefficients. The industry can ex post (in the short run) be characterised by a specific number of plants, each with a fixed capacity ceiling and fixed input coefficients. The macro function is derived from these micro functions by finding the maximum amount of output for every given level of inputs. This is the same as asking which plant should operate (and to what degree of capacity utilization) at a specific level of inputs, in order for total production to be maximized. Accordingly, the short-run macro production function:

$$Q = F(V_1, V_2, \dots, V_n) \quad (3)$$

is defined by solving the following LP problem:

$$\text{Max } Q = \sum_{i=1}^N q_i \quad \text{subject to} \quad (4a)$$

$$\sum_{i=1}^N \xi_{ij} \cdot q_i \leq V_j \quad j = 1, \dots, n \quad (4b)$$

$$q_i \leq \bar{q}_i \quad i = 1, \dots, N \quad (4c)$$

$$q_i \geq 0 \quad i = 1, \dots, N \quad (4d)$$

where  $Q$  denotes output and  $V_j$  current inputs for the industry, and  $i = 1, \dots, N$  refers to plants with capacity  $\bar{q}_i$ .

<sup>3</sup> In paper mills, the input coefficient of variable factors usually declines with output. The assumption above is accordingly an approximation based on optimal technical efficiency.

The economic interpretation of the LP-problem stated above is most easily seen by formulating the dual, i.e. by minimizing

$$\sum_j p_j V_j + \sum_i r_i \cdot \bar{q}_i \quad (5a)$$

subject to

$$\sum_j p_j \cdot \xi_{ij} + r_i \geq 1 \quad i = 1, \dots, N \quad (5b)$$

Correspondence between the solutions to the primal and the dual problem yields:

$$\begin{aligned} & > 1 & q_i &= 0 \\ \sum_j p_j \xi_{ij} &= 1 & 0 \leq q_i \leq \bar{q}_i \\ & < 1 & q_i &= \bar{q}_i \end{aligned} \quad (6)$$

The variables  $p_j$  are shadow prices of current inputs in terms of units of output. The interpretation of (6) is that if variable costs (per unit of production) exceed the product price, then nothing is produced at a given plant; if variable costs are below product price, then the plant produces at full capacity and if costs and revenue are equal, then the production level is determined by the total level of production in the sector. It also follows that the  $p_j$  represent the marginal productivities of the various factors.<sup>4</sup>

The macro production function can be interpreted in two ways. The normative interpretation would be that the macro production function represents the most efficient way production can be carried out in the sector, given the micro technologies at the plant level. The positive interpretation would be that the function represents actual market behaviour under decentralised decision-making when all plants face the same input and output prices. Since certain costs, e.g. transport costs, are excluded from the analysis, the

<sup>4</sup> A more detailed presentation is given in Johansen (1972, p. 13–19).

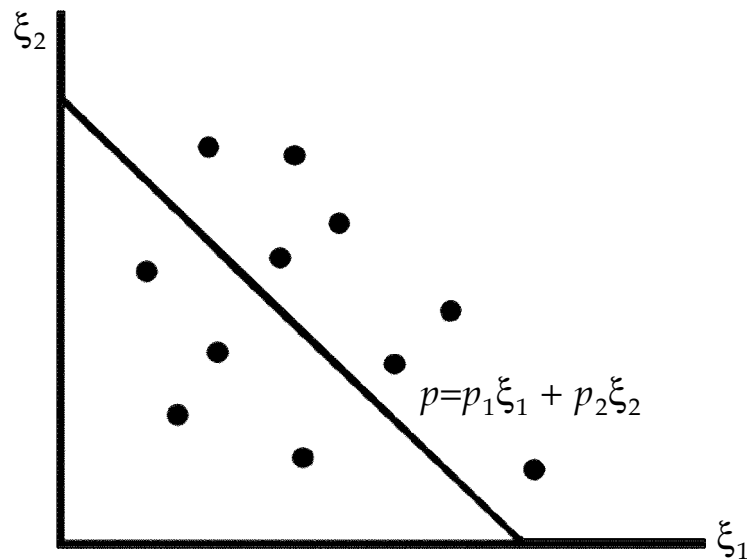


FIGURE 1. ILLUSTRATION TO THE CONSTRUCTION OF SHORT RUN MACRO PRODUCTION FUNCTIONS

normative interpretation is probably the most realistic. Nevertheless the function can still be useful as a (partial) description of industrial structure and structural change over time.

An intuitive explanation of the correspondence between the normative and positive interpretation can be given with the help of Figure 1.

Assume that plant unit input figures are given as the dots in the figure. Assume further that the product price is  $p$  and that the variable input prices are  $p_1$  and  $p_2$ . The line  $p = x_1 \cdot p_1 + x_2 \cdot p_2$  then divides the industry plants into those with revenues greater than, and those with revenues less than, variable costs. In a market economy, this is the same as a division between those plants producing (at full capacity) and those plants which are not producing. (The production level for those plants exactly at the line is indeterminate and dependent on the total level of production in the industry.) Shifting the price-line outwards (and inwards) or shifting the slope yields new combinations of inputs and output, as new plants (wholly or partly) shift sides or land exactly on the line.

### *Elasticities of Scale and Substitution*

The elasticity of scale ( $\varepsilon$ ) of a production function is conventionally defined as:

$$\varepsilon \cdot Q = \sum_j \frac{\partial Q}{\partial V_j} \cdot V_j \quad (7)$$

Since we know that

$$\frac{\partial Q}{\partial V_j} = p_j \quad (8)$$

we find that the scale elasticity can be calculated as:<sup>5</sup>

$$\varepsilon = p_1 \cdot \frac{V_1}{Q} + p_2 \cdot \frac{V_2}{Q} \quad (9)$$

Thus, to find the elasticity for a particular point on the production function  $Q$ ,  $V_1$ ,  $V_2$ , we need to find the corresponding shadow prices  $p_1$ ,  $p_2$ . This is done by utilising the fact that the slope of the isoquant is equal to the ratio between  $p_1$  and  $p_2$ , and that, for the marginal unit, we have according to (6)  $p_1 \cdot \xi_1 + p_2 \cdot \xi_2 = 1$ . This gives us two equations in two unknowns.

In traditional production theory, the elasticity of substitution is used to describe the curvature of the isoquants. This elasticity is defined as:

$$\sigma = \frac{\partial(V_2/V_1)}{\partial(\partial V_2/\partial V_1)} \cdot \frac{\partial V_2/\partial V_1}{V_2/V_1} \quad (10)$$

By analogy with this definition, it is possible to calculate the elasticity of substitution as the proportional change in factor proportions (between two successive line segments of the isoquant)<sup>6</sup> divided by the proportional change in slope (between the same line segments).

<sup>5</sup> In the case of two factors of production.

<sup>6</sup> Factor proportions are then measured at the mid-point of the line segment.

$$\sigma = \frac{\partial FP/FP}{\partial SLOPE/SLOPE} \quad (11)$$

where

$FP$  = factor proportions, and  $SLOPE$  = slope.

### THE DATA

The data consists of plant input and output information for Swedish paper plants for the years 1972, 1980 and 1990. These data were obtained from the annual industrial statistics collected by the SCB, Sweden's Official Statistical Bureau. Only those plants producing with more than 80% virgin fibre were chosen. Two factors of production were used, energy and labour.<sup>7</sup>

Energy was measured in watt-hours and labour input in hours. Production was measured in Metric tons of paper produced. Input data are given in the appendix.

### EMPIRICAL RESULTS

#### *The Substitution Region*

The empirical results are shown in Figure 2, where the short run functions for the years 1972, 1980 and 1990 are shown. The distance between the isoquants is 100 000 Metric tons. As shown, the substitution region has shifted in the labour-saving direction, despite the fact that the period witnessed a rapid increase in the price of energy.<sup>8</sup>

The average factor ratio of labour to energy (i.e. the factor ratio at full capacity utilisation) has fallen from 1.15 (hrs/Mwh) to 0.84 between 1972 and 1990, a decrease of approximately 25%. For the Best Practice technology (in this case the average factor ratio for the 200 000 Metric tons

<sup>7</sup> A third variable factor is of course raw material (wood). We used energy and labour for two reasons. First, we wanted to compare the results with the study by Försund *et al.* (1980). Second, the variation in the input coefficients of raw material between firms is very small.

<sup>8</sup> In real terms, the price of electricity fell by 40 % during the 22 year period 1950–1972. It rose by 20 % during the period 1972–1990. The development was the same for the price of oil.

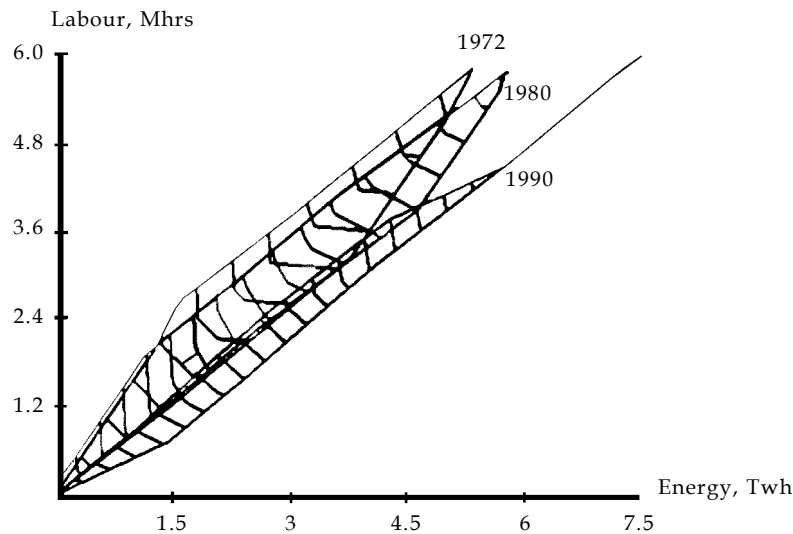


FIGURE 2. SHORT RUN MACRO PRODUCTION FUNCTIONS 1972, 1980 AND 1990. DISTANCE BETWEEN THE ISOQUANTS EQUALS 100 000 METRIC TONS.

isoquant) the same factor ratio fell from 1.18 to 0.70, which represents a decrease of about 40%. It is interesting to note that the shift in the labour-saving direction was much slower during the 1970s compared to the 1980s — 9% vs 20%. At the same time, the relative price energy-labour rose quicker in the 1970s as comparison with the 1980s. The slow increase in the factor ratio in the 1970s could accordingly be due to substitution.<sup>9</sup>

#### *Capacity Region*

Analysing the change of the capacity region is a convenient way of observing the changes in structure and technology over time. The capacity region is a transformation of the short run production function on the unit input space. It is arrived at by dividing each input point on the production function  $Q = F(V_1, V_2)$  by  $Q$ , thus obtaining a relation

$$1 = G(\xi_1, \xi_2) \quad (12)$$



<sup>9</sup> Or rather, that factor substitution neutralised the ongoing technological shift in the labour-saving direction.

for each level of output. The set of such points  $(\xi_1, \xi_2)$  constitutes the capacity region, which represents the possible unit input points if production is carried out in accordance with the optimality conditions required in (4).

The capacity region for the three years is shown in Figure 3 below. There is a clear tendency for the whole region to move towards the origin, implying that less energy and labour are used to produce a specific amount of paper for each year. The movement of the capacity region can be thought of as technological progress which affects the whole industrial structure.

The shift in the labour-saving direction is clearly visible. As indicated, there is a difference between the two time periods, which can be illustrated by the percentage decline in average input coefficients in the two periods. Between 1972 and 1980, the average input coefficient for energy decreased by 20%, and the average input coefficient for labour decreased by 27%.

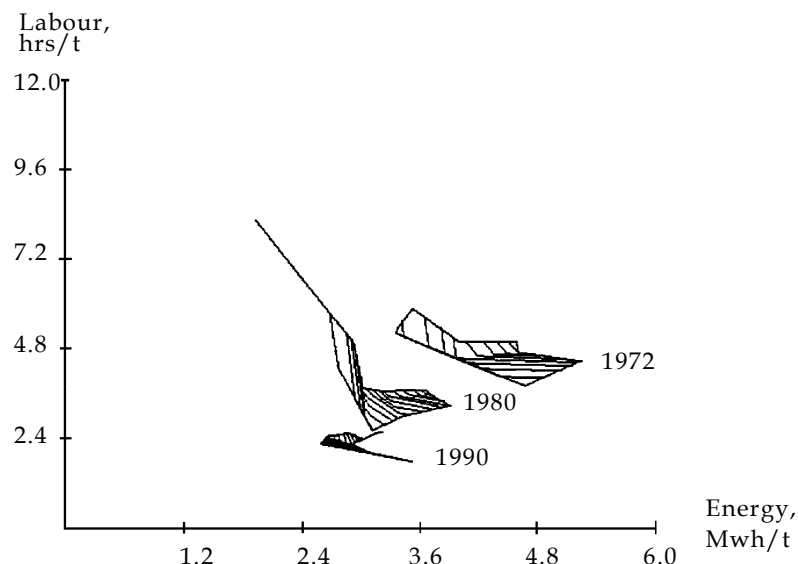


FIGURE 3. CAPACITY REGIONS FOR THE SHORT RUN MACRO PRODUCTION FUNCTIONS 1972, 1980 AND 1990.

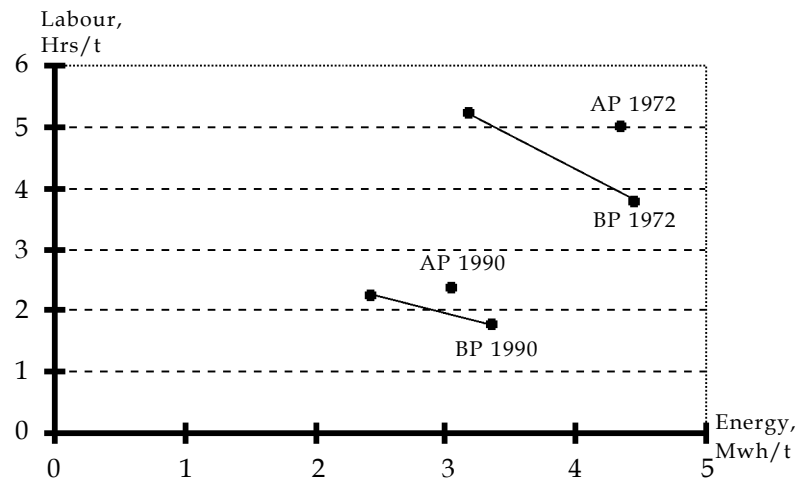


FIGURE 4. BEST AND AVERAGE PRACTICE TECHNOLOGIES 1972 AND 1990 AS INDICATED BY THE SHORT RUN FUNCTIONS.

The corresponding figures for the period 1980–1990 were, for energy, 13%, and for labour, 31%. It appears that the saving of labour occurs at a more or less constant rate, but that the saving of energy input is more dependent on the movements in energy prices.<sup>10</sup>

#### *Best and Average Practice Technology*

In analysing the change of technology, it is often fruitful to distinguish between Best Practice and Average Practice technology. Average Practice technology can be defined as the average input coefficients at full capacity utilization, and Best Practice technology as the convex hull to the input coefficients. This is shown in the figure below for the years 1972 and 1990.

Over time, both Average and Best Practice move towards the origin, and there are only small differences with respect to direction and speed of change. For the two years the relative position of Average Practice with respect to

<sup>10</sup> An explanation for this could be that labour-saving progress is more or less highly dependent on price development.

TABLE 1. TECHNOLOGICAL PROGRESS

*Decline in factor input per unit of output for Best Practice and Average Practice technology between 1972 and 1990.*

	TOTAL	PER YEAR
Average Practice	39.9%	1.88%
Best Practice	42.4%	1.96%

Best Practice is almost the same. If a factor ray from the origin to the Average Practice technology is used to measure relative (technical) efficiency (see Farrell, 1957), we find that the relative efficiency of Average Practice technology was 89% in 1972 and 86% in 1990. Thus, Average Practice was only 10–15% more input consuming than Best Practice the two years.

It is not easy to obtain a unique measure of the speed of technological progress for the period. One reason is that capital input is excluded from the analysis. But even if only variable inputs are considered, measures of the input-saving progress depend on factor proportions and different figures are obtained along each factor ray. We have chosen to measure progress along the “average” factor ray<sup>11</sup> with a weighting of the factors equal to the average of the (Best Practice) isoquant slopes for 1972 and 1990.<sup>12</sup> Using these approximations we obtain the measures of technological progress that are presented in Table 1.

Progress is a little faster for Best Practice, compared with Average Practice, but the difference is small. A decline of about 2% per year might seem small, but it amounts to a reduction of almost 50% during 20 years. Since we earlier noticed that the Best Practice technology uses 10–15% less inputs (compared to the Average Practice technology), a yearly improvement of 2% means that Average Practice technology is approximately 5 years behind the Best Practice technology.

<sup>11</sup> I.e. the factor ray with factor proportions equal to the average of the average technologies of 1972 and 1990. For this ray factor proportions (labour/energy) equals 0.972.

<sup>12</sup> Using the Best Practice isoquant slopes is motivated by the fact that these slopes should theoretically correspond to the relative factor prices in the respective years.

### *Marginal Productivities 1972–1990*

Another way of analysing technological progress is to study the shift of the marginal productivity curves over time. However, the marginal productivities shift heavily along the isoquants and between the isoquant levels. To facilitate presentation, we used the material from the production tables to estimate simple statistical equations. These equations were:

$$MP_j = a_0 + a_1 FP + a_2 SIZE \quad j = L, E \quad (13)$$

where

$MP$  = Marginal productivity (of energy, labour),

$FP$  = Factor proportions,

$SIZE$  = Level of output.

Factor proportions are measured as the energy/labour ratio and output level in Mt. The results are presented in Table 2.

Correlation coefficients and t-values show that the simple equations are reasonable statistical approximations of the underlying figures. The results are also consistent with

TABLE 2. REGRESSION RESULTS

*Linear regressions  $MP = a + a_1 FP + a_2 SIZE$  for the years 1972, 1980 and 1990 (t-values in parenthesis).*

COEFFICIENT	ENERGY			LABOUR		
	1972	1980	1990	1972	1980	1990
$a_0$	0.30 (4.4)	0.12 (3.3)	0.32 (4.1)	-0.28 (-4.1)	-0.084 (-3.6)	-0.60 (-4.4)
$a_1$	0.30 (4.4)	0.12 (3.3)	0.32 (4.1)	-0.28 (-4.1)	-0.084 (-3.6)	-0.60 (-4.4)
$a_2$	0.15 (2.5)	-0.14 (-4.6)	0.094 (9.0)	-0.17 (-2.7)	0.057 (3.0)	-0.17 (-9.4)
Adj. $R^2$	0.39	0.59	0.86	0.35	0.65	0.87

The number of observations was more than 30 in each regression.

TABLE 3. VALUES OF MARGINAL PRODUCTIVITIES

Values of marginal productivities at factor proportions in 1972, 1980 and 1990 (1.15, 1.05, 0.84 hrs/Mwh) and  $Q = 1000$  t.

MARGINAL PRODUCTIVITY OF	YEAR		
	1972	1980	1990
Energy (t/Mwh)	0.135	0.156	0.202
Labour (t/hr)	0.068	0.109	0.186

respect to the sign and significance of the factor proportion variable. Marginal productivity of energy increases, and marginal productivity of labour decreases, with (increases in) the energy-labour ratio. The sign of the parameters for the output variable is negative in three out of six cases, i.e. 50%. Normally, we would expect the marginal productivities to vary negatively with output as technically less efficient plants go into operation when output increase. However, this need not be the case since the production function can be non-homothetic and of (more or less) constant elasticity of scale.

Marginal productivities can also be used to illustrate the speed of technological progress. In Table 3 above, we have calculated the value of the marginal productivities at output  $Q = 1000$ .

As shown, the marginal productivity of energy increases by about 50% during the period, whereas the marginal productivity of labour increases about 150% (at that particular output level).

#### *The Elasticity of Substitution*

As usually is the case for short run macro functions, the elasticity of substitution varies heavily between line segments on one specific isoquant and between isoquant levels. However, it is possible to obtain simple approximations. If  $FP$  denotes factor proportion (on one line segment),  $SLOPE$  denotes the slope (i.e. the ratio of marginal productivities) and  $SIZE$  denotes amount of capacity (production) at the different isoquant level, the following equation can be estimated:

$$\ln FP = a_0 + a_1 \ln SLOPE + a_2 \ln SIZE \quad (14)$$

since the elasticity of substitution is defined by

$$\sigma = \frac{\partial \ln(FP)}{\partial \ln(SLOPE)} \quad (15)$$

we realise that the elasticity of substitution is measured by the parameter  $a_1$ . The regressions results are shown in Table 4.

The results show that the elasticity of substitution is very small, around 0.1. It should in addition be remembered that possibilities for substitution are further limited by the width of the substitution region. A switch from one corner of the substitution region to the other does not, in general, change factor proportions by more than 5–10 % altogether.

#### *The Elasticity of Scale*

By definition, the maximum value for the elasticity of scale is 1.0. Intuitively, one should expect the highest value for the first part of the substitution region, and decreasing values when plants with lower technical efficiency come into operation. However, the elasticity does not (in general) decrease monotonically along factor rays, but can both fall

TABLE 4. REGRESSION RESULTS

*Estimation results (linear regression) for the equation  $\ln(FP) = a_0 + a_1 \ln(SLOPE) + a_2 \ln(SIZE)$ , (t-values in parenthesis).*

COEFFICIENT	YEAR		
	1972	1980	1990
$a_0$	1.66 (5.98)	-0.687 (-1.29)	0.541 (2.09)
$a_1 (= \sigma)$	0.039 (4.97)	0.179 (4.60)	0.076 (3.16)
$a_2$	-0.22 (-5.15)	0.104 (1.32)	-0.105 (-2.63)
Adj. $R^2$	0.655	0.590	0.334

TABLE 5. REGRESSION RESULTS

Estimation results (linear regression) for the equation  $\varepsilon = a_0 + a_1 \cdot FP + a_2 \cdot SIZE$ , (t-values in parenthesis).

COEFFICIENT	YEAR		
	1972	1980	1990
$a_0$	0.928 (19.1)	0.849 (11.7)	1.403 (12.1)
$a_1 (= \sigma)$	-- <sup>*</sup>	0.094 (1.99)	-0.431 (-3.35)
$a_2$	-0.000113 (-1.59)	-0.000084 (-2.20)	-0.0000907 (-5.27)
Adj. R <sup>2</sup>	0.054	0.41	0.70

\* No significant estimate.

and rise with the level of output. In order to facilitate presentation, the material was treated in the same way as the elasticity of substitution. The different points of the production table were used for a linear regression of the equation:

$$\varepsilon = a_0 + a_1 \cdot FP + a_2 \cdot SIZE \quad (16)$$

These regressions gave the results shown in Table 5.

As shown, the elasticity for two of the three years is significantly (negatively) correlated with output. The explanatory power is good except for 1972. As expected, the elasticity value for each output level increases (measured at  $FP=1$ ) over the years considered. This is to be expected since total industrial capacity increases over time, and any specific output level then represents a smaller fraction of the total and accordingly a better position in the whole structure.

## CONCLUSIONS

By using the Leif Johansen production model and concentrating on the development of short run production functions the study analyses changes in technology and in industrial structure in the Swedish paper industry for the

years 1972–1990. It is shown that technological progress has decreased input consumption (at full capacity utilisation and per unit of output) by about 50% over the whole period. This amounts to an input-saving progress at a rate of about 2% annually. The difference between progress for Best and Average technology is very small.

In general, Best Practice technology uses 10–15% less inputs (at a fixed production level) compared with Average Practice technology. If progress amounts to 2% annually, this means that Average Practice technology in the industry is approximately 5 years behind Best Practice. Another way of putting it is to say that the average plant has capital equipment 5 years older than the best plant.

Technological progress is shown to have been largely labour-saving, despite the fact that the 1970s was a period of a drastic increase in the relative price of energy. This result is the same as in the study by Försund *et al.* (1980). In total, the average factor ratio (labour/energy) fell by about 25%. The decline was even bigger for Best Practice, where it amounted to 40%.

Finally, and hardly surprisingly, our analysis shows that ex post substitution possibilities are very small for the industry as whole. The elasticity of substitution is in general approximately 0.1, and the width of the substitution region normally not greater than 5–10% of average factor proportions.

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## APPENDIX

### PLANT DATA 1972\*

Capacity (kt/a)	Energy Input (Mwh/t)	Labour Input (hrs/t)
400	5.42	5.01
10	4.03	12.08
375	3.18	5.21
65	4.20	8.92
325	4.45	3.79

### PLANT DATA 1980

Capacity (kt/a)	Energy Input (Mwh/t)	Labour Input (hrs/t)
350	3.55	3.39
350	2.85	4.68
30	1.84	8.26
400	2.95	2.58
450	4.52	3.79

### PLANT DATA 1990

Capacity (kt/a)	Energy input (Mwh/t)	Labour input (hrs/t)
400	2.46	2.24
600	2.55	2.52
500	3.19	2.74
420	3.34	1.76
400	3.54	3.25
50	5.69	4.20

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\* Capacity are measured in thousand Metric tons per year. Energy input coefficient in Mwh per Metric ton of production and labour input in labour hours per Metric ton.

