Production structure and input substitution in Canadian sawmill and wood preservation industry

Rao V. Nagubadi and Daowei Zhang

Abstract: We use a translog cost function to analyze the sawmill and wood-preservation industry in Canada from 1958 to 2003. The estimated cost function is homothetic and Hicks neutral. Allen elasticities of substitution indicate that significant substitution possibilities exist. According to Morishima elasticities of substitution, substitution of labour by other inputs is easier than the substitution of other inputs by labour, and substitution of other inputs by materials is easier than the substitution of materials by other inputs. The demand for production labour, nonproduction labour, and electric power inputs is elastic. In contrast to the previous findings of zero or negative rate of technical change, we find technical progress at the rate of 0.57% per annum and a total factor productivity growth rate of 0.54% per annum in the Canadian sawmill and wood preservation industry.

Résumé : Nous utilisons une fonction du coût de type translog pour analyser l'industrie du sciage et de la préservation du bois au Canada, de 1958 à 2003. La fonction du coût estimée est homothétique et neutre au sens de Hicks. Les élasticités de substitution d'Allen indiquent que de fortes possibilités de substitution existent. Selon les élasticités de substitution de Morishima, la substitution de la main-d'œuvre par d'autres facteurs de production est plus facile que la substitution des autres intrants par la main-d'œuvre et la substitution des autres intrants par les matériaux est plus facile que la substitution des matériaux par les autres intrants. La demande pour les intrants sous forme de main-d'œuvre responsable de la production, de personnel de soutien et d'énergie électrique est élastique. Contrairement aux conclusions précédentes concernant la mesure d'un taux de progrès technique nul ou négatif, nous observons un taux de progrès technique de 0,57 % par année et une productivité globale des facteurs de production de 0,54 % par année dans l'industrie du sciage et de la préservation du bois au Canada.

[Traduit par la Rédaction]

Introduction

The sawmill and wood-preservation industry is an important industry in Canada, contributing 2.06% of the total value of manufacturing shipments in 2003. Previous studies of technical change in the industry in Canada present mixed results. Several studies using data between 1955 and 1984 (Martinello 1985; Nautiyal and Singh 1985; Singh and Nautiyal 1986) report negative or no technological progress in the Canadian sawmill or softwood lumber industry. However, Ghebremichael et al. (1990) estimate 0.4% per year improvement in total factor productivity (TFP) growth for the lumber industry between 1962 and 1985, whereas Bernstein (1994) reports a TFP growth of 3% per year for softwood lumber industry between 1963 and 1987.

The objective of this study is to analyze the production structure and input substitution in the Canadian sawmill and wood-preservation industry. We use a translog cost function approach. The total cost function is estimated simultaneously with the cost-share equations for seven inputs — production labour (P), nonproduction labour (N), machinery and equipment capital (Q), plants and structures capital (S), fuels energy (F), electric power (R), and materials (M). The output is the sum of all products in the industry, including softwood lumber, hardwood lumber, wood chips, wood-preservation products, wood ties – shingles – shakes, and other products. In addition to the usual Allen elasticities of substitution and own and cross price elasticities of demand, we also compute Morishima elasticities of substitution between inputs.

This study differs from previous studies in several aspects. Firstly, previous studies (e.g., Ghebremichael et al. 1990; Abt et al. 1994) cover only lumber and woodchips but not other important segments of lumber production, wood-preservation products, and shakes and shingles. Since chemically treated lumber and wood-preservation products have become an important form of lumber consumed in the outdoor applications of home construction and other uses (Nagubadi et al. 2004), we combine the sawmill industry and wood-preservation industry in this study.

Secondly, previous studies use aggregated inputs and do not take into account the difference between production labour and nonproduction labour, machinery and equipment (M&E) capital and plants and structures (P&S) capital, and fuels energy and electric energy. To demonstrate the differences between these subdivisions of inputs, we use seven inputs in our analysis. Thirdly, a few studies use value added minus labour cost as the cost share of capital in valuing capital services, which leads to unrealistically high estimates of service price of capital as a percentage (in some years as high as 151%) of total capital stock. In this study, we use the

Received 10 June 2005. Accepted 28 June 2006. Published on the NRC Research Press Web site at http://cjfr.nrc.ca on 20 January 2007.

R.V. Nagubadi and D. Zhang.[1] School of Forestry and Wildlife Sciences, Auburn University, AL 36849, USA.

[1]Corresponding author (e-mail: zhangdw@auburn.edu).

opportunity cost principle to estimate the service prices of capital.

Finally, previous studies have used Allen elasticity of substitution to explain the substitution structure in the industry. However, according to Blackorby and Russell (1989), the Allen measure cannot be interpreted in the spirit of the marginal rate of substitution and is not informative about the relative share of inputs and the curvature of the isoquant, and the correct measure of the substitutability is the Morishima elasticity of substitution (MES). Blackorby and Russell (1989) also state that the MES is a measure of curvature, or ease of substitution; is a sufficient statistic for assessing, quantitatively and qualitatively, the effects of changes in prices or quantity ratios on relative factor shares; and is a logarithmic derivative of a quantitative ratio with respect to a marginal rate of substitution or a price ratio. Chambers (1988) characterizes the Allen measure as one-factor, one-price elasticity of substitution and the Morishima measure as two-factor, one-price elasticity of substitution. As such, MES is the correct measure of elasticity of substitution in the multifactor context.

Our results indicate that significant substitution possibilities between major inputs exist and demand for production labour, nonproduction labour, and electric power inputs is elastic for the Canadian industry. We find all inputs are substitutes according to the MESs. The next section discusses study methods, followed by a brief description of data used in the estimation. The remaining sections present the results and conclusions.

Methods

We use an econometric approach to study the production structure and input substitution in the industry. Unlike the index number approach, the econometric approach (translog function) enables us to estimate the parameters of interest, that is, elasticities of factor substitution, elasticities of factor demand, and economies of scale. The translog function provides a second-order approximation to an arbitrary twice continuously differentiable linear homogenous function and is flexible in the sense that it does not impose any restrictions. The production function of the industry can be written as

$$[1] \qquad Y = f(\boldsymbol{X},\ t)$$

where Y is the quantity of output, $\boldsymbol{X}$ is a vector of inputs, and t is time in years. Under cost-minimization, $\boldsymbol{X}$ is the least-cost combination of inputs that can produce output Y. According to duality theory, there exists a dual cost function to the above production function:

$$[2] \qquad C = f(\boldsymbol{P},\ Y,\ t)$$

where C is total cost, $\boldsymbol{P}$ is vector of factor prices, and Y and t are as previously defined. In terms of an unrestricted translog cost function (Christensen et al. 1973), the above function takes the form:

$$[3] \qquad \ln C = \alpha_0 + \alpha_Y \ln Y + \tfrac{1}{2}\alpha_{YY}(\ln Y)^2 + \alpha_t t + \tfrac{1}{2}\alpha_{tt}t^2 + \alpha_{Yt}\ln Yt + \sum_i \beta_i \ln P_i + \tfrac{1}{2}\sum_i\sum_j \gamma_{ij}\ln P_i \ln P_j + \sum_i \varphi_{iY}\ln P_i \ln Y + \sum_i \psi_{it}\ln P_i t$$

where P_i and P_j are input prices (i, j = P, N, Q, S, F, R, and M); t is time in years (t = 1, …, 46; starting from 1958 = 1); and α, β, γ, ϕ, and ψ are coefficients to be estimated. To correspond to a well-behaved production function, a cost function must be homogeneous of degree one in the input prices and requires the following conditions to be satisfied:

$$[4] \qquad \sum_i \beta_i = 1;\ \sum_j \gamma_{ji} = 0;\ \gamma_{ij} = \gamma_{ji};\ \sum_i\sum_j \gamma_{ij} = 0;\ \sum_i \varphi_{iY} = 0;\ \sum_i \psi_{it} = 0$$

According to Shephard's lemma, the cost minimizing shares, S_i, are

$$[5] \qquad \frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i}\frac{P_i}{C} = \boldsymbol{X}_i\frac{P_i}{C} = S_i = \beta_i + \sum_i \gamma_{ji}\ln P_j + \varphi_{iY}\ln Y + \psi_{it}t + e_i$$

where e_i are random errors and the other variables are as defined above. From the above system of equations, we can derive several measures of interest.

Allen own- and cross- partial elasticities of factor substitution (σ_{ii}, and σ_{ij}) measure the ease with which inputs can be substituted for one another in the production of a fixed level of output and are estimated as

$$[6] \qquad \sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \text{ for all } i,\ i = j;$$

$$\sigma_{ij} = 1 + \frac{\gamma_{ij}}{S_i S_j} \text{ for } i,\ j,\ i \neq j$$

Positive and negative signs indicate that the factors are substitutes and complements, respectively. Own- and cross-partial elasticities of factor demand (ε_{ii} and ε_{ij}) are estimated as

$$[7] \qquad \varepsilon_{ii} = S_i\,\sigma_{ii} \text{ for all } i,\ i = j;\ \varepsilon_{ij} = S_j\,\sigma_{ij} \text{ for } i,\ j,\ i \neq j$$

As mentioned previously, the MES is the correct measure of the ease of substitution in the multifactor context to assess the effects of changes in price or quantity ratios on relative shares of inputs according to Blackorby and Russell (1989). The MESs are estimated as

$$[8] \qquad \sigma_{ij}^{\mathrm{M}} = \varepsilon_{ij} - \varepsilon_{jj}$$

The rate of technical change ($\dot{T}$), also known as technical change parameter, is the negative of the derivative of the cost function with respect to time

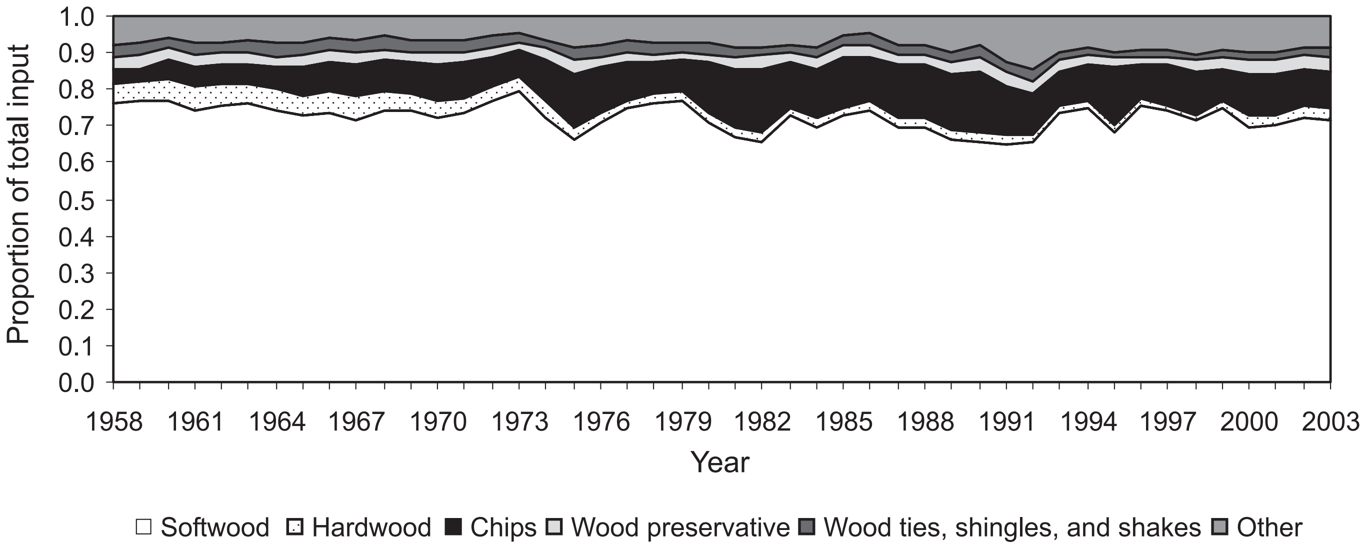
$$[9] \qquad \dot{T} = -\frac{\partial \ln C}{\partial t} = -(\alpha_t + \alpha_{tt}t + \alpha_{Yt}\ln Y + \sum_i \psi_{it}\ln P_i)$$

The rate of technical change not only varies over time and is influenced by output level and factor prices. Factor prices influence technical change through ψ_{it}.

The percentage change in the total factor productivity ($\dot{\text{TFP}}$) is estimated as (Capalbo 1988, p. 179; Baltagi and Griffin 1988)

$$[10] \qquad \dot{\text{TFP}} = \dot{T} + (1 - \varepsilon_{CY})\dot{Y}$$

Fig. 1. Output revenue shares in the sawmill and wood preservation industry in Canada, 1958–2003.



where $\dot{T}$ is the rate of technical change defined above, $\dot{Y}$ the rate of change in output, and ε_{CY} the elasticity of cost with respect to output:

$$\varepsilon_{CY} = \frac{\partial \ln C}{\partial \ln Y} = \alpha_Y + \alpha_{YY} \ln Y + \alpha_{Yt} t + \sum_i \varphi_{iY} \ln P_i$$

The second term, $(1 - \varepsilon_{CY})\dot{Y}$, in eq. 10 represents the scale effects.[2] When scale effects are present, growth in TFP is not equal to the rate of technical change. For an industry characterized by constant returns to scale, cost elasticity of output is one and growth in TFP equals the rate of technical change, $\dot{T}$.

Data

The products included for the industry in Canada are listed as 321111 (sawmills, except shingle and shake mills), 321112 (shingle and shake mills), and 321114 (wood preservation) after 1997 under the North American Industry Classification System. Prior to 1997, these were listed as 2512/2513 (sawmill and planing mill products), 2511 (shingle and shake mills), and 2591 (wood preservation) under the Standard Industrial Classification System. The primary sources of data are annual census of manufactures and Statistics Canada publications catalogue Nos. 35-204, 35-250, and the Canadian Socioeconomic Information Management System (CANSIM-II). This study uses the data for the years from 1958 to 2003.

The quantities for six outputs — softwood lumber, hardwood lumber, wood chips, wood-preservation products, wood ties – shingles – shakes, and other products — are imputed from the value of shipments using the weighted prices constructed from available quantities and values of subcomponents for each output. Since wood chips are in bone dry tonnes, and wood ties – shingles – shakes are in squares, they are converted to thousand board feet equivalents using approximate conversion factors.[3]

The unit for production worker input is the number of actual hours paid and for nonproduction workers man-years employed. The capital stock input is in real 2001 Canadian dollars; fuels energy and electric energy are imputed quantities in British thermal units (Btu) and kilowatt-hours (kWh), respectively; and material inputs are in thousand board feet (MBF). Material inputs include nonwood materials and contract work. Wherever data are unavailable, suitable interpolations and imputations are made to fill in the gaps. The prices of all inputs, including capital stocks, are converted to the 2001 real Canadian dollars using the gross domestic product deflator.

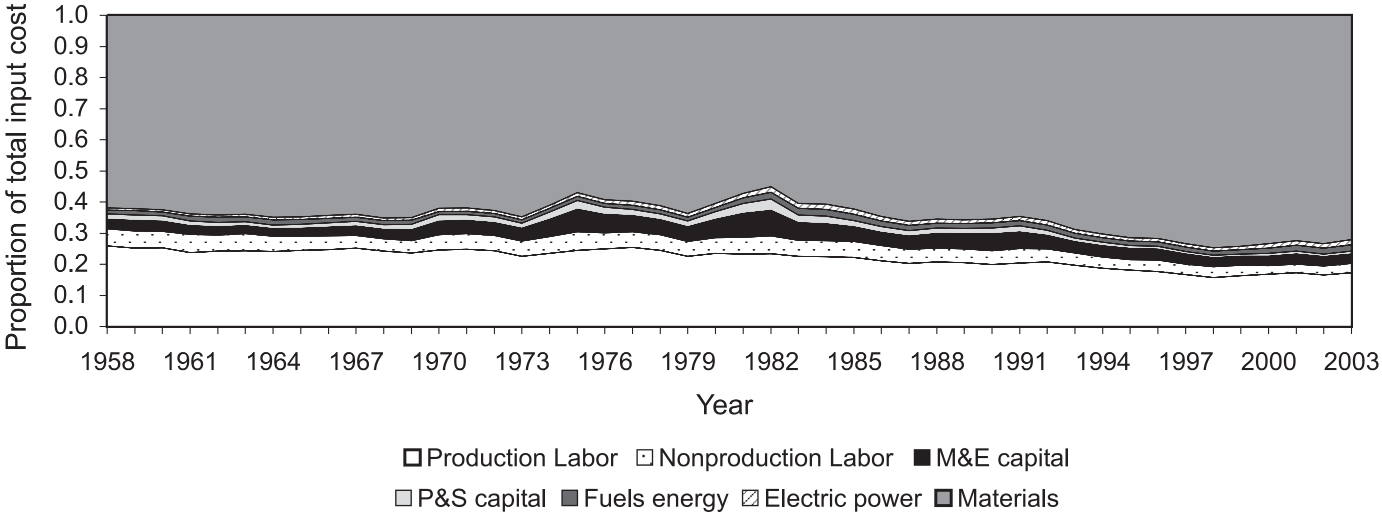
This study uses capital stock data available from Statistics Canada. The service price of capital is computed by adding (*i*) the bond interest rate on total capital stock, (*ii*) depreciation on M&E based on 12 year life (8.33%), and (*iii*) depreciation on P&S based on 20 year life (5%). For bond interest rate, we use Scotia Capital, Inc., long-term average weighted yield on bonds for Canada for period 1978–2003 and extending back to 1958–1977 period using percent changes in McLeod, Young, Weir's 10 industrials bond average yield rate for Canada.

The nominal value of shipments for the industry increased dramatically (nearly 30 times) in Canada from CAN$0.53 billion to CAN$15.79 billion over the analysis period. The changing composition of various products in the industry's

[2] According to Griliches and Ringstad (1971), deriving economies of scale or scale effects from the aggregated industry data (in contrast to firm-level data) has no relevance to the scale issue (Baardsen 2000). Furthermore, according to Diamond–McFadden's impossibility theorem, estimation of economies of scale and technical change from the aggregates is an impossible task, because the two concepts are inseparable in the time-series setting (Diamond et al. 1978). Nevertheless, we provide estimates of scale effects and rates of technical change to ensure comparability with the results of earlier studies.

[3] The approximate conversion factor for wood chips is one bone-dry ton = 1.15 MBF (1 ton = 0.907 tonnes) and for wood ties – shingles – shakes is one square = 0.1212 MBF (David Briggs, College of Forest Resources, University of Washington, Seattle, Wash., personal communication, 2004).

Fig. 2. Input cost shares in the sawmill and wood preservation industry in Canada, 1958–2003. M&E, machinery and equipment; P&S, plants and structures.



total revenue is depicted in Fig. 1. The share of softwood lumber in Canada declined from 76% to 70%; hardwood lumber declined from 6% to 2%; wood chips increased from 4% to 12%; wood preservation products increased from 3% to 4%; wood ties – shingles – shakes products declined; other products, consisting of mainly contract work, increased marginally.

Changes in the cost shares of inputs in the industry in Canada are shown in Fig. 2. The share of input expenditure on total labour declined from 31% to 20%; the cost share of service price of both types of capital declined from 5% to 3%; the combined cost share of fuels and electric energy increased from 2% to 4%; and the share of materials cost rose from 62% to 72%.

Results and discussion

The total cost function and cost share equations are jointly estimated by means of seemingly unrelated regression equations using maximum likelihood method which is equivalent to iterative Zellner efficient estimation method (Greene 1995, p. 391). Since cost shares sum to one, one cost share equation must be omitted. The remaining six cost share equations are estimated by normalizing input prices with the price of omitted cost share equation, which in this case is materials price. The parameter estimates and their standard errors of omitted equation are derived using procedure described in Berndt (1991, p. 473). Since the maximum likelihood estimation procedure is used, parameter estimates are invariant to omitted equation (Greene 1993).

Parameter estimates

Several specifications of the translog cost function, including unrestricted, nonhomothetic Hicks-neutral technical change, homothetic non-neutral technical change, homothetic Hicks-neutral technical change, homogeneous (homothetic and no technical change), and unitary elasticity are estimated. However, only homothetic and Hicks-neutral technical change specification could satisfy the regularity conditions for a well-behaved cost function and final specification included the terms, Y and t.[4]

Table 1 presents estimated coefficients and the associated p values. Twenty seven of 30 estimated coefficients are significant at the 10% level or better. We discuss the results below in terms of elasticities of substitution and elasticities of demand.

Allen elasticities of substitution

To compare our results with those in previous studies, we first discuss the Allen measure. Allen own and cross elasticities of substitution (AES) between inputs and their approximate standard errors estimated at mean levels of cost shares are presented in Table 2. Production labour has a significant substitution relationship with all other inputs in the Allen sense. Nonproduction labour is a significant substitute for materials and both types of energy but has a significant complementary relationship with P&S capital. M&E capital has a substitution relationship with P&S capital but has a complimentary relationship with both types of energy. Both types of energy have a complementary relationship with P&S capital. Fuels energy and electric power are substitutes in the Canadian industry. These AES also show that input pairs, P&S capital and fuels energy, P&S capital and electric power, fuels energy and electric power, and fuels energy and materials are complements in the Allen sense.

Only three studies (Martinello 1985; Nautiyal and Singh 1985; Singh and Nautiyal 1986) have provided results on substitution relationships for the Canadian industry. The results differ among the studies and from our results. For example, the substitution elasticity between production labour and materials in our study is 1.16 as compared with 0.00 found by Martinello (1985) and 0.24 by Singh and Nautiyal

[4] The determinants of principal minors of matrix of Allen elasticities of substitution are, –5.44, 141.39, –2419.20, 50 786.60, –1 591 614.97, 116 792 888.91, and 0.00.

Table 1. Estimated coefficients of translog cost function for sawmill and wood preservation industry in Canada, 1958–2003.

Coefficient[a]	Estimate	P
α_0	–3.0353**	<0.0001
α_Y	1.0090**	<0.0001
α_t	–0.0057**	0.0043
β_P	0.4535**	<0.0001
β_N	0.1367**	0.0001
β_Q	0.1020*	0.0277
β_S	0.1124**	<0.0001
β_F	0.1001**	<0.0001
β_R	0.0292**	0.0012
γ_{PP}	–0.0899**	<0.0001
γ_{PN}	0.0184**	0.0033
γ_{PQ}	0.0282**	<0.0001
γ_{PS}	0.0046*	0.0173
γ_{PF}	0.0087**	<0.0001
γ_{PR}	0.0068**	<0.0001
γ_{NN}	–0.0136**	0.0029
γ_{NQ}	–0.0056*	0.0226
γ_{NS}	–0.0041**	0.0002
γ_{NF}	0.0053**	<0.0001
γ_{NR}	0.0053**	<0.0001
γ_{QQ}	0.0050	0.4899
γ_{QS}	0.0104†	0.0792
γ_{QF}	–0.0055**	<0.0001
γ_{QR}	–0.0035	0.3143
γ_{SS}	0.0052**	0.0021
γ_{SF}	–0.0014	0.6644
γ_{SR}	–0.0003**	<0.0001
γ_{FF}	0.0050**	<0.0001
γ_{FR}	0.0020**	<0.0001
γ_{RR}	–0.0021**	0.0012

Note: **, *, and † indicate significance at 1%, 5%, and 10% levels, respectively.

[a]The subscripts are as follows: P, production labour; N, nonproduction labour; Q, machinery and equipment capital; S, plants and structures capital; F, fuels; R, electric power; *Y*, output quantity; *t*, time trend. Indirectly estimated coefficients related to price of materials (and its interaction terms with other input prices) are not presented here.

(1986) for Canada. Interestingly, this is similar to the substitution elasticity of 1.15 between production labour and wood for the United States found by Abt and Ahn (2003). In the case of capital and labour, we estimate a substitution elasticity of 4.11 between production labour and M&E capital, and 2.21 between production labour and P&S capital, differing from 0.23 by Martinello (1985) and 2.58 by Singh and Nautiyal (1986) between all labour and all capital. These estimates are considerably larger than the corresponding estimates of 0.10 and 0.19 between labour and capital for the US industry estimated by Stier (1980*a*, 1980*b*). For other countries, Baardsen (2000) estimates a substitution elasticity of 0.73 between labour and capital in Norwegian sawmilling industry, and Campbell and Jennings (1990) estimated a value of 0.33 for Tasmanian sawmilling industry.

Morishima elasticities of substitution

The results of MES reported in Table 3 show that, in the Canadian industry, 32 of 36 input pairs are significant substitutes, whereas there is no evidence of any complementary relationship among input pairs in the Morishima sense. The MES, for example, σ_{NP}^{M}, is interpreted as the percent change in the nonproduction labour to production labour quantity ratio when the relative price ratio P_P/P_N is changed by changing P_P and holding P_N constant. The most striking feature is that, unlike the AES, the MES are not symmetric, that is, $\sigma_{ij}^{M} \neq \sigma_{ji}^{M}$. For example, a 1% rise in the wages of production labour causes 1.815% increase in the ratio of nonproduction labour to production labour inputs, while a 1% rise in the wages of nonproduction labour causes 1.382% increase in the ratio of production labour to nonproduction labour inputs. This implies that the substitution of nonproduction labour for production labour is easier than the substitution of production labour for nonproduction labour.

Since the MES are not symmetric, there is a difference between the substitution of first input by second input and the substitution of the second input by the first input. Looking at the numbers in the first row and first column in Table 3, we note that σ_{NP}^{M} (1.815) > σ_{PN}^{M} (1.382), σ_{QP}^{M} (2.092) > σ_{PQ}^{M} (1.008), σ_{SP}^{M} (1.677) > σ_{PS}^{M} (0.721), and so on. These relationships imply that the substitution of production labour by other inputs is easier than the substitution of other inputs by production labour in the Morishima sense. Also from the relationships between MES in second row and MES in second column from the blank cell, it is evident that the substitution of nonproduction labour by other inputs is easier than the substitution of all other inputs by nonproduction labour.

Similarly, for a 1% increase in the price of P&S capital, the ratio of M&E capital to P&S capital increases by 0.951%, whereas a 1% increase in the price of M&E capital causes an increase of 1.479% in the P&S capital to M&E capital input ratio, implying easier substitution of M&E capital by P&S capital than the substitution of P&S capital by M&E capital. Among the two energy inputs, substitution of fuels by electric power is easier than the substitution of electric power by fuels energy. Judging from the numbers in the last row and last column in Table 3, it is evident that the substitution of all other inputs by materials is easier than the substitution of materials by all other inputs.

Demand elasticities

Own-price elasticities of demand for production labour, nonproduction labour, and electric power exceed one indicating elastic demand for these inputs (Table 4). Own-price elasticities of production labour (–1.19) and nonproduction labour (–1.25) are higher than previous estimates of –0.24 (Martinello 1985), and –0.86 (Singh and Nautiyal 1986) for all labour. These own price elasticities for both types of labour for Canadian industry are also higher than Stier's (1980*b*) estimate of –0.35 for the United States, and Abt's (1987) average estimate of –0.32 for western, southern, and Appalachian regions of the United States. These estimates

Table 2. Allen own and cross partial elasticities of substitution for sawmill and wood preservation industry in Canada, 1958–2003.

	Production labour	Nonproduction labour	Machinery and equipment	Plants and structures	Fuels	Electric power	Materials
Production labour	–5.438**						
	(0.24)						
Nonproduction labour	2.846**	–27.490**					
	(0.63)	(2.19)					
Machinery and equipment	4.110**	–1.955	–20.218**				
	(0.51)	(1.30)	(4.23)				
Plants and structures	2.215**	–4.172**	15.481†	–39.399*			
	(0.51)	(1.40)	(8.25)	(17.17)			
Fuels	3.608**	8.658**	–7.721**	–4.348*	–43.299**		
	(0.42)	(1.44)	(1.45)	(1.74)	(1.96)		
Electric power	3.684**	11.023**	–6.265**	–0.618	12.511**	–100.496**	
	(0.60)	(2.06)	(2.19)	(3.73)	(2.34)	(4.84)	
Materials	1.162**	0.802**	–0.080	–0.277	–0.424†	–0.091	–0.424**
	(0.10)	(0.28)	(0.40)	(0.73)	(0.21)	(0.32)	(0.05)

Note: Elasticities were evaluated at the means of estimated cost shares. **, *, and † indicate significance at 1%, 5%, and 10% levels, respectively. Values in parentheses are approximate standard errors (Binswanger 1974): SE (σ_{ij}) = SE (γ_{ij}) / S_iS_j.

Table 3. Morishima elasticities of substitution for sawmill and wood preservation industry in Canada, 1958–2003.

	j						
i	Production labour	Nonproduction labour	Machinery and equipment	Plants and structures	Fuels	Electric power	Materials
Production labour		1.382**	1.008**	0.721*	0.715**	1.213**	1.031**
		(0.10)	(0.17)	(0.29)	(0.03)	(0.06)	(0.07)
Nonproduction labour	1.815**		0.890**	0.611*	0.792**	1.299**	0.797**
	(0.14)		(0.18)	(0.29)	(0.04)	(0.06)	(0.18)
Machinery and equipment	2.092**	1.163**		0.951**	0.542**	1.097**	0.224
	(0.12)	(0.11)		(0.33)	(0.04)	(0.06)	(0.26)
Plants and structures	1.677**	1.062**	1.479**		0.594**	1.163**	0.096
	(0.12)	(0.12)	(0.38)		(0.04)	(0.07)	(0.47)
Fuels	1.982**	1.646**	0.518**	0.608*		1.316**	0.0003
	(0.10)	(0.12)	(0.18)	(0.29)		(0.06)	(0.14)
Electric power	1.999**	1.754**	0.578**	0.672*	0.851**		0.216
	(0.14)	(0.14)	(0.20)	(0.30)	(0.05)		(0.21)
Materials	1.446**	1.289**	0.834**	0.678*	0.653**	1.169**	
	(0.06)	(0.10)	(0.17)	(0.29)	(0.03)	(0.06)	

Note: Elasticities were evaluated at the means of estimated cost shares. ** and * indicate significance at 1%, and 5% levels, respectively. Values in parentheses are approximate standard errors (Frondel 1999): $\mathrm{SE}(\sigma_{ij}^{\mathrm{M}}) = \sqrt{\frac{\mathrm{Var}(\gamma_{ij})}{S_j^2} + \frac{\mathrm{Var}(\gamma_{jj})}{S_i^2} - \frac{2\mathrm{Cov}(\gamma_{ij}\gamma_{jj})}{S_iS_j}}$.

are also higher than –0.57 for Norwegian sawmilling industry found by Baardsen (2000) and –0.58 for Australian sawmilling industry (Bigsby 1994).

The demand elasticity for M&E capital for Canada is –0.84, higher than previous estimates of –0.30 (Martinello 1985) and –0.24 (Singh and Nautiyal 1986) for the Canadian industry for all capital. The demand elasticity for M&E capital is higher than the estimate of –0.66 for Norwegian sawmilling (Baardsen 2000) and –0.69 for Australian sawmilling (Bigsby 1994) for all capital.

The demand elasticity for materials is –0.28 for the Canadian industry, which is lower than Martinello's (1985) estimate of –0.37 and Singh and Nautiyal's (1986) estimate of –0.69 for materials in Canadian industry. The corresponding estimates reported for materials for Norway and Australia are –0.70 and –0.30, respectively.

The price elasticity of demand for fuels in the Canadian industry is –0.66, which is lower than the Norwegian industry estimate of –1.92 and higher than Australian industry estimate of –0.47. The price elasticity of demand for electric power for the Canadian industry is –1.17, which is higher than the corresponding estimates for Norwegian (–0.70) and Australian (–0.47) industries.

Rate of technical change and total factor productivity change

Canada experienced a mean percent technical change of 0.57%/year in the industry during the period of analysis.

Table 4. Own- and cross-price elasticities of demand for sawmill and wood preservation industry in Canada, 1958–2003.

	For a 1% change in the price of						
% change in the quantity demanded of	Production labour	Nonproduction labour	Machinery and equipment	Plants and structures	Fuels	Electric power	Materials
Production labour	–1.191**	0.130**	0.170**	0.038**	0.055**	0.043**	0.755**
	(0.05)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.06)
Nonproduction labour	0.624**	–1.252**	0.052	–0.072**	0.132**	0.128**	0.521**
	(0.14)	(0.10)	(0.05)	(0.02)	(0.02)	(0.02)	(0.18)
Machinery and equipment	0.900**	–0.089	–0.837**	0.268†	–0.118**	–0.073**	–0.052
	(0.11)	(0.17)	(0.17)	(0.14)	(0.02)	(0.03)	(0.26)
Plants and structures	0.485**	–0.190**	0.641†	–0.683*	–0.066*	–0.007	–0.180
	(0.11)	(0.06)	(0.34)	(0.30)	(0.03)	(0.04)	(0.47)
Fuels	0.790**	0.394**	–0.320**	–0.075*	–0.660**	0.146**	–0.275†
	(0.09)	(0.07)	(0.06)	(0.03)	(0.03)	(0.03)	(0.14)
Electric power	0.807**	0.502**	–0.259**	–0.011	0.191**	–1.170**	–0.059
	(0.13)	(0.09)	(0.09)	(0.06)	(0.04)	(0.06)	(0.21)
Materials	0.255**	0.037**	–0.003	–0.005	–0.006*	–0.001	–0.276**
	(0.02)	(0.01)	(0.02)	(0.01)	(0.003)	(0.004)	(0.03)

Note: Elasticities were evaluated at the means of estimated cost shares. **, *, and † indicate significance at 1%, 5%, and 10% levels, respectively. Values in parentheses are approximate standard errors (Binswanger 1974): $SE(\varepsilon_{ij}) = SE(\gamma_{ij}) / S_i$.

This is in contrast to previous findings of negative or zero rate of technical change (Martinello 1985; Singh and Nautiyal 1986), but less than 2.35% estimated for softwood lumber industry by Bernstein (1994).

From the results of the translog cost function, using the values from eq. 10, we estimate the total factor productivity growth of 0.54%/year for Canada.[5] This estimate is closer to the estimate of growth rate of 0.61%/year for Canada using Törnqvist–Theil index under growth accounting procedure (Zhang and Nagubadi 2006). Our results differ from 0.4%/year growth for the lumber industry for period 1962–1985 (Ghebremichael et al. 1990) and from 3.24%/year TFP growth estimated for Canadian softwood lumber industry (Bernstein 1994).

Summary and conclusions

In this paper, we examine various aspects of production in the sawmill and wood-preservation industry in Canada over the period 1958–2003. We use the translog cost function approach with seven inputs and output quantity as a sum of six products. The cost function for Canadian industry was homothetic, Hicks-neutral, and satisfied all conditions of an ideal cost function.

According to the estimated Allen elasticities of substitution, significant substitution possibilities exist between production labour and M&E capital, production labour, and materials in the Canadian industry. Significant substitution possibilities also exist between both types of capital, between both types of energy, and between nonproduction labour and both types of energy in the Allen sense. Complementary relationships exist between capital and energy, between nonproduction labour and P&S capital, and between materials and fuels energy in the Allen sense. Thus, the Canadian industry is in a better position in controlling production costs in case of an input price hike by substituting low cost inputs to high cost inputs.

Morishima elasticities of substitution indicate that the substitution of production labour by other inputs is easier than the substitution of other inputs by production labour. This may indicate rigidities related to production labour compared with other inputs in the Canadian industry. Similarly, substitution of all other inputs by materials is easier than the substitution of materials by all other inputs. This may suggest that efficiency related to materials is a not a priority compared with efficiency related to other inputs as Canada has relatively abundant forest resources.

Demand for all inputs except fuels energy and materials is elastic in the Canadian industry. Among the cross-price elasticities of inputs in the Canadian industry, only price of M&E capital input has a positive elastic response on quantity demanded of P&S capital input. The Canadian industry experienced a compound growth rate of 0.57%/year in technical change and 0.54%/year in total factor productivity during the study period. Further studies are warranted for the sawmill and wood-preservation industry in the United States and other major wood products producing countries.

Acknowledgements

The authors gratefully acknowledge helpful comments from Henry Kinnucan, Henry Thompson, Shashi Kant, and two reviewers and an associate editor of this journal on an earlier draft. However, the authors are solely responsible for any remaining errors.

[5] Rate of technical change, cost elasticity of output, and rate of change in output for Canada are 0.57, 1.009, and 3.567, respectively. The first two statistics are estimated from translog cost function at mean levels of variables, and the last statistic is derived from semi-log equation, $\ln Y = a + bt$, where $\ln Y$ is natural logarithm of quantity of output, t is time in years (1958 = 1), a, and b are parameters, and the rate of change in output is estimated as $(e^b - 1)100$.

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