Production Technology in the Pulp and Paper Industry in the European Union: Factor Substitution, Economies of Scale, and Technological Change

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Abstract

The objective of this paper is to analyse the cost implications of several important features of the production technology in the pulp and paper industry in the member states of the European Union. A flexible industry cost function with three inputs is estimated for the EU with annual panel data for the period from 1970 to 1995. Substitution and price elasticities are estimated, together with technological biases. The results show significant but small substitutability between labour and both capital and wood, and complementarity between the latter. Evidence was found of important economies of scale in this industry. Technological change has been labour saving and capital using. Finally, important differences were found amongst the EU countries. In Finland, Portugal and Sweden, the three biggest EU producers and exporters of pulp, technological change has been more labour saving, and both labour and cross wood substitution and price elasticities are higher than in the rest of the EU.

Keywords: Panel data, pulp and paper industry, translog cost functions.

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Introduction

The objective of this paper is to analyse the cost implications of several important features of the production technology in the pulp and paper industry in the member states of the European Union (hereafter EU). A flexible industry cost function is estimated for the member states of the EU with annual panel data for the period from 1970 to 1995 using panel data estimation methods, which is then used to estimate substitution and price elasticities, and technological biases for the industry's inputs. In this way we can

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overcome the problem of having data available for each country over only a short period of time, but still be able to estimate efficiently country specific factor elasticities and technological biases.

The pulp and paper industry plays an important part in the EU economy. The pulp industry is particularly important in Finland, Portugal and Sweden, whereas the paper industry, which can be divided into sectors producing writing and printing paper, newsprint, cardboard and wrapping paper, household and sanitary tissues, amongst other products, is spread across the EU (see Andrade (1998), for example). There is an extensive literature on cost functions applied to different sectors of the economy, in particular translog cost functions (see Jorgenson (1986) and references therein, for example). Stier & Bengston (1992) review applications of this methodology to the pulp and paper industry. Recent studies of this industry include Chas-Amil & Buongiorno (1999), who use a Cobb-Douglas function to model paper and paperboard price changes in the EU, and Lundgren and Sjostrom (1999), who study the Swedish pulp industry using a dynamic factor demand model based on a translog cost function with (quasi-fixed) capital, labour, electricity and pulpwood as inputs.

We will follow broadly Stier (1985) who estimates a translog cost function for the US industry over the period 1948–1976 using three inputs, labour, capital and wood, and obtains estimates for the relevant industry features, and will develop this methodology one step further by using panel data for the EU member states for a more recent period. It would be interesting to use data on more factors, like energy, wastepaper and other materials, but there is no consistent and reliable data available on them for all countries for this period of time. Also, it would be interesting to estimate separate cost functions for the main industry sectors, in particular separating pulp from paper, but again there is no data available.

This paper is organised as follows: next we describe the translog cost function and show how the technological features of interest can be derived from combinations of its parameters; then we describe the data and the definitions of the variables used; thereafter, we present and discuss the estimation results; and finally our conclusions are presented. Hereafter, 'industry' will be taken to mean the 'pulp and paper industry'.

MODEL

The cost function used in this study is assumed to have the same homothetic translog cost specification as in Stier (1985), and is defined as

$$\begin{aligned}\ln C(\underline{P},Q,T) = {} & \alpha_0 + \alpha_Q \ln Q + \tfrac{1}{2}\alpha_{QQ}(\ln Q)^2 + \alpha_T T + \tfrac{1}{2}\alpha_{TT}T^2 \\ & + \sum_i \beta_i \ln P_i + \tfrac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_i P_j + \sum_i \delta_{Ti} T \ln P_i \end{aligned} \tag{1}$$

where C is total cost, Q is aggregate industry output, P is a vector of factor prices with general element P_i, T is a time trend, ln denotes natural logarithm, and $\beta_{ij} = \beta_{ji}$, $i \neq j$. We consider three factors, L, K, and W, respectively labour, capital and wood (defined as pulpwood), and therefore $i,j=L,K,W$. The time trend is included to proxy for the changing state of technology in the industry. In order to correspond to a well-behaved production function, a cost function must be homogeneous of degree one in prices, which implies the following restrictions on the parameters of (1)

$$\begin{aligned} & \sum_i \beta_i = 1 \ , \\ & \sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \sum_j \beta_{ij} = 0 \ , \\ & \sum_i \delta_{Ti} = 0 \ . \end{aligned} \tag{2}$$

A cost function should also have the following properties: positivity, monotonicity, and concavity, meaning that it should be positive for positive input prices and level of output, increasing in all of them, and concave in input prices. (see Jorgenson (1986), for example).

Using Shepard's lemma, the cost minimising demand functions for the factors of production, also known as factor share equations, are obtained from (1) by calculating $\dfrac{\partial \ln C}{\partial \ln P_i} = \dfrac{P_i X_i}{C} = S_i$ giving

$$S_i = \beta_i + \sum_j \beta_{ij} \ln P_j + \delta_{Ti} T, \; all \; i, \tag{3}$$

where S_i is the share of input i cost in the total industry cost, and $\Sigma_i S_i = 1$, $i = L, K, W$ (cost exhaustion). An important property of (3) is that there are n factor share equations, but only $n-1$ are linearly independent. The parameters of (3) should also verify the restrictions in (2).

Allen factor partial elasticities of substitution for the translog cost function are given by (see Christensen & Greene (1976), for example)

$$\sigma_{ij} = \frac{\beta_{ij} + S_i S_j}{S_i S_j} = \frac{\beta_{ij}}{S_i S_j} + 1, \; i \neq j \;,$$

$$\sigma_{ii} = \frac{\beta_{ii} + S_i (S_i - 1)}{S_i^2} = \frac{\beta_{ii}}{S_i^2} - \frac{1}{S_i} + 1 \;. \tag{4}$$

The (own and cross) price elasticities of derived demand for factors are given by

$$\eta_{ij} = S_j \sigma_{ij}, \; all \; i, j \;. \tag{5}$$

The specification of the cost function shown in expression (1) does not impose any restriction on returns to scale. Christensen & Greene (1976) define scale economies as $SCE = 1 - (\partial \ln C / \partial \ln Q)$ with positive values of this measure implying positive economies of scale in the industry, and negative values implying scale diseconomies. Following Binswanger (1974), technological change bias is defined as the influence of technological progress on factor shares when output and relative factor prices are held constant, the latter denoted S_i^*. It is given by

$$B_i = \frac{\partial \; S_i^*}{\partial \; T} \frac{1}{S_i} = \frac{\delta_{Ti}}{S_i} \tag{6}$$

Technological change is factor i using if B_i is positive, whereas it is factor i saving if B_i is negative, and Hicks neutral if B_i is equal to zero.

To estimate the system of equations given by the translog cost function (1) and factor shares (3) it is necessary to specify a stochastic framework (see Jorgenson (1986) and

Berndt (1990), amongst others). Typically, a random disturbance term is included in each equation, ε_t^C, ε_t^L and ε_t^K and the resulting random vector is multivariate normally distributed with mean vector zero and constant covariance matrix.

$$
\begin{aligned}
\ln C_{zt} &= \alpha_0 + \alpha_Q \ln Q_{zt} + \tfrac{1}{2}\alpha_{QQ}\left(\ln Q_{zt}\right)^2 + \alpha_T T + \tfrac{1}{2}\alpha_{TT}T^2 \\
&\quad + \sum_i \beta_i \ln P_{izt} + \tfrac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_{izt} P_{jzt} + \sum_i \delta_{Ti} T \ln P_{izt} + \varepsilon_t^C \\
S_{Lzt} &= \beta_L + \sum_j \beta_{Lj} \ln P_{jzt} + \delta_{TL} T + \varepsilon_t^L \\
S_{Kzt} &= \beta_K + \sum_j \beta_{Kj} \ln P_{jzt} + \delta_{TK} T + \varepsilon_t^K \\
& i, j = L, K;\ z = 1,\ldots,N \text{(country dimension)}; \\
& t = 1,\ldots,TT \text{ (time dimension)}. \qquad (7)
\end{aligned}
$$

As mentioned earlier, only *n-1* factor share equations are identified. We opted to keep the factor share equations for labour, *L*, and capital, *K*, and delete the factor share for wood, as in Stier (1985). All parameters relating to wood are then obtained from restrictions given in (2). Panel data methods are used to estimate efficiently the system given in (7). In particular, the EC3SLS method (Error Component 3SLS; see Hsiao (1986), chapter 5, and Baltagi (1995), chapter 7) is used to obtain estimates for the structural parameters of the system under restrictions (2). This estimator is a weighted combination of three (within, between groups and within groups and time periods) 3SLS estimators of the structural parameters. It is efficient because it takes advantage of the known error component structure of its covariance matrix. Furthermore, it is asymptotically equivalent to the full information maximum likelihood estimator, an important result in this context, because then the estimation results are invariant to which factor share equation was deleted at the estimation stage. The data used is described in the next section.

DATA

In order to be able to estimate this model for the pulp and paper industry in the EU member states we had to put together a large database. It covers the period from 1970 to

1995 and includes annual data on 13 EU countries: Austria, Belgium (including Luxembourg), Denmark, Finland, France, Germany, Italy, Netherlands, Portugal, Spain, Sweden, and UK. Two EU countries, Greece and Ireland, were excluded from the dataset due to the very small size (or inexistence) of their pulp and paper industries (see Andrade (1998)). In studies that use data from different countries it is important to guarantee that, as far as possible, data is defined in a similar way. Therefore we use one international database, OECD's (1996) STAN Industrial Database, as our main data source. In STAN, annual data is available for 14 EU countries (no data is available for Ireland) for the period 1970–1995 for ISIC 3410, 'Paper and products'. However, observations are missing for some of the variables in some or all of the countries, particularly for recent years[1]. All data is available in national currencies at current prices.

Data on industry output, number of employees and labour compensation can be obtained directly from STAN. The price of labour is defined as the ratio of labour compensation[2] over number of employees. No data is available on the costs of the other two inputs considered: capital and wood. Following Stier (1985), the price of capital is defined as the ratio between gross quasi rent and the quantity of capital input, where gross quasi rent is defined as the difference between value added and labour compensation. The two latter variables are available from STAN. Estimating capital input for this industry in the EU member states is beyond the scope of this paper. We adopted a simplified methodology which allowed us to estimate the series for each country, based on Permanent Inventory Method (or PIM) estimates of net capital stock (see, for example, Berndt (1990), pp.227–31) and a constant exponential depreciation

[1] For most countries and variables, data for ISIC 3410 is available in STAN only until 1994. We estimated ISIC 3410 1995 data using country specific rates of growth of ISIC 3400 'Paper, Paper Products and Printing', and, when these were not available, country specific rates of growth of the whole of manufacturing. In the few cases when all else failed, we used the EU average rate of growth of the variable in that period to estimate the missing observation(s). The variables with more missing observations were Gross Fixed Capital Formation and Number Engaged, and the most difficult countries were Denmark, Italy, and Spain.

[2] Defined as ''current price national accounts compatible labour costs which comprise wages as well as the costs of supplements such as employer's compulsory pension or medical payments.'' OECD (1996).

rate. Investment was defined as Gross Fixed Capital Formation, obtained from STAN. The depreciation rate was set equal to 12%. This is the 'exponentially compounded average annual capital stock depreciation rate' for 'producer durable goods' estimated by Levy (1995) for the US for the period 1948–1991, also used in Suwandee *et al.* (1998)[3]. To obtain an estimate for capital input, we used the average ratio of capital input to capital stock calculated from Jorgenson *et al.* (1987) for the US 'paper and allied products' sector in the period from 1970 to 1979, which was equal to 0.909.

Data on the third input, wood, was obtained from FAO's (1998) database under 'pulpwood', where annual data is available on pulpwood production (in quantity), imports and exports (in both quantity and value). A price index for wood was constructed as in Andrade (1998), but again there were data availability problems[4].

Under the assumption of cost exhaustion, total cost C is defined as the sum of the costs of the three inputs, labour, capital and wood, and the factor shares S_i were calculated. All data was transformed into 1990 prices using the IMF's wholesale price index, and into US$ using the 1990 exchange rates between national currencies and US$ (see OECD(1998) for a discussion of the advantages of this methodology). The estimation results are reported in the next section.

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[3] Jacob *et al.* (1997) present estimates of capital stock for some of the EU countries for SIC 3400, 1970–1992. We preferred not to use them because this SIC also includes 'publishing', very different in character to 'pulp and paper', and the estimates are only available for a subperiod for some of the EU countries in our dataset.

[4] The cost of wood was obtained by multiplying apparent consumption of wood (defined as national production plus imports minus exports, all in quantity), by its price (calculated as the quantity weighted linear combination of exports and import prices). However, FAO ceased publication of data on the international trade of this commodity in 1991. To estimate data for the period until 1995, we used a moving average of the latest three years to estimate the proportions of the wood production that were imported and exported in each country (in quantity) and the rates of growth in value of exports and imports of pulpwood available in UN's ITSY.

Table 1. Descriptive Statistics.
This table presents descriptive statistics on the variables included in the model (the EU pulp and paper industry), 1970–1995.

Variable	Mean	St. Dev.
ln C	14.66	0.985
ln Q	15.56	1.047
ln P_L	3.155	0.439
ln P_K	3.402	0.650
ln P_W	3.927	0.612
S_L	0.507	0.150
S_K	0.325	0.094
S_W	0.168	0.142

Estimation Results

Initially, EC3SLS estimates were obtained for system (7) using annual panel data on the 13 EU countries listed above over the period from 1970 to 1995 ($N \times TT = 12 \times 26 = 312$ panel data observations). However, the estimated cost function was not monotonic. A well behaved cost function could only be estimated when two countries, namely the Netherlands and the UK, were excluded from the dataset due to data heterogeneity. The exclusion of these two countries can be further justified because of the very small share of the cost of wood in them compared to the (15 countries) EU average (1.0% and 1.8% versus 14.2%). Therefore the results presented are based on a panel of 11 EU countries ($N \times TT = 10 \times 26 = 260$ panel data observations). In Table 1 we present descriptive statistics on the variables for this reduced EU. Descriptive statistics for individual countries are reported in Appendix A.

The estimate for a_{QQ} was never statistically different from zero, and therefore the variable $(\ln Q)^2$ was deleted from the system. This result suggests that the cost function is homogeneous with respect to output, similar to Stier (1985) who found the same result for the US pulp and paper industry. The estimates[5] of the parameters are reported in

[5] In the text and tables, and to simplify notation, we denote estimated parameters as, for example, α_Q and not $\hat{\alpha}_Q$.

TABLE 2. ESTIMATION RESULTS.
This table presents parameter estimates for the translog model of the EU pulp and paper industry, 1970-1995.

Parameter	Estimate	Stand Error	$\lvert t$-ratio in$\rvert$
α_0	5.368	0.032	167.70
α_Q	0.158	0.017	9.15
α_T	–0.026	0.0017	14.99
β_L	0.921	0.040	23.28
β_K	0.047	0.017	2.77
β_W	0.032	0.039	0.82
β_{LL}	0.057	0.017	3.39
β_{LK}	–0.056	0.007	8.33
β_{LW}	0.001	0.015	0.08
β_{KK}	0.118	0.006	19.49
β_{KW}	–0.062	0.006	11.10
β_{WW}	0.063	0.016	3.93
δ_{TL}	–0.004	0.002	1.80
δ_{TK}	0.007	0.002	4.48
δ_{TW}	0.00006	0.002	0.03

Table 2[6]. The estimates of all parameters involving wood were obtained from the estimates of expression (7) using restrictions given in expression (2).

The estimated cost function is homothetic, homogeneous of degree α_Q in output, positive, monotonic, and (quasi) concave, as the estimates of α_Q, β_L, β_K, β_W are all positive and the matrix of β_{ij}, i, $j = L, K, W$ is semidefinite positive. However, the estimates of β_W, β_{LW}, and δ_{TW} are not statistically different from zero. These results might suggest the deletion of factor wood from the system, but the significance of the estimates of the other terms involving this factor and of the estimated elasticities, as reported below, suggest that it should be kept in. A Cobb-Douglas production function ($\beta_{ij} = 0$, all i, j) and Hicks neutral technological change ($\delta_{Ti} = 0$, all i) are both rejected. A goodness of fit

[6] In, Pesaran & Shin (1995)'s t-bar test for heterogeneous panel unit roots with constant and a choice of lag augmentation was used to test the null hypothesis of a panel unit root in all variables actually used in the estimation. The null hypothesis was rejected in all cases.

measure often used in multivariate estimation is the correlation between actual and fitted values in each equation. The model fits well as this measure equals 97.5%, 75.0% and 80.6% for the equations for C_{zt}, S_{Lzt}, and S_{Kzt}, respectively.

The measure of scale economies, *SCE*, is simply equal to $1 - \hat{\alpha}_Q = 1 - 0.158 = 0.842$. This implies large positive economies of scale in this industry in the EU countries. This value is higher than that obtained by Stier (1985) for the US industry in 1948–1976 (0.74). Possible explanations are the use of more recent data, and in particular panel data, and for a different group of countries. It also ties in well with the growing consolidation of the industry, the most recent development of which is the merger, cleared by the European Commission in December 1998, between Swedish forestry group Stora AB and Enso Oy of Finland to create the world's largest paper group.

Technological change in this industry in the EU has been biased towards the use of two factors, capital and wood, and factor labour saving, as estimated average technological biases are $\hat{B}_L = -0.019$, $\hat{B}_K = 0.030$, and $\hat{B}_W = 0.00033$, (see Table 8). These results show the same kind of biases as Stier (1985) found in the US, but are larger in absolute value for labour and capital. Also, in the EU, $\hat{B}_W$, the wood using bias, is not significantly different from zero, suggesting technological neutrality in the use of this factor, whereas Stier has to justify a statistically significant material (wood) using bias in this industry in the US.

Estimates of the average[7] value of the partial elasticities of factor substitution are reported in Table 3. They were obtained by evaluating expression (4) using the parameter estimates in Table 2 and the average factor shares over the estimation period. All elasticities have quite high (absolute) values. Labour is found to be substitutable by both

[7] We report average elasticities, as in Stier (1985), amongst others. Caves *et al.* (1984) report elasticities for the first, middle and last year in their sample, and Lundgren & Sjöström (1999) report elasticities for one year in their sample. Strictly, elasticities should be reported and conditions checked for every observation. As discussed in Berndt & Christensen (1973), by definition a translog function does not satisfy monotonicity and concavity globally, but only in some regions of the input space. "These well behaved regions may well be large enough so that the translog function can provide a good representation of relevant production possibilities." (*ibid.*), p.85.

TABLE 3. ELASTICITIES OF SUBSTITUTION.
Average elasticities of substitution between Labour, Capital and Wood inputs in the EU pulp and paper industry, 1970–1995.

σ_{LL} –0.749**	σ_{LK} 0.659**	σ_{LW} 0.986**
	σ_{K} –0.964**	σ_{KW} –0.128*
		σ_{WW} –2.730**

** denotes significant at 5% level, and * denotes significant at 1% level. The reported significance levels of the t-ratios are only indicative and should be taken with care, as the delta method was used to estimate the elasticities standard errors and these can suffer from strong bias due to non-linearity in (4). The use of bootstrap techniques here, however, is difficult due to the arbitrary heteroscedastic and serial correlation structure in Hsiao's EC3SLS estimation method.

capital and wood, whereas capital and wood are found to be complements. The matrix is semidefinite negative, thus verifying (quasi) concavity of the cost function.

Estimates of the average own and cross price elasticities are reported in Table 4, using expression (5), results in Table 3, and the average factor shares over the period. The demand for wood is most responsive to price changes, followed closely by labour, and not so closely by capital. The demand for labour is the most price sensitive with capital and wood elasticities of 0.3 and 0.5, respectively. Capital shows much less price sensitivity (0.21 and –0.04) and the demand for wood is quite price insensitive (0.17 and –0.02), showing limited factor substitution within a given technology. The price elasticities verify the additive relationship ($\Sigma_j \eta_{ij} = 0$) as discussed in Berndt (1990).

TABLE 4. PRICE ELASTICITIES.
Average price elasticities of derived demand for Labour, Capital and Wood inputs in the EU pulp and paper industry, 1970–1995.

η_{LL} –0.380**	η_{LK} 0.214**	η_{LW} 0.166**
η_{KL} 0.334**	η_{KK} –0.313**	η_{KW} –0.022*
η_{WL} 0.500**	η_{WK} –0.042*	η_{WW} –0.459**

Notes as for Table 3.

We can now move a step further and produce elasticity estimates for each country included in the dataset by using the country specific factor shares (reported in Appendix A) in expressions (4), (5) and (6) together with the estimates of the model. As the latter are common, inter country differences are due to the structure of the (average) total cost within each country. In Table 5 we report the country specific average elasticities of substitution. There are marked differences amongst the countries, particularly in σ_{LL}, σ_{KW} and σ_{WW}. Capital and wood are substitutes in Finland, Portugal, and Sweden, the three biggest EU producers and exporters of pulp (see Andrade (1998)) together with Spain. On the other hand, in Denmark and Germany there is high complementarity between these two factors, and in two, France and Italy, these elasticities are not statistically different from zero.

These results are reflected in the country specific average price elasticities, reported in Tables 6 and 7. Labour demand is more price sensitive in the four countries mentioned (elasticities of -0.51 in Portugal to -0.43 in Spain). Wood own price elasticity varies dramatically, with high positive elasticities in Denmark and Germany, where its average share in the total cost is only about 4%, compared to the EU average of 16% (see Appendix A). The countries

TABLE 5. ELASTICITIES OF SUBSTITUTION.
Average elasticities of substitution between Labour, Capital and Wood inputs in the pulp and paper industry in EU countries, 1970–1995.

Country	σ_{LL}	σ_{LK}	σ_{LW}	σ_{KK}	σ_{KW}	σ_{WW}
Austria	-0.505^{**}	0.678^{**}	0.982^{**}	-1.049^{**}	-0.947^{**}	-2.896^{**}
Belg+Lux	-0.455^{**}	0.658^{**}	0.984^{**}	-1.101^{**}	-1.053^{**}	-2.946^{**}
Denmark	-0.345^{**}	0.706^{**}	0.956^{*}	-1.071^{**}	-4.635^{**}	16.591^{*}
Finland	-1.056^{**}	0.579^{**}	0.989^{**}	-0.984^{**}	0.262^{**}	-1.896^{**}
France	-0.485^{**}	0.718^{**}	0.970^{**}	-0.961^{**}	-1.950^{**}	0.686
Germany	-0.578^{**}	0.748^{**}	0.949	-0.788^{**}	-2.935^{**}	15.196^{*}
Italy	-0.666^{**}	0.744^{**}	0.960^{*}	-0.742^{**}	-1.736^{**}	3.550
Portugal	-2.579^{**}	0.206^{**}	0.987^{**}	-0.883^{**}	0.611^{**}	-0.927^{**}
Spain	-0.969^{**}	0.635^{**}	0.987^{**}	-0.902^{**}	0.160^{**}	-2.340^{**}
Sweden	-1.183^{**}	0.467^{**}	0.991^{**}	-1.092^{**}	0.327^{**}	-1.400^{**}
EU	-0.749^{**}	0.659^{**}	0.986^{**}	-0.964^{**}	-0.128^{*}	-2.730^{**}

Notes as for Table 3.

TABLE 6. OWN PRICE ELASTICITIES.
Average own price elasticities of derived demand for Labour, Capital and Wood inputs in the pulp and paper industry in EU countries, 1970-1995.

Country	η_{LL}	η_{KK}	η_{WW}
Austria	–0.304**	–0.304**	–0.316**
Belg+Lux	–0.284**	–0.290**	–0.336**
Denmark	–0.235**	–0.300**	0.647*
Finland	–0.444**	–0.312**	–0.499**
France	–0.296**	–0.313**	0.044
Germany	–0.330**	–0.308**	0.608*
Italy	–0.357**	–0.303**	0.195
Portugal	–0.513**	–0.314**	–0.413**
Spain	–0.428**	–0.314**	–0.491**
Sweden	–0.463**	–0.294**	–0.476**
EU	–0.380**	–0.313**	–0.459**

Notes as for Table 3.

with the most inelastic demand for wood (Finland, Portugal, Spain and Sweden) are those where the share of wood is highest, varying between 21% and 45% of the total cost.

In general, cross price elasticities are quite low, showing small substitution possibilities within a given technology. They also show significant differences between countries, particularly those elasticities involving wood. For example, η_{WK} varies between weak substitutability in Finland (0.08), and strong complementarity between the two factors in Denmark (–1.3). The highest group of cross price elasticities is found in η_{WL} and η_{KL}. Demand for wood is most responsive to changes in the price of labour (η_{WL}), in particular in the countries with a higher cost share of labour and small of wood (Austria, Belgium+Luxembourg, Denmark, France, Germany and Italy). In the same group of countries, capital is more responsive to changes in the price of labour (η_{KL}).

Finally, technological change has been biased in all countries towards labour saving and capital and wood usage, as reported in Table 8. The magnitude of wood bias is very small and is not statistically different from zero in any country, suggesting technological neutrality in its use.

TABLE 7. CROSS PRICE ELASTICITIES.
Average cross price elasticities of derived demand for Labour, Capital and Wood inputs in the pulp and paper industry in EU countries, 1970–1995.

Country	η_{LK}	η_{LW}	η_{KL}	η_{KW}	η_{WL}	η_{WK}
Austria	0.197**	0.107**	0.408**	–0.103**	0.590**	–0.275**
Belg+Lux	0.173**	0.112**	0.411**	–0.120**	0.614**	–0.277**
Denmark	0.198**	0.037*	0.481**	–0.181**	0.651*	–1.298**
Finland	0.183**	0.260**	0.243**	0.069**	0.416**	0.083**
France	0.234**	0.062**	0.438**	–0.125**	0.592**	–0.636**
Germany	0.293**	0.038	0.427**	–0.117**	0.541	–1.147**
Italy	0.304**	0.053*	0.399**	–0.096**	0.515*	–0.710**
Portugal	0.073**	0.440**	0.041**	0.273**	0.196**	0.217**
Spain	0.221**	0.207**	0.281**	0.033**	0.436**	0.055**
Sweden	0.126**	0.337**	0.182**	0.111**	0.388**	0.088**
EU	0.214**	0.166**	0.334**	–0.022*	0.500**	–0.042*

Notes as for Table 3.

Taking into account the results above on the features of this industry in the EU, it is possible to divide the EU countries into two groups. One formed by Finland, Portugal, Spain and Sweden, where technological change has been more labour saving, and own labour and cross wood sub-

TABLE 8. RATES OF TECHNOLOGICAL BIAS.
Average annual rates of technological bias for Labour, Capital and Wood inputs in the pulp and paper industry in EU countries, 1970-1995.

Country	B_L	B_K	B_W
Austria	-0.016**	0.034**	0.00051
Belg+Lux	-0.016**	0.037**	0.00049
Denmark	-0.014**	0.035**	0.00142
Finland	-0.023**	0.031**	0.00021
France	-0.016**	0.030**	0.00087
Germany	-0.017**	0.025**	0.00139
Italy	-0.018**	0.024**	0.00101
Portugal	-0.049**	0.027**	0.00012
Spain	-0.022**	0.028**	0.00026
Sweden	-0.025**	0.036**	0.00016
EU	-0.019**	0.030**	0.00033

Notes as for Table 3.

stitution elasticities, own price and cross wood price elasticities are all above the EU average. The other group consists of Austria, Belgium (including Luxembourg), Denmark, France, Germany, and Italy. The first group includes the biggest pulp producers and exporters in the EU. The second includes all of the EU's biggest markets, except Spain.

Conclusions

We have estimated a translog cost function with labour, capital and wood inputs for the EU pulp and paper industry for the period from 1970 to 1995 using panel data. Four countries were excluded from our sample. Two, Greece and Ireland, due to the small relative size of their pulp and paper industry, and two, the Netherlands and the UK, due to (wood share) data heterogeneity. The results show significant but small substitutability between labour and both capital and wood, and complementarity between the latter. Technological change has been labour saving and capital using. We also found evidence of strong economies of scale in this industry as evidenced by the recent merger between Swedish forestry group Stora AB and Enso Oy of Finland. Important differences were also found between the countries, allowing us to divide them into two groups with different characteristics. One consisting of Finland, Portugal, Spain and Sweden, where technological change has been more labour saving, and own labour and cross wood substitution elasticities, own price and cross wood price elasticities are all above EU average. The other group is formed by Austria, Belgium (including Luxembourg), Denmark, France, Germany, and Italy. Future research will involve the development of what Stier and Bengston (1992) call third generation models, which combine short-run cost minimising behaviour with the dynamics of adjustment of quasi-fixed factors (like capital) over time, thus enabling the estimation of both short and long-run elasticity measures, together with models which will include more factors, in particular energy and wastepaper, the estimation of separate cost functions for the main sectors of this industry, and the use of firm level data.

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Appendix A

Means of variables in the pulp and paper industry in EU countries, 1970–95.

Country	$\ln C$	$\ln Q$	$\ln P_L$	$\ln P_K$	$\ln P_W$	S_L	S_K	S_W
Austria	14.05	15.03	3.26	3.08	3.58	0.60	0.29	0.11
Belg+Lux	13.64	14.83	3.19	3.04	3.43	0.63	0.26	0.11
Denmark	12.97	13.94	3.38	3.42	3.74	0.68	0.28	0.04
Finland	15.15	16.11	3.48	2.93	3.77	0.42	0.32	0.26
France	15.48	16.51	3.31	3.75	3.76	0.61	0.33	0.06
Germany	16.08	16.96	3.26	3.86	3.54	0.57	0.39	0.04
Italy	15.35	16.46	3.07	3.48	3.39	0.54	0.41	0.06
Portugal	13.76	13.96	2.30	3.31	3.69	0.20	0.36	0.45
Spain	14.66	15.59	2.86	3.96	4.32	0.44	0.35	0.21
Sweden	15.43	16.17	3.46	3.18	4.05	0.39	0.27	0.34
EU	14.66	15.56	3.16	3.40	3.93	0.51	0.33	0.17