Analysis of Production Structure of the Canadian Pulp and Paper Industry: 1961-1996

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Abstract

A translog cost function with factor inputs of capital, labor, energy and materials was estimated for the Canadian pulp and paper industry over the period of 1961 to 1996. The results show that, the production technology can not be specified by a Cobb-Douglas production function and it is not Hicks- neutral. It was found out that, the industry is characterized by labor-saving and capital, energy and materials-using technical change. The estimated production function indicated the existence of economies of scale, although the size of the scale is not as large as those estimated for the European Union and the United States pulp and paper industries. Estimates for Allen's elasticities of substitution show that, all the factor inputs were found to be highly substitutable among each other. In addition, estimates for price elasticities were found to be sensitive to a change in their own price and relatively speaking, the demand for capital was found to be more responsive to changes in prices of energy and materials and the demand for materials was also found to be sensitive to changes in price of labor and energy.

I. Introduction

Estimation of production functions of firms or industries is one of the central research topics in microeconomic theory. Economists estimate production function for a variety of reasons. Some estimate it to measure technical change and efficiency. Others estimate production functions for a specific policy analysis and so on. In the process of estimation, choosing a functional form is one of the mains tasks that should be handled at the beginning. According to Griffin et.al (1987), selecting a functional form is a complicated task for a researcher due to the growing number of available functional forms. The authors identified 20 different functional forms for estimating a production function. This paper uses a family of the translog cost function using data from the Canadian pulp and paper industry over the period of 1961 to 1996. A likelihood ratio test is also applied to test a Cobb-Douglas specification since it is a restricted version of the translog cost function.

Production analysis can be carried out using identification of a production function, a cost function or a profit function. By duality, each approach is in principle equivalent to others. The above approaches use three different methods to estimate production function and measure technical change. These include: index numbers, linear programming or econometric approach. This study uses the cost function approach using econometric method to estimate a production function for the Canadian pulp and paper industry. Pulp and paper industry is not only Canada's largest manufacturing industry but also the nation's leading manufacturer in terms of production, employment and net exports. It is also a national industry in the sense that it is a geographically dispersed industrial employer. The 162 mills that comprised the industry in 1994 were located in Quebec (67), Ontario (34), British Colombia (28) and Atlantic and Prairie Provinces (33) (Hailu, 1998).

As mentioned above, measuring technical change is another reason for estimating production functions of industries. Broadly speaking, technical change can be defined as the application of new knowledge to the production processes. Technically, the rate of technical change can be measured either as an increase in output obtained from the same quantities of inputs, or equivalently, a decrease in inputs needed to produce a given level of output (Stier and Bengston, 1992). One of the objectives of this paper is to measure the rate and bias of technical change for the Canadian pulp and paper Industry. In addition, factor substitution, scale of economies and own and cross price elasticities of factor inputs are estimated and discussed.

This being the introduction, the rest of the paper is organized as follows. Section two reviews the literature on estimation of production function using a translog cost function for pulp and paper industries across the world. A survey of four papers are presented in this section. The models used for estimation and analysis of the results are outlined in section three. The parent translog cost function and the share equations derived from it are described in this section. In addition, formulas for the estimation of Allen's partial elasticity of substitution, scale of economies and, price elasticities of factor inputs are presented. Section four is devoted to estimation and analysis of results. At last, conclusions and references are presented in the last sections and the original data set is attached as an appendix.

II. Literature Review

A number of studies have been done on estimating production functions of pulp and paper industries in different parts of the world. A more comprehensive review of the literature on this subject with a special emphasis on North America's forest sector is given by Stier and Bengston (1992). These authors have summarized 24 studies over the period of 1968 to 1990. Brief surveys of four papers for Canada, Unites States and the European Union which are more related to pulp and paper industry are presented below.

Sherif (1983) estimated a long-run translog cost function for the Canadian pulp and paper mills using annual data from 1956 to 1977. He specified capital, labor, energy and wood as inputs of production in his analysis. Sherif found out that, input pairs wood-labor and capital-energy are compliments, while the other pairs of inputs are substitutes. Further more, his results show that, technical change is estimated to be capital and energy using and labor and wood saving. Similar to Sherif's work, Martinello(1985) estimated factor substitution, technical change and returns to scale of three Canadian forest industries. These industries include: pulp and paper, sawmills and shingle mills, and logging. Martinello employed a translog cost function to estimate the production technology using annual data from 1963 to 1982. Each industry's output is specified to be a function of four variable inputs namely: capital, labor, energy and materials. Marinello (1985) found out that, the technology of the industries is non-homothetic and technical change is non-neutral, capital using and labor saving for all the industries.

Another related study is the paper by Stier (1985) for the United States pulp and paper industry. Stier employed a translog cost function to investigate the implications of factor substitution, returns to scale and biased technological progress for the aggregate pulp and paper industry. Stier used annual US data from 1948 to 1976 and identified three factors of production: capital, labor and wood. Stier's results show that, the US pulp and paper industry is characterized by labor-saving technological progress relative to capital and wood. Stier (1985) reported that, a wood-saving bias suggests that, current projections of future increase in the wood / pulp ratio may lead to underestimates of future pulpwood requirements. The average annual rates of the bias were estimated to be 0.011, -0.009 and 0.014 for capital, labor and wood respectively.

Recently, Andrade (2000) estimated a production technology for the pulp and paper industry in the European Union. Andrade used a flexible industry cost function with three inputs (labor, capital and wood) using annual panel data over the period 1970 to 1995. His results show significant but small substitutability between labor and both capital and wood, and complimentarity between capital and wood. Similar to the above findings of the Canadian and US industries, Andrade found labor saving and capital using technological change. The estimated average technical biases are -0.019, 0.03 and 0.0003 for labor, capital and wood respectively. In sum, all the above discussed papers used an econometric approach in the estimation of production function and they choose the more flexible translog cost function. They give more emphasis to the nature and extent of factor relationships as measured by the elasticities of factor substitution, returns to scale and the extent and bias of technical change. This paper will adopt similar approach in the analysis.

III. Models[1]

The following translog cost function with the assumption of homothetic production structure is used to estimate the Canadian pulp and paper industry:

$$\ln C(P,Y,T) = \alpha_o + \alpha_y \ln Y + \alpha_t T + \sum_i \beta_i \ln P_i + \tfrac{1}{2}\Sigma\Sigma \beta_{il} \ln P_i \ln P_j + \sum \delta_i T \ln P_i \qquad (1)$$

Where C is total cost calculated as the sum of quantities of factor inputs multiplied by their respective prices. Four inputs are considered in this study, namely capital, labor, energy and materials. Y is the aggregate industry output, P is a vector of factor prices, the i^{th} element of which is P_i and T is a time trend that serves as a proxy for technical change. Some authors include the square of the time trend and square of logarithm of output as additional explanatory variables. However, this paper opted to deleted them since they were found to be statistically insignificant in the previous studies (Martinello 1985, Andrade 2002).

The parameters of the cost function are assumed to be constants. The following restrictions must hold for the symmetry of cross partial derivatives and linear homogeneity in factor prices of the cost function:

$$\begin{aligned} &\beta_{ij} = \beta_{ji} \cdots\cdots i \neq j \\ &\sum_i \beta_i = 1 \\ &\sum_i \beta_{ij} = \sum_j \beta_{ij} = \Sigma\Sigma \beta_{ij} = \sum_i \delta_i = 0 \end{aligned} \qquad (2)$$

[1] The models are basically compiled from the works of Stier (1985), Martinello (1985) and Andrade (2000).

Using Shepherd's lemma, the cost minimizing demand functions for the factors of production, also known as factor share equations, are obtained by differentiating the translog cost function with respect to factor prices as follows:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C} = S_i \qquad \text{This will give us:}$$

$$S_i = \beta_i + \sum_j \beta_{ij} \ln P_j + \delta_i T \qquad (3)$$

Where S_i is the share of input i^{th} cost in the total industry cost in which $\sum S_i = 1$ for i = capital, labor, energy and materials. This is commonly called cost exhaustion.

Returns to scale are usually defined in terms of the relative increase in output resulting from a proportional increase in the quantity of all inputs. From the above specified translog cost function, the elasticity of total cost with respect to output is calculated as:

$\phi = \frac{\partial \ln C}{\partial \ln Y}$ from this, the returns to scale (SCE) can be derived as

$$SCE = 1 - \phi \qquad (4)$$

This measure is interpreted as the positive values of SCE imply economies of scale where as the negative values imply diseconomies of scale.

Let us now turn to the issue of measuring the degree of substitutability between any pair of factors. One of the most famous ones is the elasticity of substitution introduced by Allen in 1938. Formally, the elasticity of substitution measures the percentage change in factor proportions due to a change in marginal rate of technical substitution. Allen's elasticities of substitution (also known as the *partial elasticity of substitution*) for the translog cost function can be derived from the parameter estimates and estimated share of inputs as follows:

$$\sigma_{ij} = \frac{\beta_{ij}}{S_i S_j} + 1, i \neq j$$
$$\sigma_{ii} = \frac{\beta_{ij}}{S_i^2} - \frac{1}{S_i} + 1 \qquad (5)$$

The own and cross price elasticities of derived demand for factors are usually estimated for purposes of policy analysis. Estimates of these elasticities, given constant output and constant prices of all inputs, can be derived directly from Allen's elasticity of substitution in the following manner:

$$\eta_{ij} = S_j \sigma_{ij} \qquad (6)$$

The technological change bias is defined as the influence of technological progress on factor shares when factor prices and output are held constant. According to Binswanger(1974), this bias is measured as:

$$\mathrm{B}_i = \frac{\partial S_i^*}{\partial T} \frac{1}{S_i} = \frac{\delta_i}{S_i} \qquad (7)$$

where S_i^* denote that relative factor prices are held constant. If B_i is positive, technological change is said to be factor i-using, if B_i is negative, the process is said to be factor i-saving, and $B_i = 0$ implies Hicks neutral technical change.

To gain more efficiency, the optimal procedure of the estimation process is to consider both the parent cost function given in equation (1) and the share equations derived from it (equation 3). These equations are then estimated jointly as a multivariate system including a random disturbance term in each equation. The random term is assumed to be a multivariate normally distributed with zero mean and constant covariance matrix. According to Stier (1985), the random terms in these equations are assumed to arise from errors in cost minimizing behavior, and to be contemporaneously correlated. The later assumption is logical since overuse of any one input would likely imply under-use of one or more other inputs. The four factor share equations given in equation (3) must sum to unity. Hence in performing the estimation, it is necessary to drop one share equation in order to avoid the problem of a singular covariance matrix. The share equation for materials input is deleted in this paper and iterative Zellner procedure is performed on the remaining systems of equations. The Zellner procedure is a computationally efficient method of obtaining a maximum likelihood estimates which satisfy the restrictions specified in equation (2) and it is invariant to which share equation is deleted. Based on the above specified models, basic data descriptions and the estimated results are discussed in the next sections.

IV. Data and Descriptive Statistics

Data for the Canadian pulp and paper industry are obtained from Statistics Canada, Micro-Economic Analysis Division[2]. It consists of annual observations of pulp and paper gross output, quantities and prices of factor inputs for the years 1961 to 1996. Capital, labor, energy and materials are the four inputs are considered for analysis. All the data are expressed in Fisher's volume and price indices of gross output and inputs taking 1961 as the base period. The different types of inputs and outputs which make up a single category of input or output are not assumed to be perfect substitutes. Rather, they are aggregated up according to a technology which is a second-order approximation to arbitrary constant returns to scale technology. The data set expressed in Fisher's indices is attached as *appendix 1*.

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[2] I would like to thank Grant Hauer (PhD) ,Department of Rural Economy, University of Alberta, for allowing me to use his data set.

Basic descriptive statistics of the logarithms of prices of inputs, total cost and output, and cost share of each input is given in Table 1 below. On average, labor has relatively higher value than the others inputs. Energy has the highest cost share among the other inputs . It is twice as large as capital's cost share. Labor and materials has almost the same cost shares, 24.4 and 26.8 percent respectively.

Table 1 Basic Descriptive Statistics

Variable	Mean	St. Dev.	Minimum	Maximum
LnP_K	4.80	0.867	2.576	6.3540
LnP_L	5.97	0.895	4.605	7.1751
LnP_E	5.65	0.856	4.605	6.6812
LnP_M	5.46	0.625	4.605	6.4257
LnC	12.07	0.945	10.59	13.474
LnY	5.14	0.258	4.605	5.5326
S_K	0.166	0.069	0.014	0.288
S_L	0.244	0.034	0.164	0.312
S_E	0.322	0.065	0.242	0.438
S_M	0.268	0.020	0.239	0.306

Note: LnP_i refers to logarithms of the price of input i,, where i = capital, labor, energy and materials. LnC and Ln Y refer to logarithms of total cost and output respectively and Si refers to cost share of inputs.

Average annual rate of change of the quantities and prices of factor inputs over the study period are reported in Table 2. Average rates of changes are obtained by regressing logarithms of the variables on a time trend. As it is shown in Table 2, a substantial rate of decrease in labor is observed over the study period. In particular, labor declined in the 1980s and 1990's after increasing at a rate of 2.54 percent in the 1960's and 0.51 percent in the 1970's.[3] Labor and energy costs have increased almost three times as fast as the cost of capital. The rate of change in the price of capital has been volatile since the study period. A sharp decline in the price is observed in the early 90s. The decline in capital expenditure in 1996 mirrored the rapid price decrease for pulp and paper products, after the most prosperous year ever on record for pulp prices in 1995 (Statistics Canada, website). The cost of materials has shown a 5.6% annual rate of increase since 1961. The rates of increase in the quantities of capital, energy and materials are on average between 2.4 and 3.7 percent.

Table 2 Average Annual Rate of Change of Factor Quantities and Prices

	Rate of change in :	
Variable	Quantity (%)	Price (%)
Capital	3.69	2.79
Labor	-0.55	8.41
Energy	2.38	7.79
Materials	2.78	5.57

[3] These figures are calculated from the data set.

V. Estimation and Results[4]

The estimated coefficients with standard errors of the translog cost function are given in Table 3 below. The results are based on estimation of equation (1) and (3) as a system. All parameters related to materials input are derived from the restrictions give in equation (2). As it is shown in Table 3, all the coefficients are found to be statistically significant. The coefficients of the logarithm of output (α_y) and factor prices (β_i) are all positive, which shows that, the cost function is non-decreasing in factor prices and output. Further more, monotonicity of the cost function is satisfied since the predicted cost shares are positive at every point of the data set. Their average values are given as 0.16, 0.24, 0.32 and 0.27 for capital, labor, energy and materials respectively.

A likelihood ratio test was employed to test whether the production technology can be characterized by a Cobb-Douglas production function (β_{ij} = 0 or all i, j) and to test if the Hicks neutral technological change (δ_i = 0 for all i) would hold. Summary of the tests and the critical values from a χ^2 distribution table are given in Table 4 below. The results show that, neither the Cobb-Douglas specification nor the test for Hicks neutral technology hold. The decision rule is that, the null hypothesis of Cobb-Douglas specification or Hicks-neutral technical change is rejected if the computed value of the log-likelihood ratio is greater than the critical value.

[4] The Shazam software is used to estimate the translog cost function and the derived share equation as a system using SUR method.

Table 3 Estimated Coefficients

Parameter	Estimate (Standard Error)	Parameter	Estimate (Standard Error)
α_o	2.470	B_{kk}	0.071
	(0.318)		(0.005)
α_y	0.779	β_{KL}	-0.023
	(0.067)		(0.002)
α_T	0.004	β_{KE}	-0.023
	(0.002)		(.005)
β_k	0.192	β_{KM}	-0.025
	(0.009)		(0.003)
β_L	0.265	β_{LL}	0.133
	(0.003)		(0.013)
β_E	0.290	β_{LE}	-0.085
	(0.009)		(0.009)
β_M	0.252	β_{LM}	-0.025
	(0.005)		(0.016)
δ_K	0.0012	β_{EE}	0.243
	(0.000)		(0.018)
δ_L	-0.467	β_{EM}	-0.134
	(0.000)		(0.012)
δ_E	0.001	β_{MM}	-0.447
	(0.000)		(0.024)
δ_M	0.002		

(0.000)

Note: All figures are approximated to three decimal places

The cost function is homogenous of degree α_y = 0.78 in output. This measures the elasticity of total cost with respect to output. It is interpreted as an increase in total cost by 7.8 percent as a result of a 10 percent increase in aggregate output. The corresponding measure of scale economies (SCE) is given as 1 – 0.78 = 0.22. This suggests the presence of scale economies, though small, in the Canadian pulp and paper industry. This measure is smaller than the US pulp and paper industry (SCE = 0.74) as estimated by Stier (1985) but closer to Sherif's (1983) estimate of the Canadian pulp and paper industry (SCE = 0.35) over the period of 1956 to 1977. The presence of scale economies has important implications for the structure of the industry. If unit cost declines as output increases, large plants and firms may be necessary to capture production efficiencies (Stier, 1985).

Table 4 Likelihood Ratio Tests

Test for:	Computed Value*	Critical Value	Decision
Cobb-Douglas specification	181.18	$\chi^2_{10,\,0.05} = 18.31$	C-D specif. rejected
Hicks-neutral technical change	90.35	$\chi^2_{3,\,0.05} = 7.82$	Hicks neutral rejected

* These values are computed as L = -2(L_r - L_{unr}), where L_r and L_{unr} are log-likelihood values for the restricted and unrestricted functions respectively.

In addition to the above results, parameters of great interest from estimation of the production function include the nature and extent of factor relationships as measured by the elasticities of factor substitution, return to scale, own and cross price elasticities of factor inputs and the extent and bias of technical change. These measures and issues related to them are discussed in the subsequent paragraphs.

Allen's partial elasticities of factor substitution are reported in Table 5 below. These estimates are obtained from the expression in equation (5) using the parameter estimates and the predicted average factor shares over the study period. As it was discussed briefly on section 3, Allen's elasticity of substitution (σ_{ij}) measures the response of the i-th input demand to a change in the j-th input price, holding output Y constant (i.e., moving along an iso-quant) and other input prices constant. Normally, Allen's elasticity of substitution is symmetric and negative semi-definite, i.e. $\sigma_{ji} = \sigma_{ij}$ and $\sigma_{ii} <0$. Two inputs i and j are said to be substitutes if $\sigma_{ij} > 0$ and complements if $\sigma_{ij} < 0$. The results in Table 5 show that, all inputs were found to be substitutes. In contrast to the previous studies by Sherif (1983) and Martinello (1985), a high degree of substitutability is observed among the factor inputs. Higher values of elasticities of substitution imply that, one factor can easily be substituted for the other. The elasticity of substitution can also affect the growth rate of output when factors of production are increasing at different rates so that their ratio is changing. If both factors are increasing at the same rate, then the growth rate of output is independent of the elasticity of substitution (Pereira , 2002). It is observed in Table 2 that, energy and materials were increasing almost at the same rate, which imply that the growth rate of pulp and paper is independent of the elasticity of substitution between these inputs, at least for the Canadian case.

Table 5 Allen's Elasticities of Substitution (σ_{ij})

Input	Capital	Labor	Energy	Materials
Capital	-5.183			
Labor	0.964	-2.932		
Energy	0.953	0.887	-1.834	
Materials	0.958	0.973	0.889	-3.165

Note: All figures are approximated to three decimal places

Own and cross price elasticities of demand for the factor inputs are reported in Table 6 below. These estimates are derived from the expression in equation (6). The demand for capital and materials are more responsive to price change followed by the demand for labor and energy. On average, the own price elasticity of factor inputs suggest that, all the factors for the pulp and paper industry are price sensitive. Even though the magnitude for the cross price elasticities are almost the same for all inputs, the demand for capital seems more responsive to changes in prices of energy and materials and the demand for materials is also sensitive to changes in price of labor and energy.

The estimated coefficients of the time trend in equation (1) and (3) show that, technological change has been biased. The measures of technical change reported in Table 7 below show that, the Canadian pulp and paper industry is capital, energy and materials-using and labor-saving. The figures are estimated based on the expression in equation (7).

Table 6 Own and Cross Price Elasticities (η_{ij})

Input	P_K	P_L	P_E	P_M
Capital	-0.829	0.237	0.310	0.257
Labor	0.154	-0.721	0.288	0.261
Energy	0.152	0.218	-0.596	0.239
Materials	0.153	0.239	0.289	-0.851
Total Cost	0.160	0.246	0.325	0.269

Note: All figures are approximated to three decimal places. η_{ij}, refers to a percentage change in in put i as a result of a percentage change in price of input j. Along the diagonal i = j. The last row represents the estimated percentage change in total cost from a 1% increase in factor prices. It gives the predicted value of factor shares.

Table 7 Measures of Technical Change

Capital	Labor	Energy	Materials
0.0105	-0.019	0.003	0.0075

Consistent with this study, previous studies on technical change for the pulp and paper industries in the United States, European Union and Canada, all show labor-saving and capital-using technical change. In contrast to this study, Martinello (1985) found out that, technical change is energy and materials-saving for the Canadian pulp and paper industry, though similar to this study, the figures are almost close to zero. Sherif's (1983) results show that, technical change is estimated to be capital and energy-using and labor and wood saving. Almost similar results to this study. In sum, it is worth to note that, since technical advances occur in spurts, the use of a simple linear time trend to represent the state of technology is a major limitation of this and previous studies. Stier and Bengston (1992) suggest that, alternative measures, such as the power ratings or throughput measures, might better capture the characteristics of a technology.

VI. Conclusions

A family of the flexible translog cost function with capital, labor, energy and materials inputs was used to estimate a production function of the Canadian pulp and paper industry for the period 1961 to 1996. The results show that, the production technology can not be described by the simple Cobb-Douglas functional form and it is not Hicks-neutral. Rather, it was found out that, the industry is characterized by labor-saving technical change and capital, energy and materials-using technological process. These results are almost consistent with the previous studies on the Canadian pulp and paper industry. Further more, the estimated production function indicated the existence of economies of scale in the production process, although the size of the scale is not as large as those estimated for the European Union and the United States.

The elasticities of substitution, as suggested by Allen were estimated for the study period. The results show that, all the factor inputs were found to be highly substitutable among each other. In addition, estimates for own and cross price elasticities were obtained by multiplying Allen's partial elasticity of substitution with the predicted share of cost for each inputs. All the factor inputs were found to be price sensitive to a change in their own price. In addition, relatively the demand for capital was found to be more responsive to changes in prices of energy and materials and the demand for materials was also found to be sensitive to changes in price of labor and energy.

Estimating a production function of an industry is not as simple task for a variety of reasons. For example, it has been observed that, comparisons among different studies did not yield consistent results. One of the reasons could be the use of different functional forms. However, even studies who used the same functional forms were observed to come up with different estimates of coefficients and measures of technical change and elasticities. To increase the possibility of obtaining meaningful and consistent results, at least from an econometric approach, following some strategies might be useful. For instance, in measuring technical change, the state of technology might not be captured only by a time trend. Rather, it should incorporate technological variables that accurately reflect both the productive capability and the rate at which it changes over time. The other possible solution could be inclusion of more relevant factor inputs and more detailed break-down of the inputs. These might yield more specific and consistent results. However, availability of data, increasing the degrees of freedom once more inputs are considered and multicollinearity among explanatory variables could also be potentials problems. According to Stier and Bengston (1992), if the goal of the analysis is to forecast factor demand and cost implications of technical change, simulation models may offer a more promising alternative.

VII. References

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