Discussion Papers No. 318, May 2002
Statistics Norway, Research Department

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Energy Flexibility and Technological Progress with Multioutput Production

Application on Norwegian Pulp and Paper Industries

Abstract:
We analyse the energy flexibility and technological change in the pulp and paper industry by applying a multioutput production function. The pulp and paper industry mostly consists of heterogeneous firms. They produce a wide range of different goods with different technologies. We take the heterogeneity into consideration in two ways. First, we disaggregate the industry into three sub-sectors according to their products. Second, in each sub-sector our model accounts for the heterogeneity between firms. We apply a specific flexible cost function, which makes sure that the curvature conditions hold. In our model, the energy flexibility occurs in different ways. On one hand producers may invest in technologies, which make them able to switch between different energy sources. On the other hand they can change their output mix towards less energy intensive products when the energy prices increase.

Keywords: Multiproduct symmetric generalised McFadden cost function, energy flexibility, elasticity, technological change, curvature conditions, Pulp and paper.

JEL classification: C33, D20, Q41.

Acknowledgement: Many thanks to Torstein Bye and Jan Larsson for valuable discussions and comments.

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1. Introduction

The demand for electricity increases in Norway. In 1980 the use of electricity was 75 TWh, in 1998 it had increased to 110 TWh. Since nearly 100 percent of the Norwegian electricity production is based on hydropower, the supply of electricity depends on the amount of rain. A long period of dry weather could increase the electricity price sharply. At the most extreme we could run short of electricity. In order to avoid such a situation we could invest in more electricity production in Norway or we could invest in higher import capacity from abroad. Another possibility, which could be less expensive, is to increase the energy flexibility among the consumers. Higher energy flexibility makes the consumers more able to switch between different energy sources as the energy prices fluctuate. In this article we study the energy flexibility in the pulp and paper industry. In 1998 the pulp and paper industry used about 6.4 TWh of electricity, which was about 6 percent of the total electricity consumption in Norway, and they used about the same amount of fossil fuels. The pulp and paper sector is one of the most energy demanding industries in Norway. The energy flexibility can occur in at least two different ways in this sector.

1): They can increase the energy flexibility by changing their output mix towards less energy intensive products when the energy prices increase. In the literature, most papers dealing with micro data assume homogenous products. The pulp and paper is a heterogeneous branch, although they belong to the same industry they produce a wide range of different goods with different technologies. In this article, we disaggregate the pulp and paper industry into three sub-sectors. Each sector produces two different products. Diewert and Wales (1987) developed a flexible cost function, where they adopted the techniques developed by McFadden (1978) and Lau (1978) to guarantee the theoretically conditions. Kumbhakar (1994) expanded the cost function developed by Diewert and Wales (1987) into a multiproduct function. We apply a modified version of Kumbhakar's model, where we introduce firm specific effects to take into account the heterogeneity between firms in each sub-sector. Ignoring heterogeneity could lead to inefficient or inconsistent estimates. We compare our results with more traditional one-industry, one-product results. In chapter 4.2 we test whether the multioutput model gives us a better model than the traditional one-industry, one-product model. In chapter 4.5 we measure the impact of increased production of each good on the energy use, and compare this with the use of an one-industry, one-product model.

2): The energy consumers can increase the energy flexibility by changing their production technology, independent of the output mix. Here we have studied two different implications of the technology influences on the energy flexibility. One possibility for the consumers to increase their energy flexibility is to invest in new technologies or improve their production technologies in order to use relatively less of the energy sources that has become more expensive. This could be measured by technological change. In this paper we measure both the technological change and the bias of it. The technological bias of one energy source measures the energy saving technological progress of this energy source. More general one could say that the technological bias measures the factor *i* saving technological progress. This is done in chapter 4.3. This is not a new issue, see for instance Stevenson (1980) or Bye and Frenger (1991). However, when we measure technological change and the bias, we take into account that the firm produces more than one good (heterogeneity in products), and apply a flexible cost function that guarantees the theoretically curvature conditions. Another possibility is that the consumers use their technology in a given period of time to switch between different energy sources, as the energy prices fluctuate. To what extent the consumers are able to switch between energy sources can be measured by the cross price elasticity. This is done in chapter 4.4.

The pulp and paper industry is one of the oldest manufacturing industries in Norway. It has existed for almost 150 years (Munthe 1993). As the technology has improved and transportation cost decreased, the industry has changed from an industry with many small plants to a few large integrated industrial companies. This structural change still goes on. In the first half of the seventies the pulp and paper industry constituted for more than 150 plants, in the first half of the nineties there was no more than about 70 plants left. In the same time period the output increased about twenty five percent. Total energy use was about the same in the nineties as it was in the seventies, but there has been a tremendous change in energy composition. In the early seventies the use of fossil fuels was nearly two times higher than the use of electricity, in the nineties the situation was turned around. There has also been a considerable change in the output mix. This indicates that the industry has gone through structural and technological changes during this period. In the pulp and paper industry we have seen a switch from fossil fuels towards electricity, and to some extend a switch from energy intensive output to less energy intensive output, mainly among the paper producers. Among the mechanical pulp producers there has actually been an increase in energy intensity. This is driven by conditions on the demand side. There has been reduced demand for the less energy intensive grinded pulp and increased demand for the more energy intensive Thermo Mechanical Pulp (TMP), which has higher quality. And the energy intensity in the production of TMP has increased in order to improve quality (Sollesnes 1993).

This paper is organised as follows. In chapter two we present the theoretical framework. The multiproduct symmetric generalised McFadden cost function (Kumbhakar 1994), and some of its advantages are discussed. In chapter three, we describe the data and some stylised facts about the pulp and paper industry. In chapter four we present the econometric specification, and the results from the analysis. In chapter five we discuss the main results from the study.

2. The model

We assume that each firm at point t in time produces output y according to a general production function:

(2.1) $$y_t = f_t(k_t, x_t),$$

where k is the capital stock and x is a vector of all variable input factors. We assume that every producer minimises his costs for the given amount of production at any time. Then the cost function (c) can be written as a function of output and input factors (Gravelle and Rees 1992):

(2.2) $$c_t = C_t(p_t, k_t, x_t, y_t),$$

where p is a vector of all the input prices.
We assume the following conditions to hold for all time periods t:
a) $C(p,k,x,y)$ increases with p.
b) $C(p,k,x,y)$ is homogenous of degree 1.
c) $C(p,k,x,y)$ is concave in p.
d) $C(p,k,x,y)$ is continuous in p.
e) $C(p,k,x,y)$ is differentiable, at least twice.

Several specifications of equation (2.2) are proposed in the literature. It could for instance be a Cobb-Douglas, CES or a more flexible function. A problem when estimating flexible cost functions is the curvature conditions, especially the concavity condition (see for instance Wales 1977, Christensen and Caves 1980 or Barnett and Lee 1985). One particular problem among the frequently used Translog (TL) or Generalized Leontief (GL) cost function, is the nonlinearity in input prices which may cause curvature problems. One could impose restrictions on both the TL and GL to avoid this problem, but this could lead to other unacceptable restrictions, see Diewert and Wales 1987. They suggest a flexible cost function where one, easily and without loss of flexibility, can impose restrictions that guarantee the curvature conditions. This function, the symmetric generalized McFadden cost function (SGM), Kumbhakar (1994) expands into a multioutput cost function named the multiproduct symmetric generalized McFadden cost function (MSGM). Kumbhakar (1989) introduces fixed factors in the SGM.

Here we will use a modified version of Kumbhakar (1994) and add capital as a quasi-fixed input factor, since we do not have factor prices on capital.[1]

The cost function is:

(2.3)
$$C_t(p_t,k_t,x_t,y_t)=g(p)\left(\sum_{r=1}^{m}\beta_r y_r\right)+\sum_{i=1}^{n}\alpha_i p_i+\sum_{i=1}^{n}\delta_i p_i k+\sum_{i=1}^{n}\varphi_i p_i t+\sum_{i=1}^{n}\alpha_{ii}p_i\left(\sum_{r=1}^{m}\beta_r y_r\right)+$$
$$k\sum_{i=1}^{n}\sum_{r=1}^{m}\kappa_{ir}p_i y_r+t\sum_{i=1}^{n}\sum_{r=1}^{m}\gamma_{ir}p_i y_r+\sum_{i=1}^{n}\sum_{r=1}^{m}\sum_{s=1}^{m}\beta_{irs}p_i y_r y_s+k^2\left(\sum_{i=1}^{n}\omega_i p_i\right)\left(\sum_{r=1}^{m}\beta_r y_r\right)$$
$$+t^2\left(\sum_{i=1}^{n}\tau_i p_i\right)\left(\sum_{r=1}^{m}\beta_r y_r\right),$$

where

(2.4)
$$g(p)=\frac{1}{2}\frac{\sum_{i=1}^{n}\sum_{l=1}^{n}S_{il}p_i p_l}{\sum_{l=1}^{n}\theta_l p_l}.$$

θ_l is non-negative constants, not all of them equal to zero, m is the number of outputs (r) and n is the number of input factors (i) except capital which is quasi-fixed. Since $C(p,y,t,k)$ is linear in input prices p_i, except in the $g(p)$ term, a sufficient condition for the cost function to be global concave in the input prices is that the S (S_{il} element) matrix is negative semidefinite. The S matrix is negative semidefinite if and only if:

(2.5) $(-1)^r\Delta_r(s) \geq 0$ for r =1-n,

jf. (Sydsæter 1990).

$\Delta_r(s)$ is a principal minor of order r, and we assume that (2.3) is defined for an open convex set (Sydsæter 1990). If the S matrix is not negative semidefinite, semidefinitness can be imposed by using Wiley, Schmidt and Brambles (1973) method, i.e. set $S=-AA^T$ where A is a lower triangular matrix of dimension $n-1$, and A^T is A's transposed matrix.

According to Shephard's lemma, we can now write the factor demand (x_i) for factor i as:

[1] For a more detailed discussion of the use of flexible cost functions, see Larsson (2002)

(2.6) $$x_i \equiv \frac{\partial C}{\partial p_i} = \left[\frac{\sum_{j=1}^{n} S_{ij} p_j}{\sum_{j=1}^{n} \theta_j p_j} - \frac{\theta_i}{2} \frac{\sum_{j=1}^{n}\sum_{l=1}^{n} S_{jl} p_j p_l}{\left(\sum_{j=1}^{n} \theta_j p_j\right)^2} \right] \left(\sum_{r=1}^{m} \beta_r y_r \right) + \alpha_i + \delta_i k + \varphi_i t + \alpha_{ii} \left(\sum_{r=1}^{n} \beta_r y_r \right)$$

$$+ k \sum_{r=1}^{m} \kappa_{ir} y_r + t \sum_{r=1}^{m} \gamma_{ir} y_r + \sum_{r=1}^{m}\sum_{s=1}^{m} \beta_{irs} y_r y_s + \omega_i k^2 \left(\sum_{r=1}^{m} \beta_r y_r \right) + \tau_i t^2 \left(\sum_{r=1}^{m} \beta_r y_r \right).$$

The price elasticity follows from ordinary definitions:

(2.7) $$\varepsilon_{ii} \equiv \frac{\partial x_i}{\partial p_i} \frac{p_i}{x_i} = \left\{ \sum_{r=1}^{m} \beta_r y_r \right\} \left[\frac{S_{ii}}{\sum_{j=1}^{n} \theta_j p_j} - 2\theta_i \frac{\sum_{j=1}^{n} S_{ij} p_j}{\left(\sum_{j=1}^{n} \theta_j p_j\right)^2} + \theta_i^2 \frac{\sum_{j=1}^{n}\sum_{l=1}^{n} S_{jl} p_j p_l}{\left(\sum_{j=1}^{n} \theta_j p_j\right)^3} \right] \frac{p_i}{x_i}.$$

As do the cross price elasticities:

(2.8) $$\varepsilon_{if} \equiv \frac{\partial x_i}{\partial p_f} \frac{p_f}{x_i}$$

$$= \left\{ \sum_{r=1}^{m} \beta_r y_r \right\} \left[\left[\frac{S_{if}}{\sum_{j=1}^{n} \theta_j p_j} - \theta_f \frac{\sum_{j=1}^{n} S_{ij} p_j}{\left(\sum_{j=1}^{n} \theta_j p_j\right)^2} \right] - \theta_i \left[\frac{\sum_{j=1}^{n} S_{jf} p_j}{\left(\sum_{j=1}^{n} \theta_j p_j\right)^2} - \theta_f \frac{\sum_{j=1}^{n}\sum_{l=1}^{n} S_{jl} p_j p_l}{\left(\sum_{j=1}^{n} \theta_j p_j\right)^3} \right] \right] \frac{p_f}{x_i}.$$

We assume symmetry in the β_{irs}'s:

i) $\beta_{irs} = \beta_{isr}$.

In order to identify all the parameters, we assume symmetry in the *S*-matrix and normalise the sum of the β_r to one:

ii) $S_{ij} = S_{ji}$.

iii) $\sum_{j=1}^{n} S_{ij} = 0$, for all i.

iv) $\sum \beta_k = 1$.

θ_l is set equal to the sample mean of factor l.

3. Data

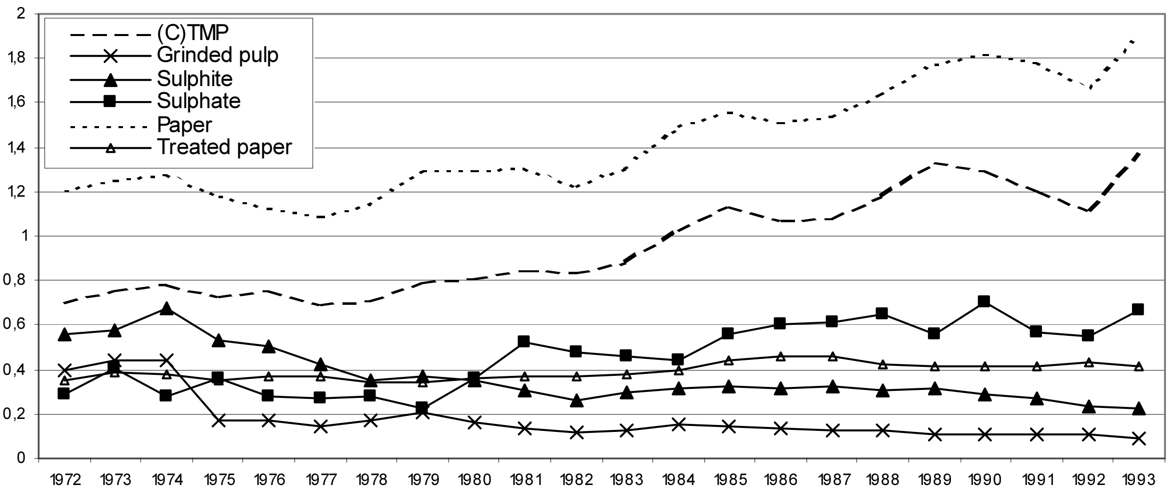
The pulp and paper industry is a heterogeneous sector. We divide the sector into three sub-sectors:

1. Mechanical pulping including grinded pulp and TMP (which also include chemical thermo mechanical pulp CTMP).
2. Chemical pulp or cellulose including sulphate and sulphite (which also include dissolving pulp).
3. Paper which is divided into production of paper and paper products.
4. Every factory is observed for at least four years and at most twenty-two years in the time period 1972-1993. The data used here are unbalanced panel data. Not all factories exist for the same amount of years. The mechanical pulp sector includes 461 observations, the cellulose sector includes 184 observations, while the paper sector includes 1795 observations.

The input factors are divided into five groups; labour measured in hours worked, electricity consumption measured in GWh, other energy sources mainly fossil fuels[2] which is also measured in GWh, other intermediate inputs and capital stock which is treated as a quasi-fixed input. Since nearly 100 percent of the Norwegian electricity production is based on hydropower, the price of electricity is not directly dependent of the price on fossil fuels.

Figure 3.1 presents the production of the different products in the pulp and paper industry. Grinded pulp and (C)TMP are mostly used in the production of more crude paper and cartoons. Sulphate and sulphite are mostly used in the production of less crude paper like writing paper.

Figure 3.1. Disaggregated outputs for pulp and paper, mill. ton



[2] For some plants the use of wood is an important energy source

In figure 3.2 we see the relative development of the input factors for the production of mechanical pulp. As we can see in figure 3.3 there has been a relatively large increase in the use of electricity and the energy intensity. Energy intensity is measured as energy pr. amount of produced output (MWh/produced ton) By combining the information from figure 3.1, 3.2 and 3.3 we find that the production of TMP has increased, as have the use of electricity and the energy intensity. This could (wrongly) lead one to believe that the production of TMP has been less effective in the use of energy during the period. But the reason for this seemingly odd relation is that the producers of TMP have increased the energy intensity in order to improve the quality of the pulp, because the quality increases with increased use of electricity per unit of output (Sollesnes 1993).

Figure 3.2. Use of inputs in the production of mechanical pulp, 1972=100

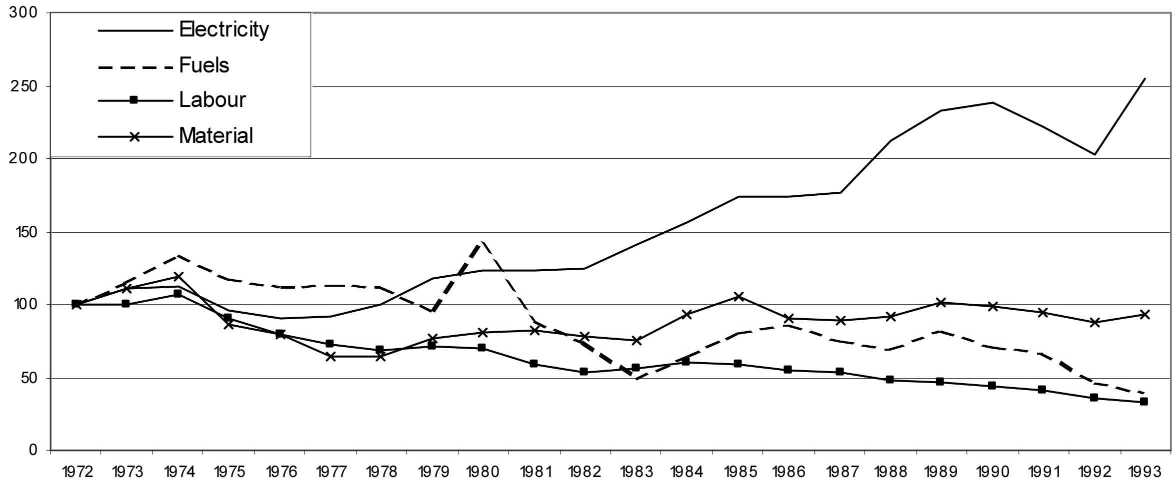


Figure 3.3. Energy intensity in the production of mechanical pulp, MWh/ton

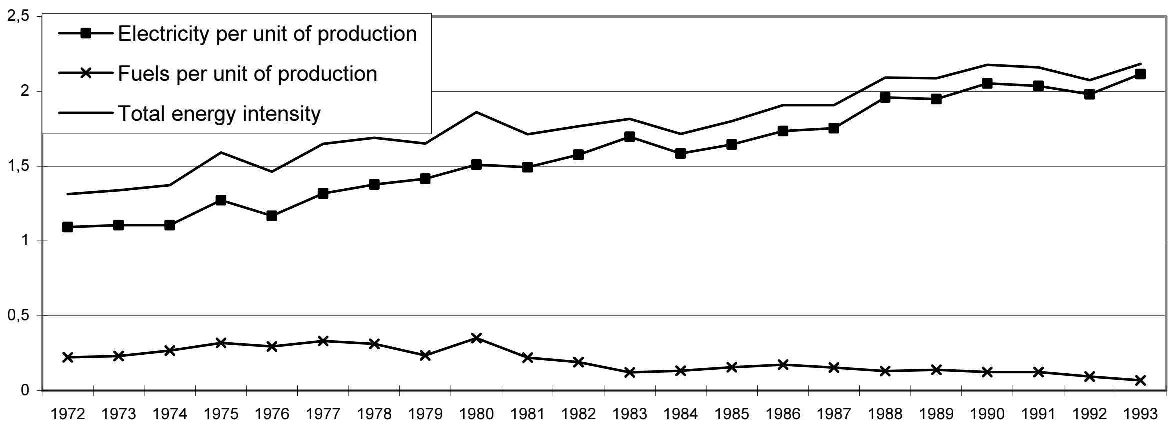


Figure 3.4 presents the relative development of the input factors for the production of cellulose. Electricity is the only input factor that increases during the period. From figure 3.1 we see that the production of sulphate has increased and the production of sulphite has decreased. Despite this change from a less energy intensive product to a more energy intensive product we see from figure 3.5 that the energy intensity has decreased during the period.

Figure 3.4. Use of inputs in the production of cellulose, 1972=100

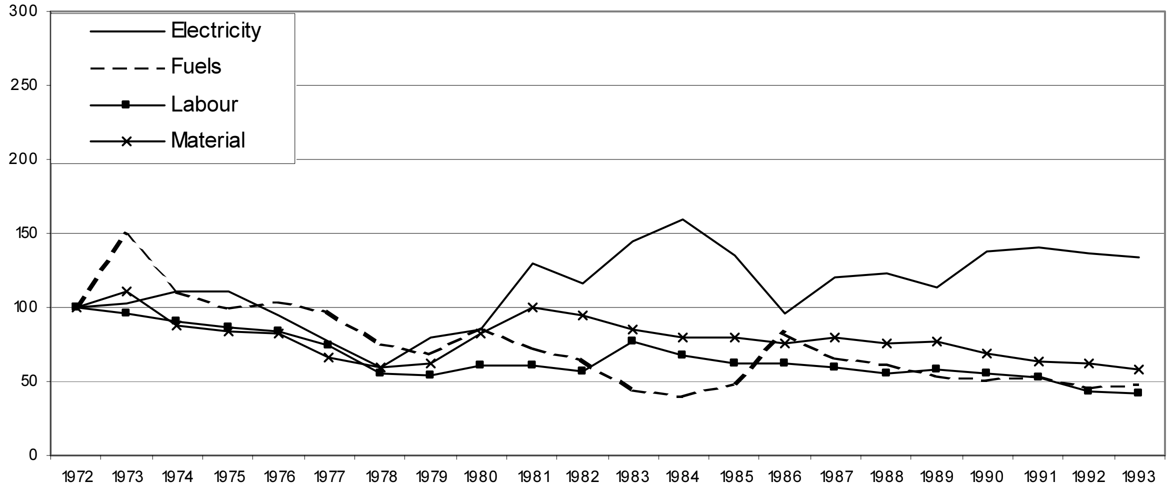


Figure 3.5. Energy intensity in the production of cellulose, MWh/ton

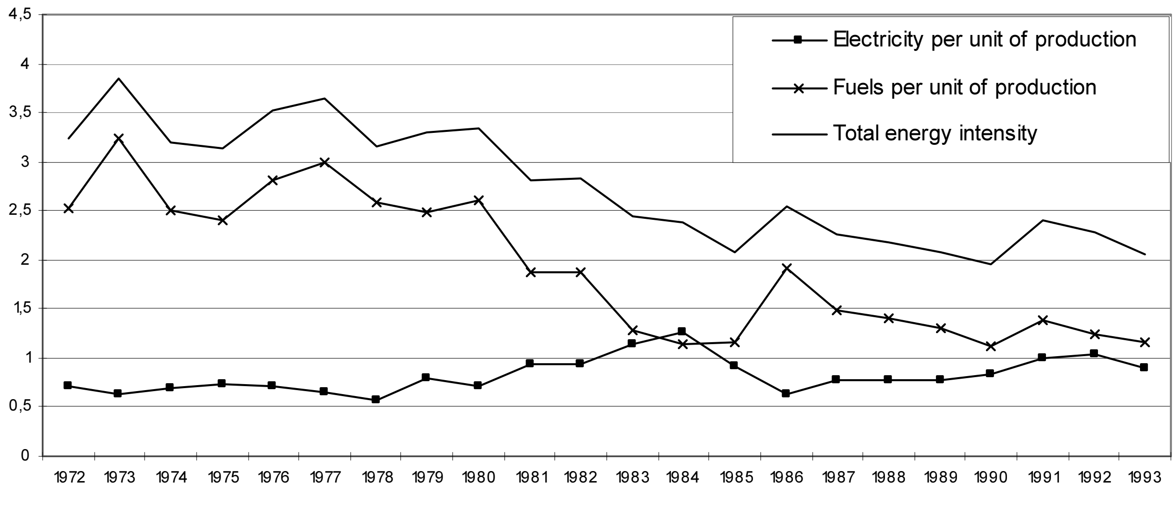


Figure 3.6 presents the relative development of the input factors for the production of paper. Also here the use of electricity has increased. The production of paper has increased by nearly 60 percent while the production of paper products has remained constant (figure 3.1). From figure 3.7 we see that the

energy intensity has fallen. Cellulose and paper producers seem to have one thing in common, they have switched the energy use from fossil fuels to electricity.

Figure 3.6. Use of inputs in the paper production, 1972=100

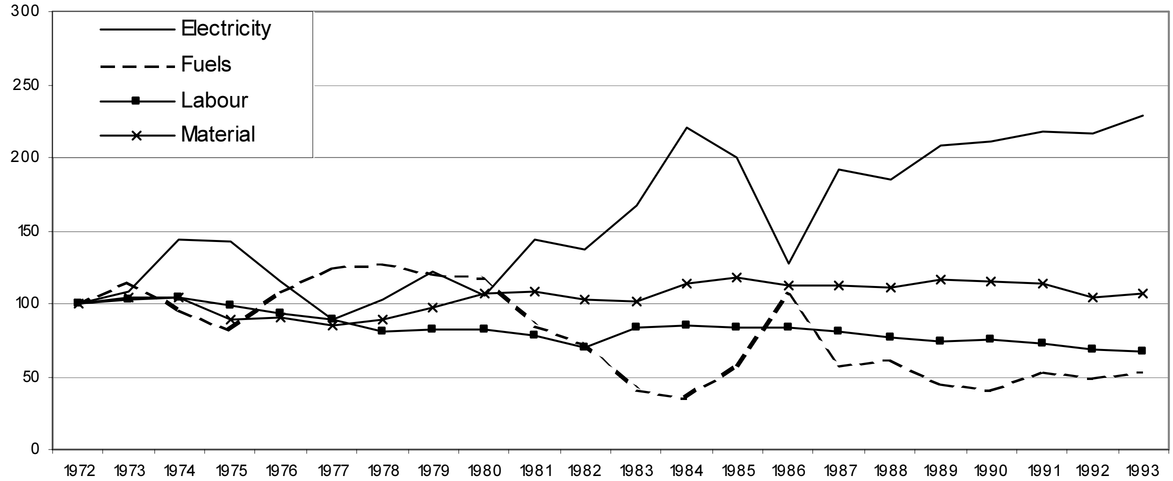
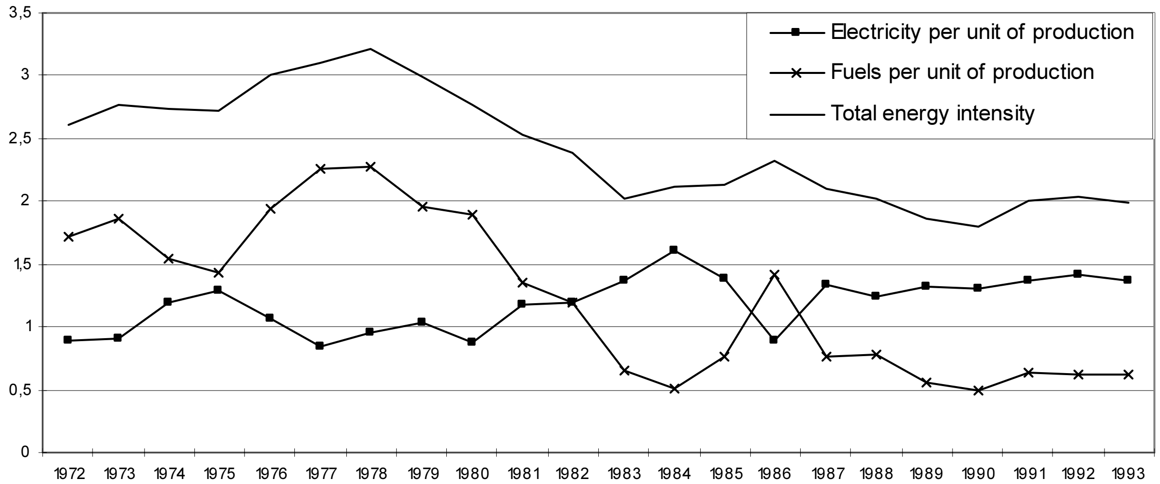


Figure 3.7. Energy intensity in the production of paper, MWh/ton



4. Empirical results

4.1 Stochastic specification

A stochastic specification of the cost function given in (2.3) is:

(4.1) $$C(p,y,t,k)=g(p)\left(\sum_{r=1}^{m}\beta_r y_r\right)+\sum_{i=1}^{n}\alpha_i p_i+\sum_{i=1}^{n}\delta_i p_i k+\sum_{i=1}^{n}\varphi_i p_i t+\sum_{i=1}^{n}\alpha_{ii} p_i\left(\sum_{r=1}^{m}\beta_r y_r\right)+$$
$$k\sum_{i=1}^{n}\sum_{r=1}^{m}\kappa_{ir} p_i y_r+t\sum_{i=1}^{n}\sum_{r=1}^{m}\gamma_{ir} p_i y_r+\sum_{i=1}^{n}\sum_{r=1}^{m}\sum_{s=1}^{m}\beta_{irs} p_i y_r y_s+k^2\left(\sum_{i=1}^{n}\omega_i p_i\right)\left(\sum_{r=1}^{m}\beta_r y_r\right)$$
$$+t^2\left(\sum_{i=1}^{n}\tau_i p_i\right)\left(\sum_{r=1}^{m}\beta_r y_r\right)+\sum_{f=1}^{M}d_f D_f+v_{cft}.$$

Stochastic specifications of the demand functions given in (2.6) are:

(4.2) $$x_i\equiv\frac{\partial C}{\partial p_i}=\left[\frac{\sum_{j=1}^{n}S_{ij}p_j}{\sum_{j=1}^{n}\theta_j p_j}-\frac{\theta_i}{2}\frac{\sum_{j=1}^{n}\sum_{l=1}^{n}S_{jl}p_j p_l}{\left(\sum_{j=1}^{n}\theta_j p_j\right)^2}\right]\left(\sum_{r=1}^{m}\beta_r y_r\right)+\alpha_i+\delta_i k+\varphi_i t+\alpha_{ii}\left(\sum_{r=1}^{n}\beta_r y_r\right)$$
$$+k\sum_{r=1}^{m}\kappa_{ir}y_r+t\sum_{r=1}^{m}\gamma_{ir}y_r+\sum_{r=1}^{m}\sum_{s=1}^{m}\beta_{irs}y_r y_s+\omega_i k^2\left(\sum_{r=1}^{m}\beta_r y_r\right)+\tau_i t^2\left(\sum_{r=1}^{m}\beta_r y_r\right)+v_{ift}.$$

To take into account the heterogeneity between plants, we have introduced a plant specific dummy D_f. In Døhl and Larsson (2002) we found that a fixed heterogeneity factor seems to be "better" than random coefficients, given the data at hand. These parameters occur only in the cost function. In order to save one degree of freedom we normalised the sum of the dummies to zero.

(4.3) $$D_1=\sum_{f=2}^{M}D_f\ ,$$

where M is the number of firms.

To adjust for the autocorrelation problem we assume that the error term follows an autoregressive process of first order. We specify the error terms as:

(4.4) $$v_{lft}=\rho_l v_{lft-1}+\eta_{lft},$$

for $l=[c,i]$,

where η_{lft} is white noise.

We have estimated (4.1) and (4.2) for each sub-sector and for the sector as a whole, below this last results are called aggregate. The estimated results are reported in appendix C. The summary results from the estimation are reported in table 4.1 below.

4.2 Testing the single- versus the multioutput model

If the heterogeneity between firms[3] has implications for the estimated results, a multioutput model should explain data better than a single-output model. In order to test this, we can use a chi-square test according to Mizon (1977). The test observator is:

$$(4.5) \qquad LR = -2\frac{\left(T-k-1+\frac{r}{2}\right)}{T}\left(L_r - L_u\right) \sim \chi^{\sim 2}(r),$$

where

T - Number of observations.

k - Number of estimated coefficients in the unrestricted (multioutput) model.

r - Number of restrictions on the unrestricted model to get the restricted (single-output).

L_u - Unrestricted log-likelihood value.

L_r - Restricted log-likelihood value.

To get single-output from (4.1) and (4.2) we set:

$\beta_r = 1$, for all r and all the following conditions must hold:

$\beta_{irs} = \beta_i$, $\kappa_{ir} = \kappa_i$ and $\gamma_{ir} = \gamma_i$.

The single-output model gives us 17 less parameters to estimate. Which again gives us 17 more degrees of freedom in the single-output than in the multioutput model.

Table 4.1 presents the summary results from the estimation of the single-output and multioutput models. We see that the multioutput production function explains the data better than the single-output production function, there is no evidence in the data to accept the assumption of product homogeneity.[4] The test statistics is 125.8 for the mechanical pulp producers, 192.7 for the cellulose producers and 332.9 for the paper producers. The critical value is 35.7 at 0.5 percent level of significance.

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[3] In the meaning that they produce several products.

[4] For a discussion of multioutput versus single-output see, Larsson (2002).

Table 4.1. Summary results from the estimation of the singel- and multioutput model

Model	Mechanical pulp		Cellulose		Paper	
	Two products	One product	Two products	One product	Two products	One product
Maximum likelihood value	6603	6526	1566	1407	19391	19205
Estimated parameters	92	75	80	63	196	179
Degrees of freedom		17		17		17
Test statistics		125.8		192.7		332.9
R^2_C - adj.	0.98	0.98	0.97	0.96	0.94	0.94
R^2_l - adj.	0.75	0.73	0.91	0.88	0.89	0.88
R^2_{el} - adj.	0.98	0.98	0.87	0.83	0.90	0.89
R^2_{en} - adj.	0.74	0.74	0.88	0.81	0.77	0.77
R^2_m - adj.	0.99	0.99	0.94	0.94	0.95	0.95

Where R^2_i - adj. is the adjusted residual sum of squares for each equation *i* in (4.1) and (4.2).

4.3 Technical change and factor biased technical change

Does technical progress lead to more or less use of one factor relatively to the other factors? If the following conditions hold in (4.1) and (4.2), the technical change has been factor neutral:

$$\varphi_i = \varphi$$
$$(4.6) \qquad \tau_i = \tau$$
$$\gamma_{ir} = \gamma_r .$$

To get a model with factor neutral technical change from the multioutput model in (4.1) and (4.2) we get 12 less parameters to estimate. This gives us 12 more degrees of freedom in the model of factor neutral technical change.

These conditions are tested within the multioutput function above. Table 4.2 shows the likelihood value for the model with neutral technical change. And the test statistics are far above any reasonable level of significance. The critical value is 28.3 at 0.5 percent level of significance. So there is no evidence in the data to accept the assumption of factor neutral technical change. This should not come as a surprise. Especially one should expect that the high increase in the oil prices during the seventies and early eighties, led to increased focus on energy saving technological progress in general, and fuel saving technological progress in particular.

Table 4.2. Estimation results

Hicks neutral technical change	Mechanical pulp	Cellulose	Paper
Maximum likelihood value	6483	1457	19304
Degrees of freedom	12	12	12
Test statistics	194.7	129.1	155.0

A way to measure the bias in the technological change is proposed by Bye and Frenger (1991). They measure overall technical progress (TP) as cost reduction over time:

(4.7) $$TP = -\frac{\partial \ln C}{dt} = -\frac{1}{C}\frac{\partial C}{\partial t}$$

$$= \sum_{i=1}^{n} \varphi_i p_i + \sum_{i=1}^{n}\sum_{r=1}^{m} \gamma_{ir} p_i y_r + 2t\left(\sum_{i=1}^{n} \tau_i p_i\right)\left(\sum_{r=1}^{m} \beta_r y_r\right) / \text{C}.$$

If *TP* is positive there has been a technological progress.

The rate of technical change of factor (*i*) is measured as the reduction in the use of factor *i* over time:

(4.8) $$TP_i = -\frac{\partial \ln p_i x_i}{dt} = -\frac{1}{p_i x_i}\frac{\partial p_i x_i}{\partial t} = -\frac{1}{x_i}\frac{\partial x_i}{\partial t}$$

$$= \varphi_i + \sum_{r=1}^{m} \gamma_{ir} y_r + 2\tau_i \left(\sum_{r=1}^{m} \beta_r y_r\right) t / \text{X}_\text{i}.$$

If TP_i is positive there has been factor *i* saving technological progress.

Factor biased technical change is defined by the change of cost share s_i:

(4.9) $$\text{FBTP}_\text{i} = \frac{\partial \ln s_i}{\partial t} = \frac{\partial \ln\left(\frac{p_i x_i}{C}\right)}{\partial t} = \frac{\partial \ln p_i x_i - \partial \ln C}{\partial t} = \text{TP-TP}_\text{i}.$$

If FBTP_i is negative the factor i saving technological progress has been larger (measured in percent) than the total cost saving technological progress.

In general, we would expect to find the highest technological progress towards that factor for which the cost-share has increased most and that is most substitutable. In table 4.3 we report the overall technical progress TP given in (4.7) as an average and the factor specific technical change TP_i given in (4.8) as an average for each sub-sector and aggregated for the whole sector. And we report the factor biased technical change as measured in (4.9). In Appendix A the year to year overall and factor specific technological progresses for each sub-sector are presented.

Table 4.3. Average technological progress measured in percent

	Mechanical pulp	Cellulose	Paper	Aggregate
TP	1.3	4.7	0.4	0.4
TP_E	-1.9	0.7	-2.0	-3.4
$FBTP_E$	3.1	4.0	2.4	3.8
TP_F	0.5	5.7	-0.2	5.5
$FBTP_F$	0.8	-1.1	0.5	-5.1
TP_L	2.9	5.6	0.4	-0.5
$FBTP_L$	-1.6	-1.0	-0.1	0.9
TP_M	1.6	3.7	0.8	1.3
$FBTP_M$	-0.3	1.0	-0.4	-0.9

For the producers of mechanical pulp the average technological progress has been 1.3 percent per year. In Appendix A we see that the progress has declined during the period. The electricity saving technical progress has in average been -1.9 percent, and it has remained relatively steady during the estimated period. This is most likely related to the same relations as discussed in chapter 3, i.e. that the producers of (C)TMP have increased the energy intensity in order to improve the quality of the product. Another, but probably less important, reason is that many of the producers of mechanical pulp have favourable electricity contracts with the government, which gives less incentives in promoting energy saving technology. The fuel saving technical progress has on the average been 0.5 percent increasing relatively sharply during the period. The mechanical pulp producers seem to have had both relatively large labour saving technological progress, and to some extent a material saving technological progress. Both show a declining trend.

Producers of cellulose seem to have had the largest overall technological progress, which has been 4.7 percent each year in average. This is most likely due to the investment that has taken place in these firms to build up a more modern sulphate capacity. We see from Appendix A that the overall technological progress has been stable during the period. The electricity saving technological progress has in average been 0.7 percent each year, and shows a weakly increasing trend. The fuel saving technological progress has in average been 5.7 percent, but is rapidly falling during the last period. Also the cellulose producers had a large labour and material saving technological progress.

The paper producers have had the lowest overall technological progress, only 0.4 percent in average, but weakly increasing during the period. The large increase in the oil prices during the seventies and eighties, meant a lot more for the paper producers, which in a less degree where protected by favourable electricity contracts than the mechanical pulp producers. In Appendix A we see that there has been a positive but decreasing fuel saving technological progress, and a negative but increasing electricity saving technological progress as electricity became more important as an energy source. In the period 1986-1993 there has been a higher technological progress for electricity than for fuel. The reason for this is probably the fact that electricity prices have increased by 15 percent between 1989-91, while the fuel prices increased 5 percent. This made it more profitable to invest in technologies that reduce the electricity input. The paper producers actually had a labour saving technological regress at the average, but we see from Appendix A, that this increases from negative to positive during the period. The paper producers had the lowest material saving technological progress, but this was weakly increasing during the period.

At the aggregate level the average overall technological progress is low. We see a relatively large fuel saving technological progress. The electricity saving technological progress has been negative in the average. We also see a material saving technological progress. But we have an odd case for labour, in the aggregate we see a negative labour saving technological progress, while this is positive for all sub-sectors.

4.4 Elasticity

The pulp and paper industry has gone through large structural changes during the seventies and eighties. If these firms are going to survive in the future they have to be able to deal with structural changes in the future too. To what extent they will handle structural changes in the future, depends among other things on how flexible these firms are. There are large differences between firms and between sub-sectors. In table 4.4 we have summarised the elasticities given in (2.7) and (2.8), for each sub-sector and the aggregated elasticities. Appendix B reports the year to year elasticity for each sub-sector and for the sector as a whole. We see that all own price elasticities have the expected signs.

For the producers of mechanical pulp there seems to exist a complementary relationship between electricity and fuel. The price-quantity response measured in percent is naturally higher when we look at the price change of electricity's influence on the fuel consumption, than if we look at the price change of fuel's influence on the electricity consumption. This is due to the fact that the electricity consumption is much higher than the fuel consumption. The positive elasticity between labour and electricity and between labour and fuel is probably due to a substitution relation between labour and capital. Increased use of capital leads to increased consumption of energy. In appendix B we see that the elasticities have been relatively stable during the period. Except the elasticities for fuel, especially we see an increasing (more negative) own price elasticity for fuel. The reason for this result, could be the extremely low share of fuel in this sector.

The cellulose producers have a moderate cross price elasticity between fuel and electricity, considered the a priori high substitution opportunities between fuel and electricity. The price elasticity for labour is relatively high. But the price elasticity for labour is probably overestimated. Some of this effect should probably have been captured in a cross price elasticity between labour and capital, which is excluded since capital is a quasi-fixed factor. The reason why this is probably overestimated is that higher price on the labour does not only lead to reduced demand for labour but also increased demand for capital, which can substitute labour, which again lead to higher energy consumption.

Table 4.4. Average elasticity

	Mechanical pulp	Cellulose	Paper	Aggregate
ε_{ee}	-0.17	-0.19	-0.42	-0.27
ε_{el}	0.06	-0.02	0.35	0.13
ε_{ef}	-0.01	0.18	0.24	0.12
ε_{em}	0.12	0.03	-0.16	0.02
ε_{ff}	-0.43	-0.30	-0.47	-0.45
ε_{fe}	-0.12	0.10	0.22	0.15
ε_{fl}	0.24	0.22	0.44	0.37
ε_{fm}	0.31	-0.02	-0.19	-0.06
ε_{ll}	-0.09	-0.33	-0.29	-0.25
ε_{le}	0.05	0.00	0.05	0.03
ε_{lf}	0.03	0.08	0.07	0.08
ε_{lm}	0.01	0.25	0.17	0.14
ε_{mm}	-0.20	-0.38	-0.27	-0.25
ε_{me}	0.14	0.00	-0.06	0.01
ε_{mf}	0.05	-0.01	-0.07	-0.02
ε_{ml}	0.01	0.38	0.40	0.26

The paper producers have the highest price elasticity for electricity. The paper producers have relatively high cross price elasticity between labour and electricity. This is probably caused by the large increase in capital stock, which have substituted some of the labour. This increase in the capital stock leads to a higher demand for energy. Electricity is chosen instead of fossil fuels because it is cheaper.

These results correspond relatively well with the results in Døhl and Larsson (2001), except for the own price elasticity of labour which is larger in the present study.

4.5 Factor biased production growth

To be able to make forecasts, it is interesting to know how production growth affects the use of input factors. In this study we were also interested in how the production growth of different products influenced the energy composition between electricity and fossil fuels. A way to measure this is by differentiation the factor demand by production:

(4.10) $$\varepsilon_{iy_r} \equiv \frac{\partial x_i}{\partial y_r}\frac{y_r}{x_i} =$$

$$\left[\beta_r\left[\frac{\sum_{j=1}^{n} S_{ij}p_j}{\sum_{j=1}^{n}\theta_j p_j} - \frac{\theta_i}{2}\frac{\sum_{j=1}^{n}\sum_{l=1}^{n} S_{jl}p_j p_l}{\left(\sum_{j=1}^{n}\theta_j p_j\right)^2} + \alpha_{ii} + \tau_i t^2 + \omega_i k^2\right] + k\kappa_{ir} + t\gamma_{ir} + 2\sum_{s=1}^{m}\beta_{irs}y_s\right]\frac{y_r}{x_i}.$$

We report the results in figure 4.1 - 4.4, and the average results in table 4.5. From table 4.5 we see that one percent increase in the production of TMP increases the use of electricity in the mechanical pulp sector by 0.9 percent. This situation illustrates the advantage of estimating on firms with heterogeneous products instead of at a more aggregated sectoral level. By taking into account that an aggregated sector actually produces a set of different products, we can estimate the different products impact on the energy use much more precisely. The elasticities between different output are not directly comparable, since one percent increase in the production of paper means a lot more for the use of energy than one percent increase in the production of paper products.

Table 4.5. Average output elasticity

		ε_{ey_r}	ε_{fy_r}	ε_{ly_r}	ε_{my_r}
Mechanical pulp	Grinded pulp	0.16	0.10	0.14	0.16
	(C)TMP	0.90	0.49	0.39	0.84
Cellulose	Sulphite	0.34	0.42	0.37	0.43
	Sulphate	0.67	0.70	0.55	0.42
Paper	Paper	0.43	1.19	0.23	0.44
	Paper products	0.01	0.10	0.11	0.13
Aggregate		0.73	1.08	0.31	0.79

In figure 4.1 we see the electricity/output elasticity and fuel/output elasticity for the mechanical pulp producers. The elasticities have been relatively stable, except the fuel/(C)TMP elasticity, which has increased during the period. As we can see from figure 3.2 the mechanical pulp producers have increased their use of electricity and decreased their use of fuels during the period. This indicates that they have increased their total electricity capacity and/or increased their share of electricity on the cost of fuel. Most possibly both have happened. This implies that if the producers are going to increase production in a given period of time where the technology is given, they have to use a relatively higher degree of fuel than electricity because they reach the capacity limit of electricity. This situation gets more important during the period. That is probably why the fuel/(C)TMP elasticity has increased during the period.

Figure 4.1. Output elasticity for the mechanical pulp producers

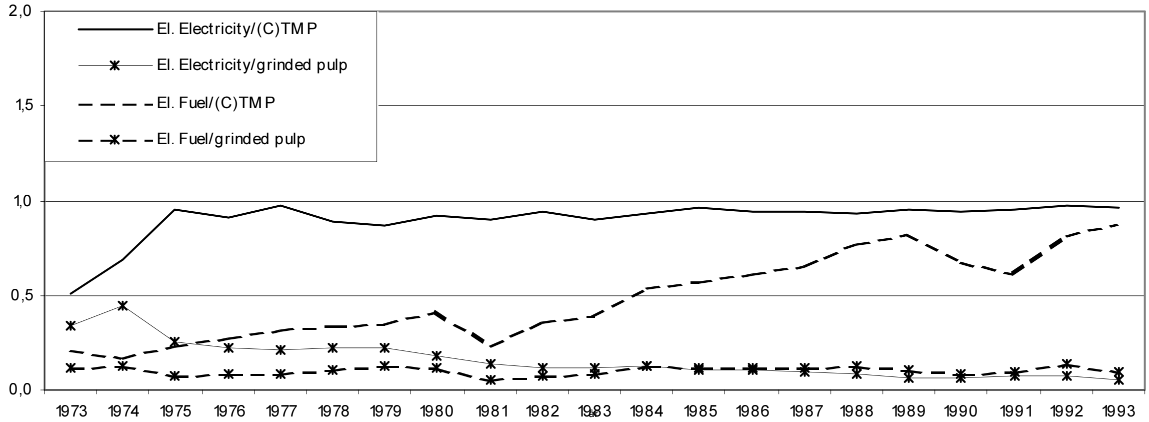
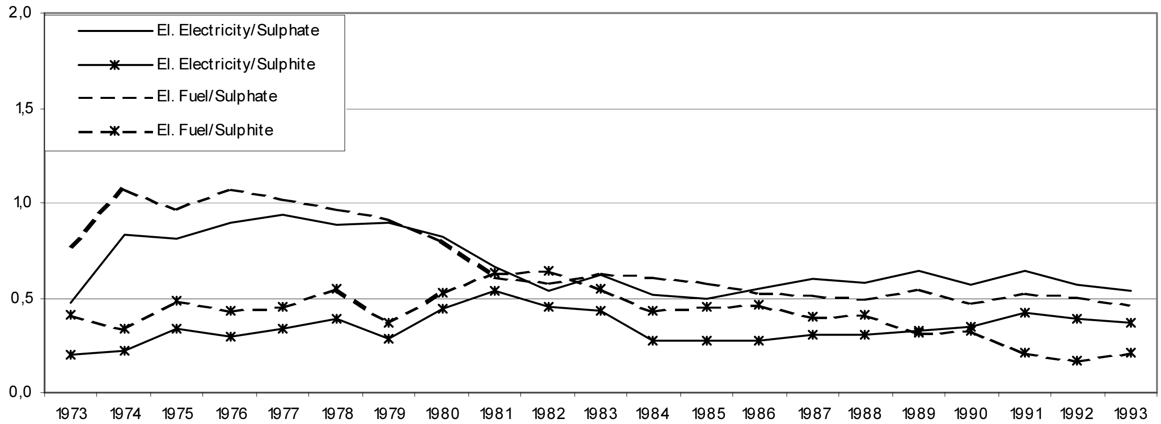


Figure 4.2 shows the electricity/output elasticity and fuel/output elasticity for the cellulose producers. Both the electricity/output elasticity and fuel/output elasticity show a decreasing trend for the sulphate producers. This is probably caused by the relatively large technological progress among the sulphate producers. The elasticities for the sulphite producers are relatively constant. But we observe a decreasing trend for fuel/output elasticity from the middle of the period. This is probably due to the decreased importance of the fuel as an energy source.

Figure 4.2. Output elasticity for the cellulose producers



From figure 4.3 we find the electricity/output elasticity and fuel/output elasticity for the paper producers. The most striking point here is that the fuel/output elasticity is higher than the electricity/ output elasticity for the paper producers and has been so during the entire period. It is also higher than one from the middle of the period. This figure may mislead us to conclude that the use of fuel has increased more than the use of electricity. However, figure 3.6 shows that this can not be true. The paper producers have increased their total electricity capacity and increased their share of electricity on the behalf of fuel. This means that if the producers are going to increase production in a given period of time where the technology is given, they have to use a relatively higher share of fuel than electricity because they have reached the capacity limit of electricity. And this situation has become more important over time. That is why the fuel/paper elasticity has increased during the period.

Figure 4.3. Output elasticity for the paper producers

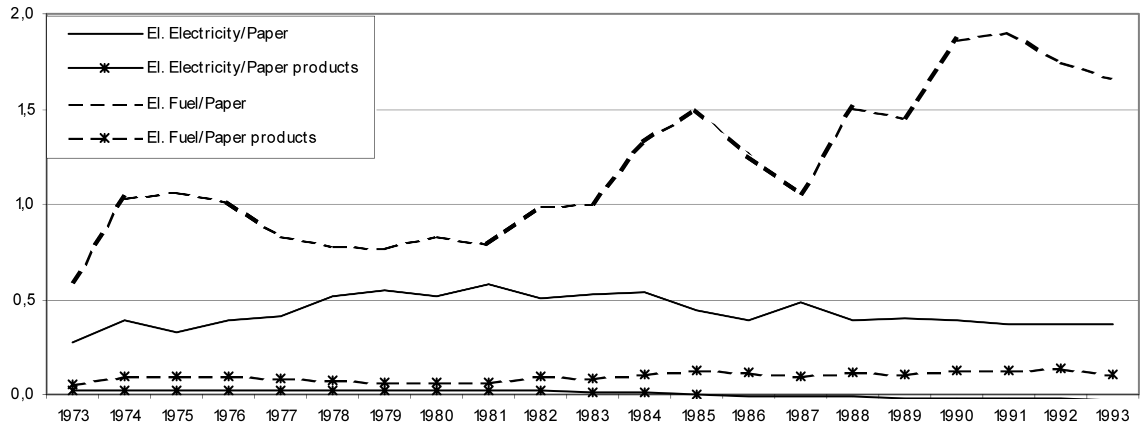
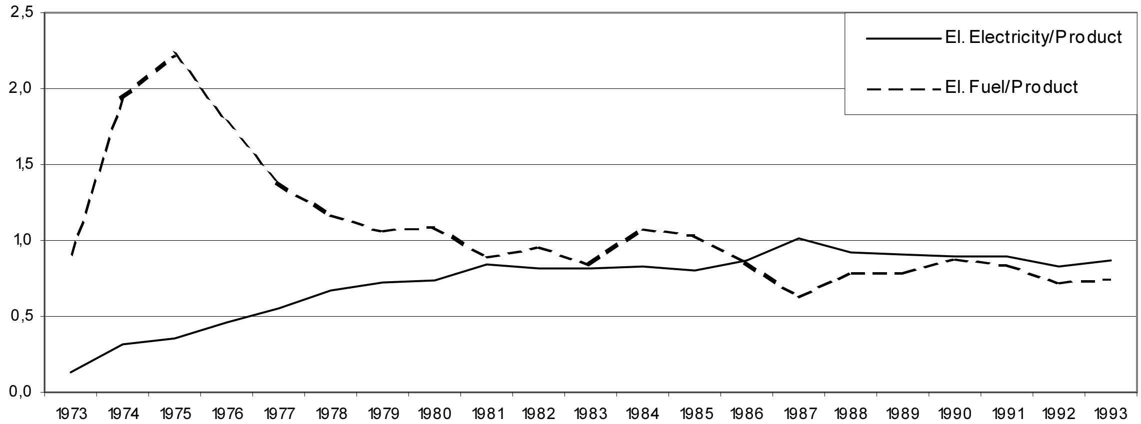


Figure 4.4. Aggregate output elasticity



In figure 4.4 we see the aggregate electricity/output elasticity and fuel/output elasticity. We see that the fuel/output elasticity has declined during the first half of the period and has remained relatively stable thereafter. The electricity/output elasticity has increased during the first half of the period and has remained stable thereafter. Here we see that the effect of higher electricity capacity and the lower importance of fuel has overweighed the effect of which is occurred by limited capacity of electricity which again lead to relatively more use of fuel if the producers want to increase output.

4.6 Factor biased capital change

Will increased capital stock lead to more or less use of one variable factor relatively to the another variable factors? This can be tested by estimating 4.1) and 4.2) by setting:

$$\delta_i = \delta$$

(4.11) $$\omega_i = \omega$$

$$\kappa_{ir} = \kappa_r.$$

We use the same test statistics according to Mizon (1977) as in chapter 4.2. The test results from the estimation of (4.1) and (4.2) compared by using the restrictions given in (4.11) are reported in table 4.6. There is no evidence in the data to accept the assumption of factor neutral capital expansion. The critical value is 28.3 at 0.5 percent level of significance. According to the discussion above this is not surprising. If a firm invests in new capital the reason for this should be that they could produce a given amount of output cheaper. Or the investment should give the firm an opportunity to change their output mix in such a way that they could have a higher profit. According to the discussion above it is not unreasonable to believe that the capital expansion during the period has lead to relatively less use of fuels.

Table 4.6. Estimation results

Factor neutral capital increase	Mechanical pulp	Cellulose	Paper
Maximum likelihood value	6554	1485	19221
Test statistics	79.5	96.0	151.4
Degrees of freedom	12	12	12
R^2_C - adj.	0.98	0.97	0.98
R^2_l - adj.	0.74	0.89	0.89
R^2_{el} - adj.	0.98	0.87	0.90
R^2_{en} - adj.	0.74	0.88	0.80
R^2_m - adj.	0.99	0.93	096

Where R^2_i - adj. is the adjusted residual sum of squares for each equation *i* in (4.1) and (4.2), given the restriction in (4.11).

5. Conclusion

In this study the importance of heterogeneity[5] and what impact this have on estimated elasticities in the pulp and paper branch is studied. This is done by applying a multiproduct symmetric generalized McFadden cost function. This function guarantees that the theoretically curvature conditions are fulfilled. In this study the producers in the sector are divided into separate sub-sectors according to homogeneity of their products. By using aggregate sectoral data one can overlook some important relations. In particular, the estimated technological progress and output elasticities are sensitive for the aggregation level. But it is important to be aware that we do not know a priori which ones of the elasticities that are sensitive for the level of aggregation.

The energy flexibility in the pulp and paper sector differs with respect to technology and product choice. The producers of cellulose and paper are relatively flexible, while the producers of mechanical pulp are not so flexible with respect to energy choices, at least in the short term.

During the examined period there have been large changes in the energy prices, in particular the oil price shocks in the seventies and eighties are presumably important. They lead to an increased focus on cost reductions through reduced energy costs, both through energy saving and energy switching. In this article we have measured this as a factor biased technological change. The technological progress seems to have been fuel saving, at least in the seventies and early eighties. In the later eighties and early nineties there has been a switch in factor saving technological progress away from fuel and towards other input factors. The reason behind this is that fuels became less important over time. The focus of the technological progress changed towards other factors that meant more in the cost saving process. This is important for both cellulose and paper producers to a lesser degree the case for mechanical pulp producers. There are probably two reasons behind this. The mechanical pulp producers, to a larger extent than the cellulose and paper producers, had favourable electricity contracts with the government and electricity has always been their major energy source. The oil price shocks in the seventies meant much less for them. The other reason is that the focus for the mechanical pulp producers has been on increasing the energy intensity in order to improve the quality of the products.

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[5] In the meaning of disaggregating the products.

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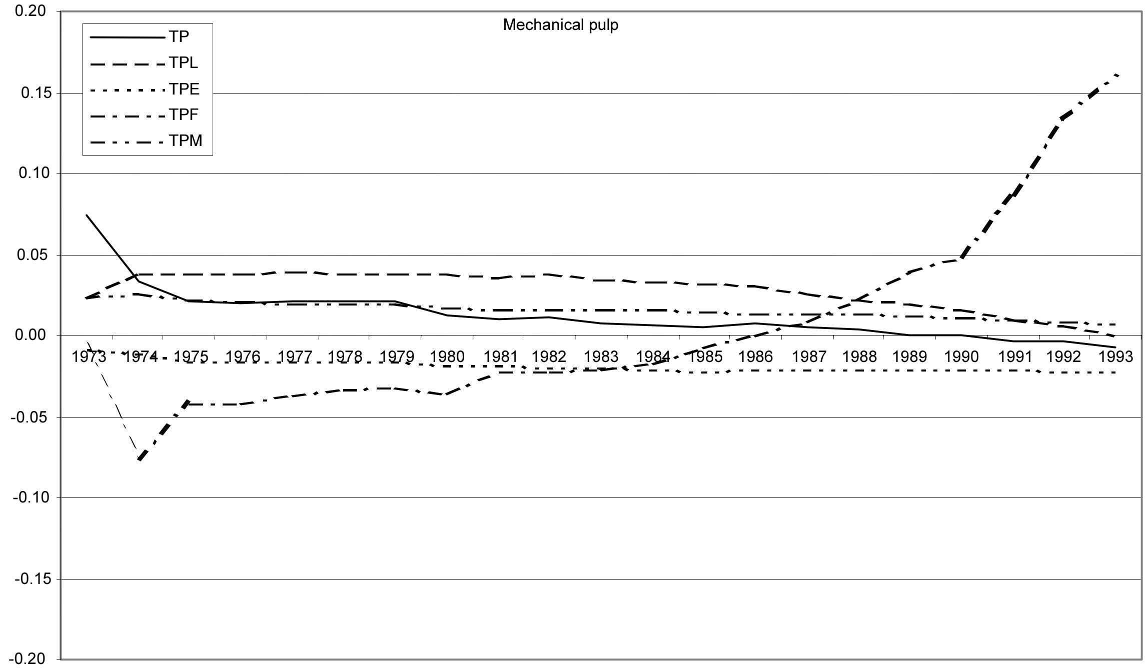
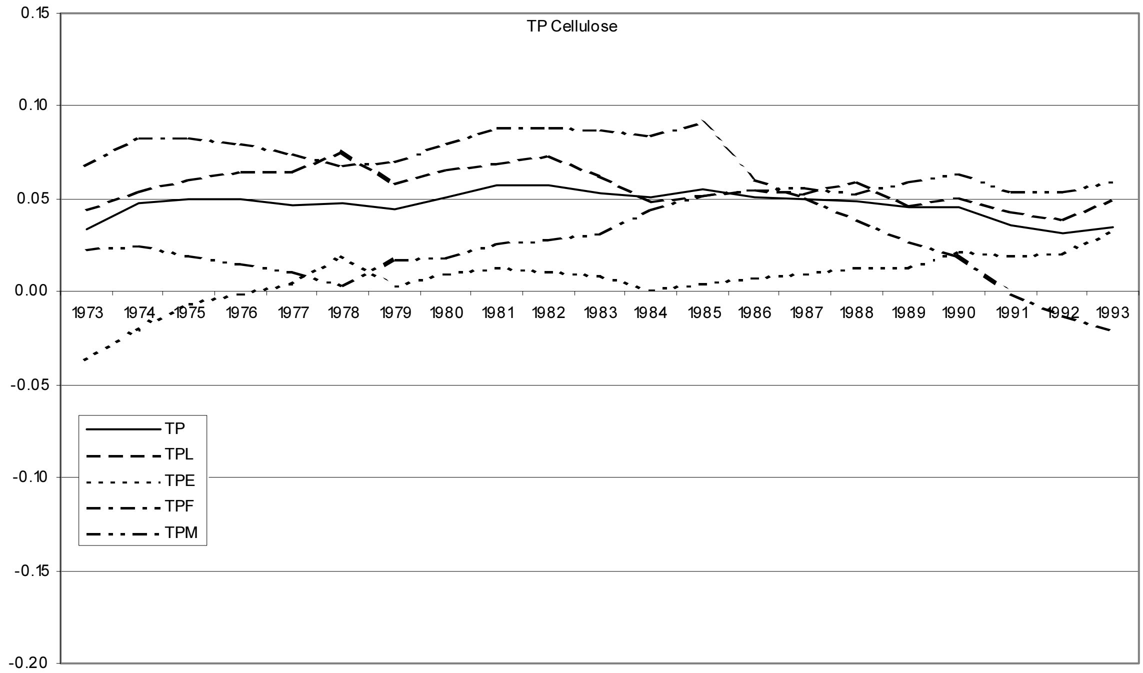
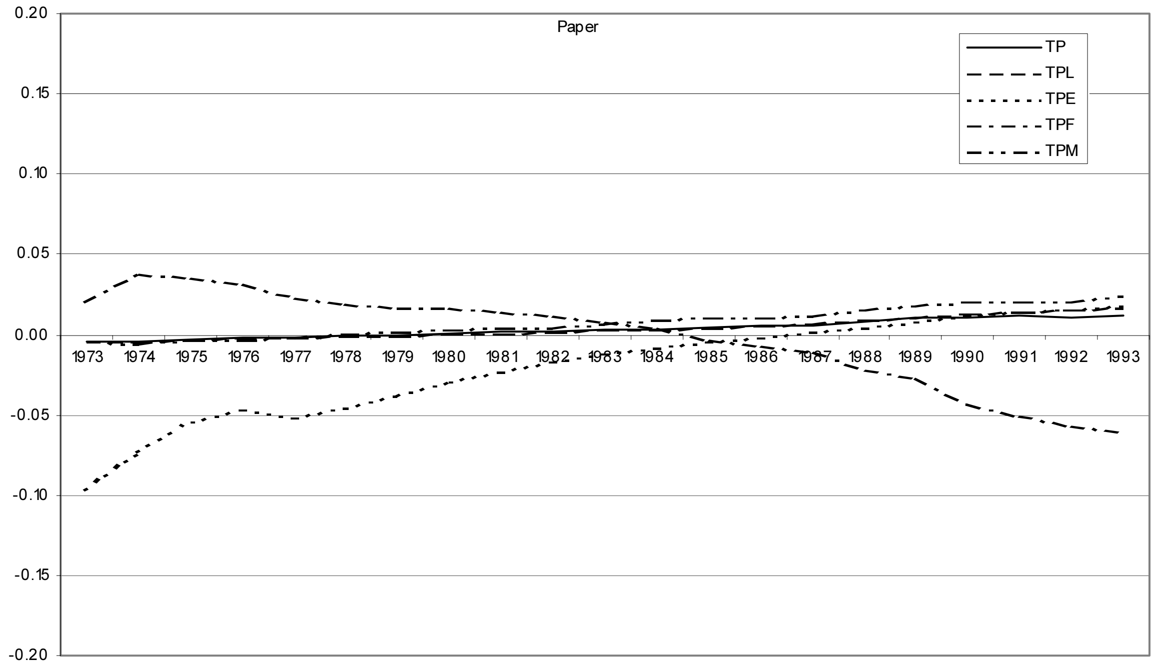
Technological progress



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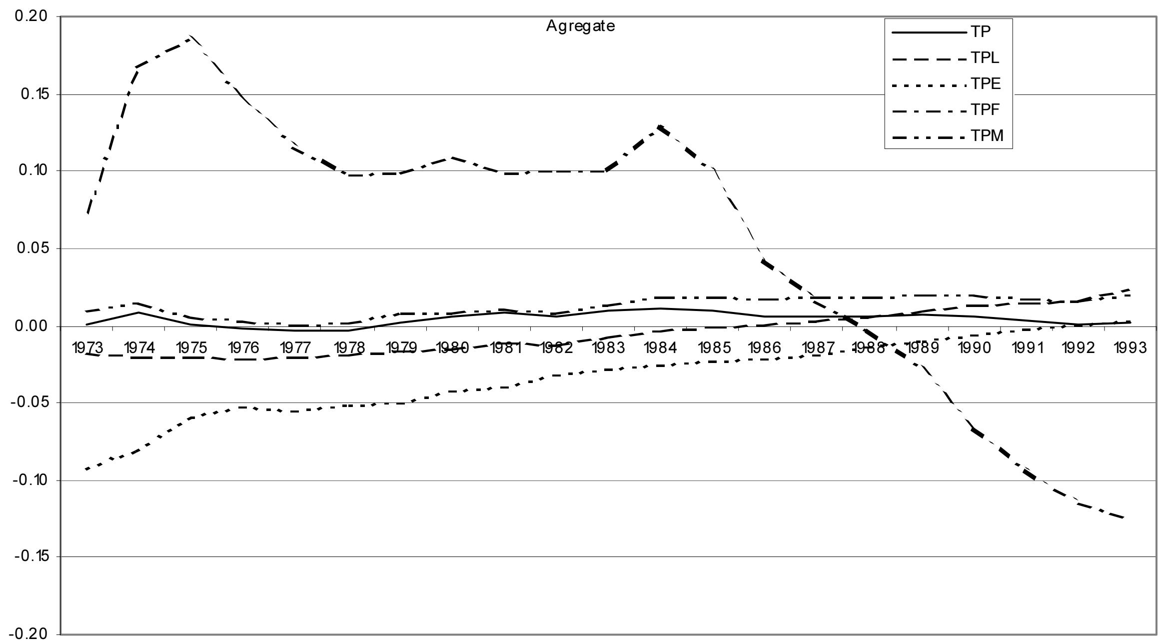
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Elasticity

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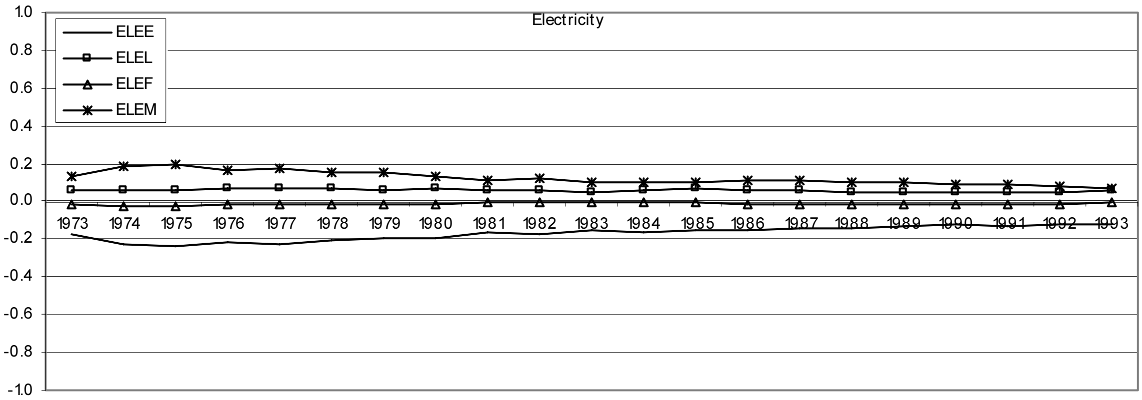

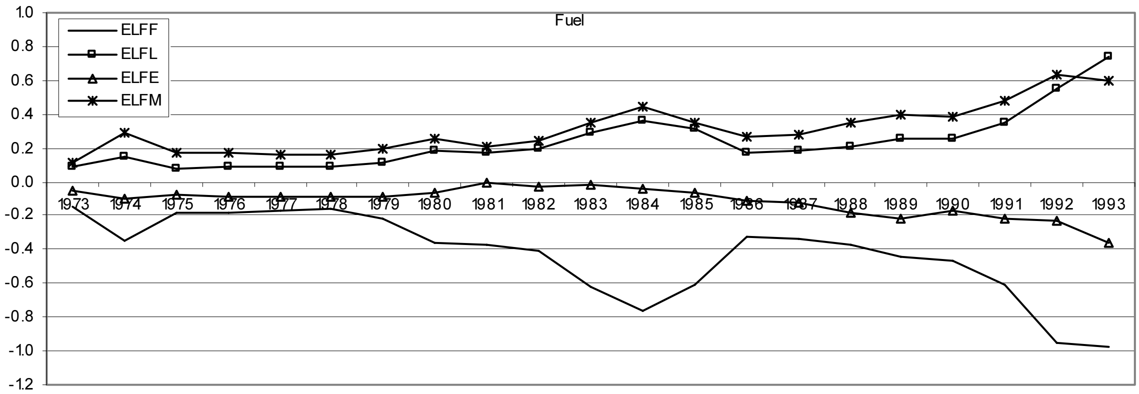

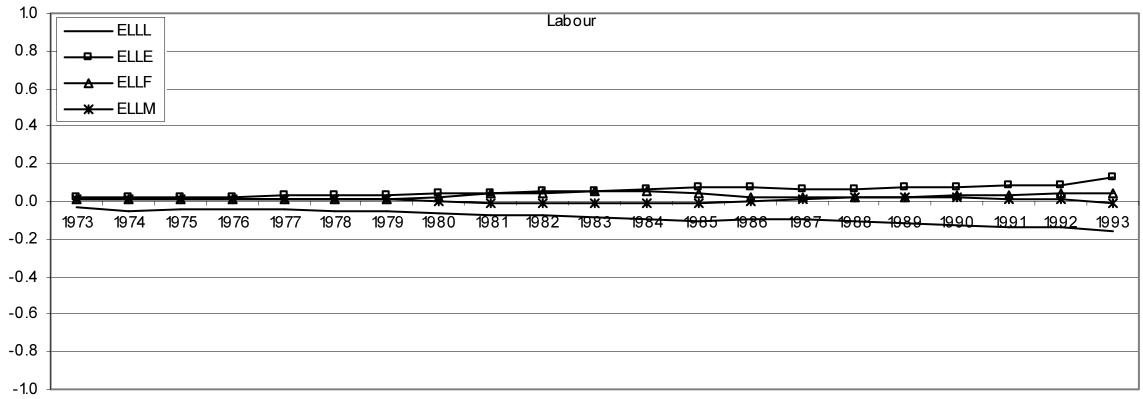

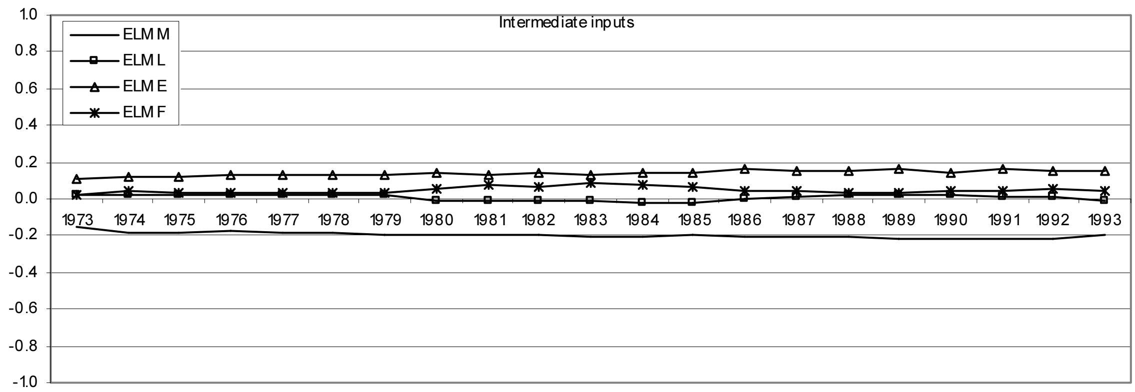

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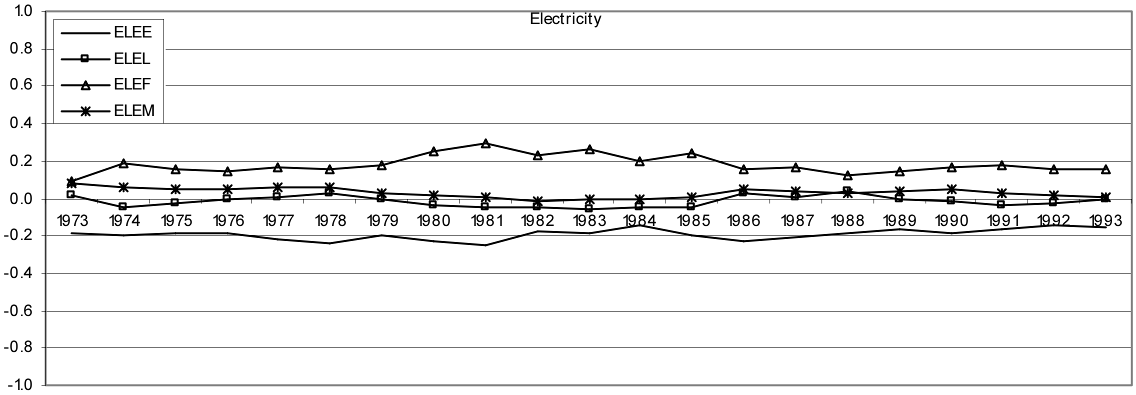
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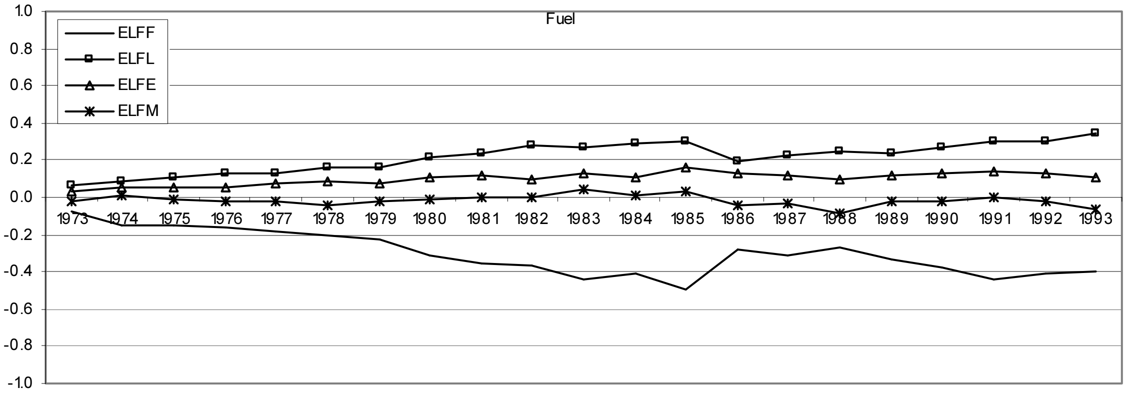
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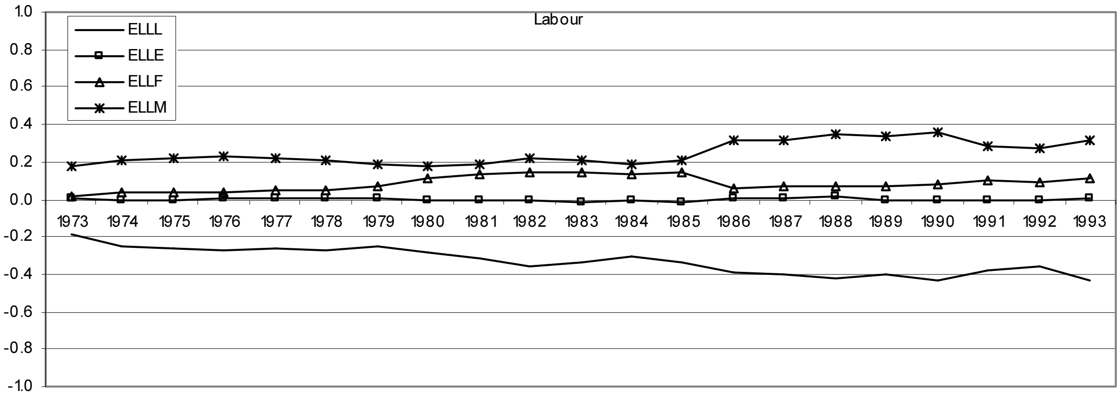
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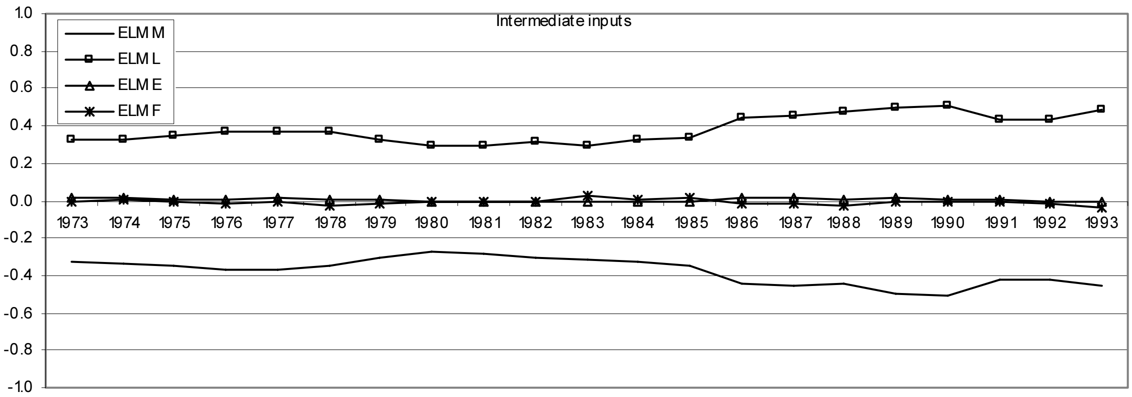
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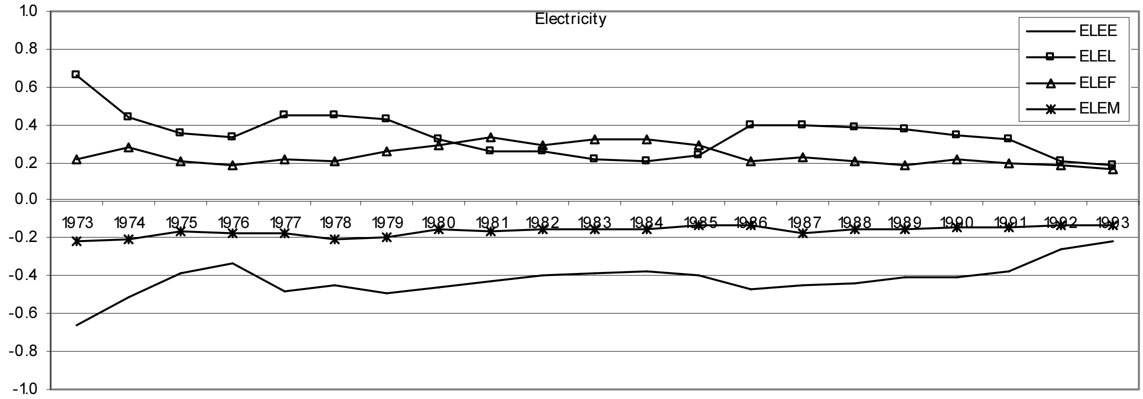
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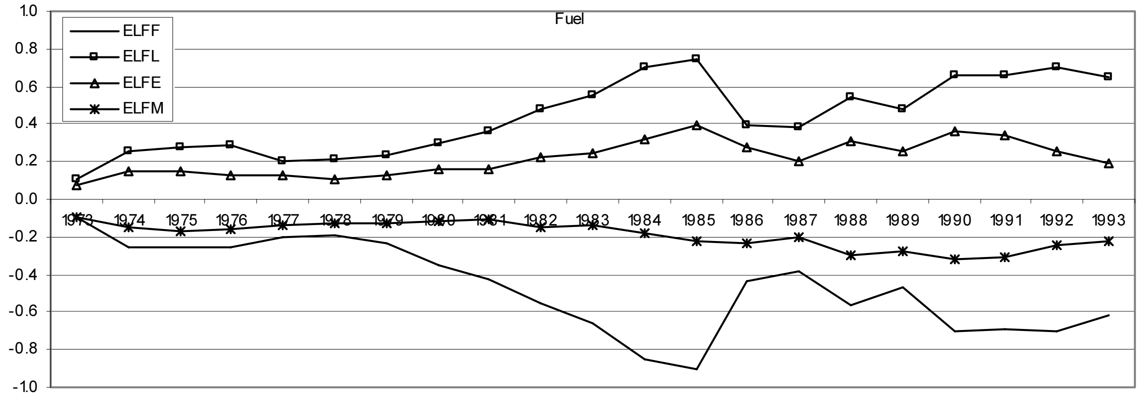
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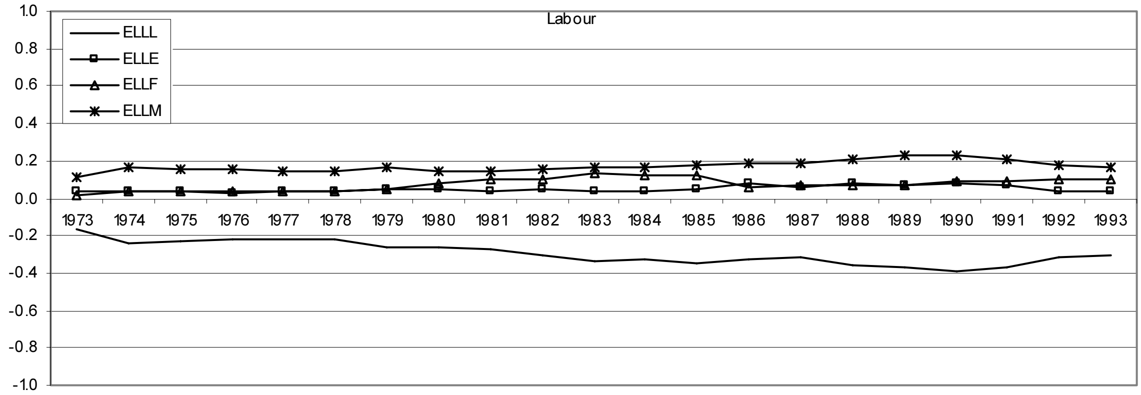
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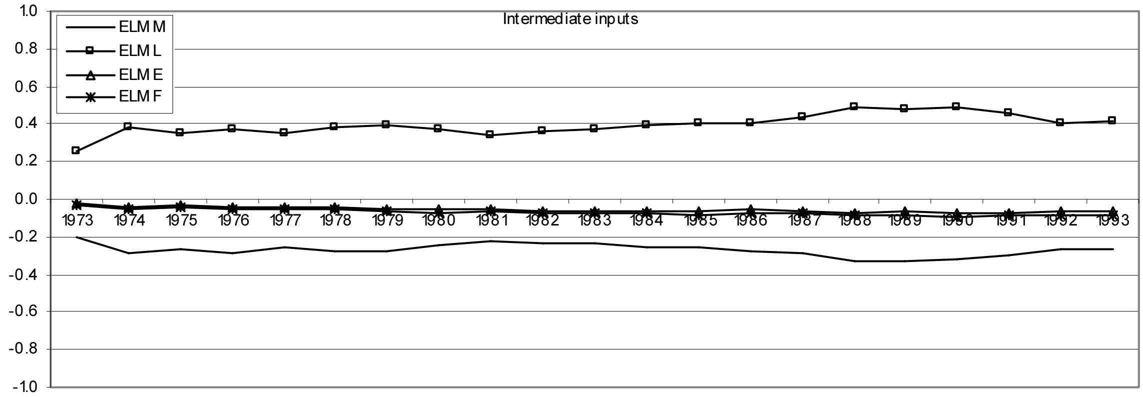
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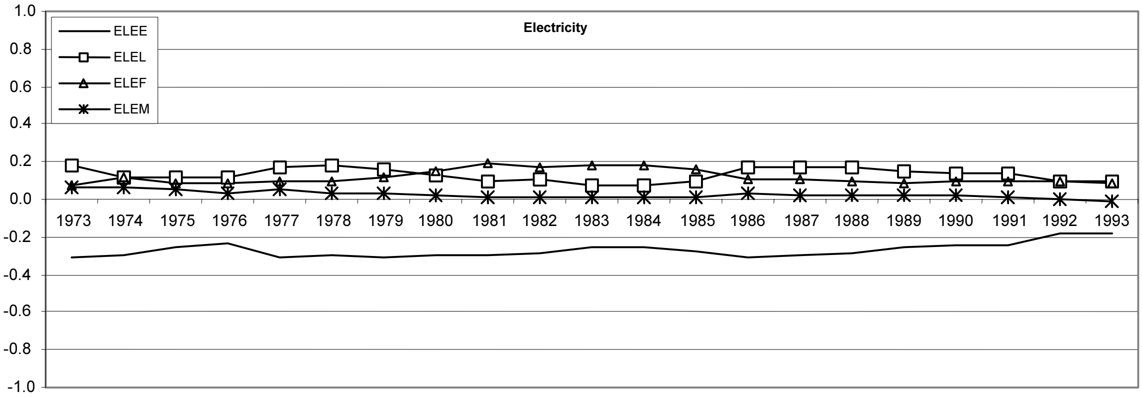

Electricity
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ELEL
ELEF
ELEM
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0.4
0.2
0.0
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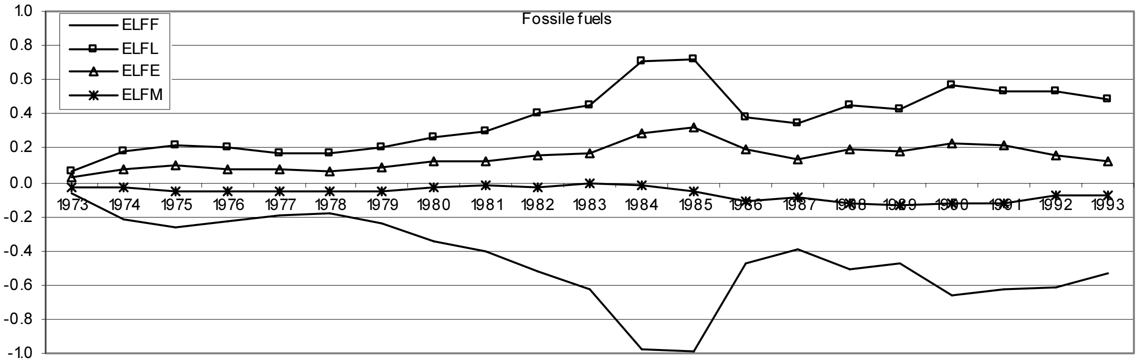
-0.4
-0.6
-0.8
-1.0
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993



Fossile fuels
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ELFL
ELFE
ELFM
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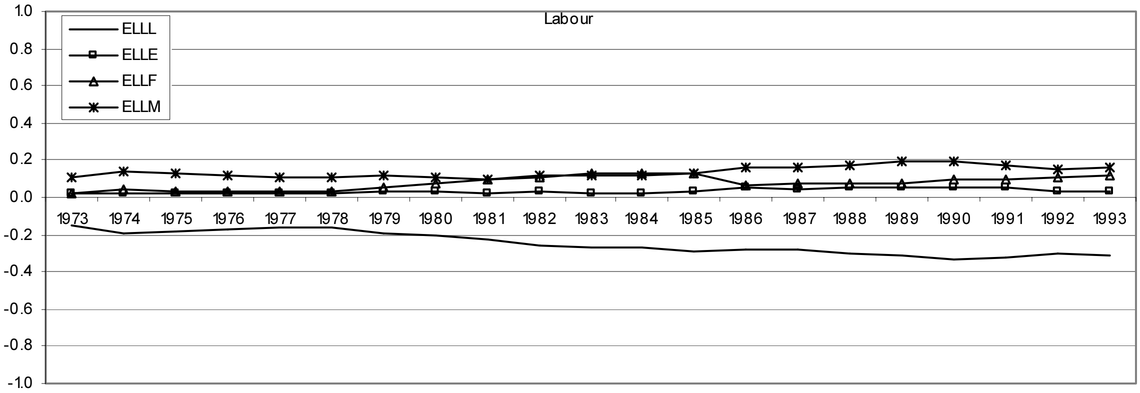
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993



Labour
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ELLF
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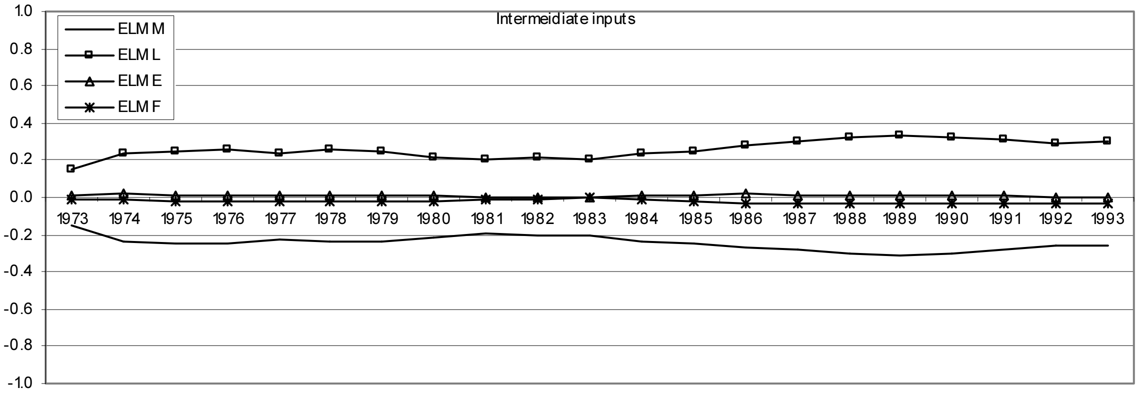
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993



Intermeidiate inputs
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ELML
ELME
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-0.8
-1.0
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993

Estimates

Aggregate				Paper		Cellulose		Mechanical pulp	
Parameter	Estimate	T-value	Parameter	Estimate	T-value	Estimate	T-value	Estimate	T-value
S_{LL}	-0.3838	-22.87	β_1	0.7696	20.06	0.5590	30.18	0.4510	41.26
S_{LE}	0.0622	8.27	S_{LL}	-0.9747	-15.12	-2.3920	-3.90	-0.0840	-2.30
S_{LF}	0.1122	11.91	S_{LE}	0.1949	8.49	-0.0317	-0.10	0.0552	2.30
S_{EE}	-0.1137	-18.09	S_{LF}	0.2310	11.85	0.6514	2.36	0.0194	1.37
S_{EF}	0.0447	10.28	S_{EE}	-0.2312	-13.68	-0.2872	-1.37	-0.1421	-5.31
S_{FF}	-0.1318	-23.18	S_{EF}	0.1208	13.03	0.2967	2.15	-0.0122	-0.92
α_L	-0.0105	-0.71	S_{FF}	-0.2440	-12.20	-0.9446	-4.02	-0.0342	-3.91
α_E	0.0064	0.57	α_L	0.0556	4.63	-0.0580	-1.29	0.0625	6.71
α_F	-0.0232	-3.04	α_E	-0.0029	-0.47	0.0015	0.05	-0.0067	-0.95
α_M	-0.0266	-4.04	α_F	0.0029	0.35	-0.1084	-2.45	0.0060	0.97
α_{LL}	2.2702	11.70	α_M	0.0092	1.73	-0.1137	-3.83	-0.0006	-0.20
α_{EE}	-0.0184	-0.18	α_{LL}	2.1690	4.83	16.3699	8.22	4.1913	9.37
α_{FF}	4.1869	40.06	α_{EE}	0.4712	3.44	1.7321	1.27	2.5579	6.08
α_{MM}	3.8069	40.59	α_{FF}	3.5909	14.52	11.8967	6.71	0.1071	0.47
φ_L	0.0034	3.18	α_{MM}	2.9663	13.99	11.3575	11.26	3.5724	23.26
φ_E	-0.0007	-1.19	φ_L	-0.0008	-0.95	-0.0070	-1.24	-0.0018	-2.72
φ_F	0.0014	2.65	φ_E	0.0003	0.58	-0.0017	-0.43	-0.0003	-0.55
φ_M	0.0027	5.37	φ_F	0.0000	0.00	0.0055	1.06	0.0000	0.01
κ_L	0.9441	4.61	φ_M	0.0000	-0.01	0.0087	2.82	0.0003	1.10
κ_E	-0.5207	-5.54	κ_{L1}	0.1500	0.46	2.3893	0.99	-1.7643	-1.83
κ_F	-0.6266	-3.78	κ_{E1}	-0.8840	-4.53	1.6446	0.73	-0.0598	-0.13
κ_M	0.7772	8.51	κ_{F1}	-1.1001	-4.80	0.6572	0.21	-0.2729	-0.37
γ_L	0.0148	0.74	κ_{M1}	-1.0180	-4.62	2.7000	1.29	-0.1345	-0.68
γ_E	0.1293	11.54	κ_{L2}	31.4632	10.86	4.2881	2.14	-2.8619	-1.18
γ_F	-0.3901	-30.83	κ_{E2}	-1.6840	-0.89	1.0337	0.69	0.2828	0.35
γ_M	-0.1616	-14.43	κ_{F2}	-0.1922	-0.07	-0.7459	-0.31	-0.4329	-0.44
β_{11L}	-4.2947	-15.07	κ_{M2}	-0.3079	-0.20	2.9415	1.91	-0.2223	-0.82
β_{11E}	-0.3841	-2.38	γ_{L1}	0.1436	4.55	-0.2646	-1.84	-0.1057	-4.68
β_{11F}	0.2085	0.89	γ_{E1}	0.0666	4.92	0.0530	0.46	0.0304	1.33
β_{11M}	-2.0467	-13.48	γ_{F1}	-0.1048	-6.81	-0.4772	-3.87	0.0184	1.01
ω_L	-0.2682	-4.11	γ_{M1}	0.0033	0.22	-0.2646	-3.10	-0.0411	-4.64
ω_E	0.0996	4.01	γ_{L2}	0.1246	3.35	-0.3235	-3.06	-0.0560	-1.50
ω_F	0.0828	1.64	γ_{E2}	0.0098	0.46	0.0087	0.11	-0.0041	-0.12
ω_M	-0.1521	-6.34	γ_{F2}	-0.0304	-1.05	-0.4027	-5.11	0.0247	1.07
δ_L	0.2364	8.44	γ_{M2}	0.1092	8.85	-0.1796	-2.67	-0.0714	-5.43
δ_E	0.0711	4.71	β_{L11}	-3.6962	-5.30	-7.9434	-2.16	-0.2111	-0.24

Aggregate				Paper		Cellulose		Mechanical pulp	
Parameter	Estimate	T-value	Parameter	Estimate	T-value	Estimate	T-value	Estimate	T-value
δ_F	0.0630	2.39	β_{E11}	0.8202	2.46	-2.0610	-0.97	0.6008	1.18
δ_M	0.0628	4.26	β_{F11}	-1.2281	-2.58	-0.2164	-0.05	-0.2491	-0.54
τ_L	-0.0034	-5.65	β_{M11}	2.4960	7.83	-5.3339	-3.19	0.4261	2.41
τ_E	-0.0028	-8.51	β_{L12}	-22.4295	-0.70	5.0695	0.32	183.2658	0.21
τ_F	0.0107	24.60	β_{E12}	70.1056	5.08	-3.8353	-0.27	125.9827	0.44
τ_M	0.0018	5.06	β_{F12}	58.9964	3.05	-1.9969	-0.27	96.8548	0.72
ρ_Y	-0.8939	-167.91	β_{M12}	-109.8439	-3.20	-18.2890	-1.35	-411.1030	-0.46
ρ_L	-0.8409	-271.66	β_{L22}	-148.0711	-4.75	-8.5131	-2.07	-16.2432	-0.48
ρ_E	-0.8732	-148.92	β_{E22}	1.3218	0.09	-1.8867	-0.53	-23.5023	-1.77
ρ_F	-0.6939	-151.75	β_{F22}	-10.2072	-0.62	-0.7951	-0.18	-1.9784	-0.21
ρ_M	-0.6719	-168.03	β_{M22}	101.8885	3.95	-3.9899	-0.94	35.9952	1.07
d2	0.0621	0.42	ω_L	-0.3421	-2.39	-4.6395	-1.52	2.1191	1.39
d3	-0.0340	-0.07	ω_E	0.1424	2.26	-0.8244	-0.54	-0.1682	-0.20
d4	0.0023	0.02	ω_F	0.3491	4.82	0.4954	0.28	0.7239	0.49
d5	-0.2118	-3.18	ω_M	0.1344	1.53	-2.3973	-0.91	-0.0747	-0.27
d6	0.0160	0.09	δ_L	0.4882	10.17	0.3645	2.09	0.1306	1.43
d7	0.2490	7.58	δ_E	0.2221	7.55	0.0029	0.02	0.0711	1.43
d8	0.0056	0.04	δ_F	-0.0851	-2.41	0.1072	0.51	-0.0445	-0.69
d9	0.0010	0.00	δ_M	0.2146	7.25	0.0477	0.57	-0.0244	-1.12
d10	-0.0432	-0.11	τ_L	-0.0078	-6.34	0.0106	1.14	0.0060	3.46
d11	0.1031	2.24	τ_E	-0.0032	-5.41	-0.0011	-0.19	0.0010	0.62
d12	-0.0339	-0.15	τ_F	0.0050	7.32	0.0203	3.58	-0.0014	-0.89
d13	-0.0114	-0.06	τ_M	-0.0031	-4.69	0.0010	0.17	0.0016	2.66
d14	0.0549	0.29	ρ_Y	-0.8197	-110.96	-0.2384	-4.50	-0.5978	-28.89
d15	0.5780	16.04	ρ_L	-0.7663	-157.97	-0.2400	-3.98	-0.5908	-26.71
d16	-0.0377	-0.16	ρ_E	-0.6493	-77.34	-0.3533	-3.51	-0.3281	-13.36
d17	0.0839	0.69	ρ_F	-0.6724	-131.02	-0.1245	-2.72	-0.8306	-49.12
d18	-0.0074	-0.04	ρ_M	-0.5987	-117.98	-0.0647	-0.84	-0.1203	-4.07
d19	0.0515	0.40	d2	0.0395	0.84	-0.0322	-1.54	0.0027	0.25
d20	-0.0578	-0.78	d3	-0.0135	-0.12	0.0043	0.11	0.0295	1.90
d21	-0.1120	-2.32	d4	0.0198	0.51	0.0191	0.64	-0.0155	-2.71
d22	-0.0428	-0.17	d5	-0.0810	-1.99	-0.0084	-0.48	-0.0066	-0.58
d23	-0.0417	-0.14	d6	0.0187	0.43	-0.0100	-0.16	0.0084	0.61
d24	0.1733	4.77	d7	0.0558	2.78	0.0328	1.72	0.0008	0.05
d25	0.1938	2.82	d8	0.0110	0.14	-0.0109	-0.32	-0.0329	-2.82
d26	-0.0487	-0.50	d9	-0.0184	-0.24	0.0224	0.69	0.0208	2.82
d27	0.1331	4.27	d10	-0.0171	-0.14	-0.0025	-0.08	0.0423	6.34
d28	-0.0285	-0.16	d11	0.0414	2.14	0.0121	0.22	-0.0314	-2.94
d29	-0.0359	-0.25	d12	-0.0106	-0.11	-0.0498	-2.30	0.0133	0.96
d30	-0.0159	-0.03	d13	0.0153	0.24	0.0167	0.84	0.0265	1.02
d31	0.0263	0.27	d14	0.0171	0.26	0.0188	0.61	0.0107	0.80
d32	0.1196	1.25	d15	0.3410	18.92	-0.0088	-0.24	-0.0026	-0.19

Aggregate				Paper		Cellulose		Mechanical pulp	
Parameter	Estimate	T-value	Parameter	Estimate	T-value	Estimate	T-value	Estimate	T-value
d33	0.1290	1.74	d16	-0.0065	-0.10	0.0377	0.70	-0.0081	-0.42
d34	0.0079	0.03	d17	0.0537	1.45	-0.0387	-1.17	-0.0004	-0.02
d35	0.0414	1.01	d18	-0.0067	-0.10			-0.0133	-0.54
d36	0.2852	5.37	d19	0.0543	1.21			0.0030	0.13
d37	0.2623	8.25	d20	-0.0152	-0.51			-0.0059	-0.42
d38	0.0867	0.58	d21	-0.0563	-2.81			-0.0016	-0.11
d39	0.0060	0.07	d22	-0.0199	-0.21			-0.0028	-0.17
d40	0.1039	2.08	d23	-0.0161	-0.20			-0.0161	-0.94
d41	-0.0709	-0.69	d24	0.0382	2.05			-0.0171	-1.39
d42	0.0525	0.30	d25	0.0272	1.07			0.0177	0.84
d43	0.2885	9.17	d26	-0.0136	-0.33			-0.0031	-0.10
d44	-0.0014	-0.01	d27	0.0095	0.59			-0.0075	-0.34
d45	0.1337	1.25	d28	-0.0017	-0.03			0.0157	1.14
d46	-0.0411	-0.10	d29	-0.0042	-0.08			-0.0352	-2.06
d47	-0.0186	-0.06	d30	-0.0022	-0.02				
d48	-0.0494	-0.19	d31	-0.0298	-1.08				
d49	-0.0347	-0.09	d32	0.1017	3.20				
d50	-0.0524	-0.20	d33	0.0783	2.94				
d51	0.0190	0.12	d34	0.0243	0.23				
d52	-0.0227	-0.45	d35	-0.0760	-5.37				
d53	-0.0673	-0.45	d36	0.1381	6.12				
d54	-0.0425	-0.29	d37	0.0307	1.71				
d55	-0.0449	-0.15	d38	0.0853	2.17				
d56	0.0044	0.01	d39	-0.0099	-0.30				
d57	-0.0461	-0.09	d40	0.0874	4.29				
d58	-0.0238	-0.31	d41	-0.0337	-0.78				
d59	-0.0064	-0.02	d42	0.0505	0.91				
d60	-0.0268	-0.22	d43	0.0709	5.16				
d61	-0.0427	-0.33	d44	0.0094	0.19				
d62	-0.0267	-0.04	d45	0.0502	1.24				
d63	-0.0078	-0.09	d46	-0.0162	-0.09				
d64	0.1397	1.45	d47	-0.0067	-0.06				
d65	-0.0236	-0.19	d48	-0.0175	-0.14				
d66	0.0554	0.71	d49	-0.0147	-0.11				
d67	-0.0314	-0.09	d50	-0.0315	-0.52				
d68	-0.0170	-0.10	d51	0.0091	0.07				
d69	-0.0035	-0.01	d52	0.0086	0.43				
d70	-0.0100	-0.03	d53	-0.0247	-0.46				
d71	0.0184	0.04	d54	-0.0143	-0.27				
d72	-0.0476	-0.15	d55	-0.0285	-0.31				
d73	-0.0347	-0.03	d56	0.0176	0.13				
d74	-0.0270	-0.03	d57	-0.0284	-0.19				
d75	-0.0345	-0.13	d58	-0.0061	-0.23				
d76	-0.0179	-0.08	d59	0.0022	0.03				
d77	0.0253	0.13	d60	0.0027	0.06				
d78	-0.0477	-0.25	d61	-0.0214	-0.49				
d79	0.0054	0.02	d62	-0.0099	-0.10				

Aggregate				Paper		Cellulose		Mechanical pulp	
Parameter	Estimate	T-value	Parameter	Estimate	T-value	Estimate	T-value	Estimate	T-value
d80	-0.0246	-0.03	d63	-0.0125	-0.36				
d81	-0.0248	-0.03	d64	0.1113	2.91				
d82	-0.0288	-0.09	d65	-0.0319	-0.92				
d83	-0.0418	-0.07	d66	-0.0056	-0.18				
d84	-0.0927	-0.50	d67	-0.0116	-0.16				
d85	-0.0384	-0.11	d68	-0.0038	-0.06				
d86	-0.0353	-0.12	d69	0.0140	0.12				
d87	0.0135	0.04	d70	0.0082	0.06				
d88	0.0080	0.01	d71	0.0260	0.17				
d89	-0.0373	-0.05	d72	-0.0247	-0.21				
d90	-0.0265	-0.13	d73	-0.0154	-0.06				
d91	-0.0163	-0.02	d74	-0.0117	-0.06				
d92	0.0317	0.28	d75	-0.0076	-0.09				
d93	-0.0762	-0.48	d76	0.0073	0.09				
d94	-0.0273	-0.08	d77	-0.0004	-0.01				
d95	0.0364	0.20	d78	-0.0313	-0.57				
d96	-0.0358	-0.04	d79	-0.0037	-0.04				
d97	-0.0171	-0.03	d80	-0.0037	-0.01				
d98	-0.0315	-0.04	d81	-0.0092	-0.03				
d99	-0.0336	-0.10	d82	-0.0120	-0.08				
d100	-0.0216	-0.03	d83	-0.0134	-0.07				
d101	-0.0349	-0.04	d84	-0.0463	-0.89				
d102	-0.0342	-0.04	d85	-0.0238	-0.21				
d103	-0.0372	-0.03	d86	-0.0166	-0.13				
d104	-0.0747	-0.08	d87	0.0056	0.03				
d105	-0.0389	-0.10	d88	-0.0028	-0.02				
d106	-0.0348	-0.03	d89	-0.0059	-0.01				
d107	-0.0342	-0.05	d90	-0.0227	-0.33				
d108	-0.0546	-0.11	d91	0.0000	-0.01				
d109	-0.0327	-0.03	d92	0.0321	0.85				
d110	-0.0442	-0.04	d93	-0.0287	-0.53				
d111	-0.0460	-0.08	d94	-0.0215	-0.19				
d112	-0.0475	-0.06	d95	-0.0213	-0.46				
d113	-0.0272	-0.02	d96	-0.0110	-0.04				
d114	-0.0819	-0.17	d97	0.0084	0.09				
d115	-0.0557	-0.11	d98	-0.0039	-0.03				
d116	-0.0440	-0.04	d99	-0.0237	-0.25				
d117	-0.0412	-0.04	d100	-0.0064	-0.06				
d118	-0.0481	-0.05	d101	-0.0119	-0.04				
d119	-0.0317	-0.07	d102	-0.0142	-0.04				
d120	0.0108	0.01	d103	-0.0141	-0.04				
d121	-0.1465	-1.27	d104	-0.0321	-0.14				
d122	-0.0736	-0.15	d105	-0.0189	-0.12				
d123	-0.1291	-0.57	d106	-0.0006	0.00				
d124	-0.0488	-0.07	d107	-0.0110	-0.03				
d125	-0.0481	-0.05	d108	-0.0146	-0.05				
d126	-0.0545	-0.06	d109	-0.0072	-0.01				

Aggregate				Paper		Cellulose		Mechanical pulp	
Parameter	Estimate	T-value	Parameter	Estimate	T-value	Estimate	T-value	Estimate	T-value
d127	-0.0571	-0.10	d110	-0.0108	-0.02				
d128	-0.0619	-0.11	d111	-0.0230	-0.09				
d129	-0.0459	-0.05	d112	-0.0169	-0.05				
d130	-0.0508	-0.05	d113	-0.0133	-0.03				
d131	-0.0549	-0.06	d114	-0.0312	-0.27				
d132	-0.0364	-0.07	d115	-0.0240	-0.11				
d133	-0.0559	-0.21	d116	-0.0073	-0.02				
d134	-0.0140	-0.05	d117	-0.0115	-0.03				
d135	0.0064	0.11	d118	-0.0219	-0.08				
d136	0.0615	1.06	d119	-0.0200	-0.13				
d137	-0.0960	-2.38	d120	-0.0021	-0.01				
d138	-0.0197	-0.07	d121	-0.0357	-0.60				
d139	-0.0514	-0.51	d122	-0.0140	-0.08				
d140	-0.0338	-0.69	d123	-0.0560	-0.65				
d141	0.0619	0.72	d124	-0.0146	-0.03				
d142	0.0362	0.45	d125	-0.0126	-0.04				
d143	0.0329	0.44	d126	-0.0228	-0.05				
d144	-0.0553	-0.77	d127	-0.0184	-0.05				
d145	0.0469	0.30	d128	-0.0236	-0.08				
d146	0.3182	5.65	d129	-0.0192	-0.11				
d147	0.0455	0.49	d130	-0.0135	-0.03				
d148	-0.0380	-0.17	d131	-0.0285	-0.20				
d149	-0.0312	-0.15	d132	-0.0140	-0.05				
d150	-0.0119	-0.02	d133	-0.0500	-0.59				
d151	-0.0114	-0.02							
d152	0.0270	0.08							
d153	-0.0098	-0.05							
d154	0.0419	0.12							
d155	-0.0092	-0.02							
d156	-0.0041	-0.02							
d157	0.0656	0.29							
d158	0.0348	0.13							
d159	-0.0143	-0.01							
d160	0.0124	0.02							
d161	0.0188	0.04							
d162	0.0033	0.02							
d163	-0.1177	-1.24							
d164	-0.0500	-1.43							
d165	0.3128	7.05							
d166	0.0389	0.59							
d167	-0.0212	-0.52							
d168	-0.1058	-2.94							
d169	-0.0437	-0.27							
d170	-0.0980	-0.91							
d171	0.0223	0.22							
d172	0.0373	0.07							
d173	0.7839	11.87							

Aggregate				Paper		Cellulose		Mechanical pulp	
Parameter	Estimate	T-value	Parameter	Estimate	T-value	Estimate	T-value	Estimate	T-value
d174	-0.5712	-9.54							
d175	0.0161	0.09							
d176	-0.1674	-2.15							
d177	0.0587	0.37							
d178	0.0208	0.12							
d179	-0.1194	-0.60							

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