An econometric analysis of output supply and input demand in the Canadian softwood lumber industry

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Abstract: Few studies have examined the own-price elasticity of Canadian softwood lumber supply or output-adjusted factor demand elasticities over the past two decades, despite the utility of these measures in understanding producer response to tariffs, to market shifts (such as the decline in U.S. public harvest), and to changes in domestic forest policies. The present analysis employs a normalized, restricted quadratic profit function approach to estimate lumber supply and Marshallian factor demand elasticities for three Canadian regions. Results indicate that the lumber supply elasticity in the British Columbia coast region may be twice as large as that in the interior or eastern regions. Comparison of Hicksian factor demand elasticities with earlier studies suggests that the own price elasticity of labor demand may be two or more times larger than that for wood. Results also indicate differential time trends in Marshallian lumber output and wood demand elasticities across regions, rising in the British Columbia coast and falling elsewhere over the past two decades. Morishima elasticities of substitution from the present and past studies indicate that the wood for labor factor intensity is more sensitive to changes in labor price than is the labor for wood intensity to changes in wood price.

Résumé : Au cours des deux dernières décennies, peu d'études ont examiné l'élasticité-prix de l'offre de bois d'oeuvre résineux canadien ou les élasticités de la demande pour le facteur de production ajusté, malgré l'utilité de ces mesures afin de comprendre la réaction du producteur aux tarifs, aux changements du marché (tel que le déclin dans la récolte sur la forêt publique des États-Unis) et aux changements dans les politiques forestières domestiques. Cette étude utilise l'approche d'une fonction quadratique de profit, restreinte et normalisée, pour estimer l'offre de bois d'oeuvre et les élasticités marshalliennes de la demande pour le facteur de production, le tout portant sur trois régions canadiennes. Les résultats indiquent que l'élasticité de l'offre de bois d'oeuvre dans la région côtière de la Colombie-Britannique peut être deux fois plus élevée que celle de la zone intérieure ou des régions de l'Est. Une comparaison des élasticités hicksiennes de la demande du facteur avec des études antérieures, suggère que l'élasticité-prix de la demande de main-d'oeuvre peut être deux fois plus élevée, et même davantage, que celle pour le bois. Les résultats indiquent aussi qu'au cours des deux dernières décennies, il y a eu différentes tendances temporelles marshalliennes dans la production de bois et dans les élasticités de la demande de bois entre les régions : une augmentation dans la région côtière de la Colombie-Britannique et une diminution ailleurs. Les élasticités de substitution de Morishima provenant de la présente étude et des études antérieures indiquent que l'intensité du facteur bois pour main-d'oeuvre est plus sensible aux changements de prix de la main-d'oeuvre que ne l'est l'intensité du facteur main-d'oeuvre pour bois aux changement du prix du bois.

[Traduit par la Rédaction]

Introduction

In the ongoing debate over tariffs and other restrictions in the Canadian – United States softwood lumber trade, economic analysis of potential output, price, and trade responses have played an important role in the negotiation process (Kalt 1988). A critical element in this analysis is knowledge of the price responsiveness of Canadian softwood lumber output, the own- and cross-price elasticities of supply, and input factor demand (Adams et al. 1986; Chen et al. 1988; Myneni et al. 1994). Over the past two decades, production characteristics of the Canadian lumber industry have received considerable attention from economists. All but a few of these studies have employed cost function approaches, assuming (in some cases arguing) that industry output is exogenous. As a result, while these studies have given much insight into factor substitution in the sector, they have not extended our understanding of output-price responsiveness. At the same time, the utility of those few studies directly addressing lumber-supply behavior is limited. In some cases they examine only a few of the lumber-producing regions in Canada, most employ estimation samples that do not include data from the 1990s, some fail to meet behavioral (curvature) conditions necessary for the approaches employed, and some report widely divergent results.

The present study offers an analysis of Canadian softwood lumber supply designed to fill a portion of this information

Received November 19, 1999. Accepted May 3, 2000.

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Table 1. Characteristics of past production studies of the Canadian softwood lumber industry.

Study	Functional form[a]	Outputs[b]	Inputs[c]	Data	Regions[d]
Profit functions					
Adams and Haynes 1996	NQ	L	WV(K)	56–89	BIE
Baker 1989	TLD3	L*XC	WLKT	63–82	C
Baker 1990	TLD3	LC	WLEMT	62–86	BIQO
Bernard et al. 1997	SNQ	L	VT	65–90	QO
Constantino and Haley 1988	TL	LC	WL(KQ)T	57–81	B
Cost functions					
Banksota et al. 1985	TL	L	WLEKT	1978	A
Martinello 1985	TL	L*	WLEKT	63–82	C
Martinello 1987	TL	L	WLKT	63–79	BI
Meil and Nautiyal 1988	TL	O	WLE(K)T	68–84	BIQO
Meil et al. 1988	TLD2	O	WLE(K)T	48–83	I
Nautiyal and Singh 1985	TL	L*	WLEKT	65–81	C
Singh and Nautiyal 1986	TLD2	L*	WLEKT	55–82	C
Production functions					
Constantino and Townsend 1986	TL	L	(WLEK)T	62–83	C

[a] NQ, normalized quadratic; SNQ, symmetric normalized quadratic; TL, translog; TLD2, translog with partial adjustments; TLD3, translog with endogenous adjustments.

[b] L, softwood lumber (* indicates hardwood lumber included); X, lumber produced for export; C, chips; O, all outputs.

[c] W, roundwood; L, labor; E, energy; K, capital stock; Q, wood quality; V, all or other variable inputs; T, technology level (time trend); (*x*), quasi-fixity of input *x*.

[d] A, Alberta; B, BC coast; C, Canada; E, east; I, BC interior; O, Ontario; Q, Quebec.

gap. It employs a restricted profit function approach applied to three lumber-producing regions embracing all of Canada, using data for costs, prices, and output from the 1962–1995 period. Empirical findings are converted into forms that allow direct comparison with past studies. The discussion proceeds in the next section with a summary and characterization of previous work. The empirical model and data are then presented followed by the analysis and discussion of results.

Past studies

Production studies of the Canadian lumber industry have employed both cost and profit function forms. In most cases, data for the industry are derived from Statistics Canada for standard industrial classification code (SIC) 2512, sawmills and planing mills. Table 1 lists studies of the Canadian lumber industry published since 1980 indicating functional form; outputs; inputs, with quasi-fixed factors in parentheses; data sample; and regions considered. Output has most often been taken as softwood lumber (ignoring chips and sometimes including hardwoods) or as a chip and lumber composite. Three studies have treated lumber and chips as joint products.[2] Inputs have included roundwood, labor, energy, and capital stock (and various composites of these groups). Most studies include a time trend to represent technology.

Five prior studies have employed profit function approaches. Their elasticity results are summarized in Table 4. Adams and Haynes (1996) estimate only the supply relations for three Canadian regions derived from a normalized quadratic profit function (thus curvature properties were not considered). Baker (1989) reestimated the Bernstein (1988) model with a corrected data set for all of Canada. This model utilized a translog profit function with endogenous capital stock adjustment, reporting elasticities for three lengths-of-run to illustrate the effects of adjustment over time. Curvature properties of the model were not reported. Baker (1990) also applied the Bernstein model to the British Columbia coast, British Columbia interior, Quebec, and Ontario. Curvature properties of the model were not presented, and elasticities in some cases were 10 times larger than others reported in the literature. Bernard et al. (1997) used a symmetric normalized quadratic profit function to model lumber production and factor demand in Quebec and Ontario. They considered air-dried and kiln-dried grades independently, including all inputs in a single "variable input" category. Convexity was obtained by constraint. Constantino and Haley (1988) estimated a translog profit function for the B.C. coast. Wood quality was included as a quasi-fixed input to test whether declining wood quality explained the lack of growth in productivity. While the estimated supply and factor demand curves had the expected slopes, the full set of second-order curvature conditions were violated in 60% of observations.

Most previous studies have employed cost functions. As a group these studies are all at least a decade old, with data bases extending only into the early 1980s. In all cases output

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[2] Statistics Canada reports wood chip sales or shipments but not production data. Residues used for internal energy generation or discarded are not estimated.

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is treated as exogenous and supply behavior or unconditional factor demand response to price changes are not explored.[3] Key elasticity results from these studies are summarized in Table 6. Banksota et al. (1985) applied a translog cost function to cross-sectional data from a 1978 sample of 83 Alberta sawmills. Curvature properties were not discussed. Martinello (1985) employed a translog cost function to estimate factor share equations for the industry at the three-digit SIC level (SIC 251, which includes shakes and shingles) for all Canada. In a later study, Martinello (1987) employed the same basic technique but considered the industry at the four digit SIC level (SIC 2512) for the B.C. coast and B.C. interior. In both studies, curvature properties of the models were checked only at the means of the data.

Nautiyal and Singh (1985) estimated a translog cost function for Canada as a whole using a composite of softwood and hardwood lumber as the output measure. Meil and Nautiyal (1988) developed a translog cost function model applied to four regions (B.C. coast, B.C. interior, Ontario, and Quebec), classifying firms into four size groups depending on the number of employees. In both studies, curvature properties were satisfied at all observations. Singh and Nautiyal (1986) estimated a translog cost function applying a cross-stock adjustment process to factor demands to test rates of factor-use adjustment. In a related study, Meil et al. (1988) applied a translog cost function to the B.C. interior, incorporating a partial adjustment mechanism for capital stock in the factor demand relations. In these studies, only the necessary conditions for concavity were checked by examining the main diagonal of the Allen elasticity of substitution matrix.[4]

Finally, in a unique production function approach, Constantino and Townsend (1986) compared the performance of a system of translog output elasticity (equivalent to cost share) equations with an alternative model, which jointly estimated cost shares and an operating rate (output/capacity) function. Constant returns to scale for the industry was assumed, and curvature was not checked.

The empirical model and data

In the present study, the Canadian softwood lumber sector is divided into three producing regions;[5] the British Columbia coast (BCC), British Columbia interior and Alberta (INT), and the rest of Canada (EAST). One output, a composite of softwood lumber and chips (the latter treated as a by-product produced in fixed proportions to lumber) is considered. Inputs include softwood roundwood, labor, and other variable factors. Capital stock is treated as quasi-fixed, and technology is represented by a time trend. The industry is assumed to be competitive, producers attempting to maximize profits given endogenous prices of lumber and wood and exogenous prices of labor and other variable inputs.

We approximate the industry's indirect profit function by means of a normalized restricted quadratic form, as given by

$$[1]\qquad \tilde{\pi} = \alpha_0 + \sum_i \beta_i \frac{p_i}{p_n} + \frac{1}{2}\sum_i \sum_j \beta_{ij} \frac{p_i}{p_n}\frac{p_j}{p_n} + \sum_i \beta_{ik} \frac{p_i}{p_n} k + \sum_i \beta_{it} \frac{p_i}{p_n} t + \beta_k k + \beta_t t + \beta_{kt} kt + \beta_{kk} k^2 + \beta_{tt} t^2$$

Applying Hotelling's Lemma, the supply curve and negatives of the factor demand curves are given by[6]

$$[2]\qquad \frac{\partial \tilde{\pi}}{\partial (p_i/p_n)} = x_i = \beta_i + \sum_j \beta_{ij} \frac{p_j}{p_n} + \beta_{ik} k + \beta_{it} t \qquad \text{for } i = o, w, l$$

where o is the output composite of lumber and chips, w is softwood roundwood, l is labor, n is other variable inputs, k is capital stock, t is level of technology, p_i's are prices, and x_i's are quantities of inputs and output (negative for inputs).

To exhibit the properties of a well-behaved profit function, $\tilde{\pi}$ must be[7]

non-decreasing in output price:

$$[3]\qquad \beta_{ii} \geq 0, \qquad \text{for } i = o$$

non-increasing in input prices:

$$[4]\qquad \beta_{ii} \leq 0, \qquad \text{for } i = w, l$$

quasi-convex in all prices:

$$[5]\qquad \beta = \left\| \beta_{ij} \right\|, \qquad \text{positive semi-definite}$$

The empirical model consists of eqs. 1 and 2 with symmetry imposed and normally distributed stochastic disturbances of mean zero and constant variance appended. Dummy variables were included in the supply and factor demand equations in BCC and INT to represent the effects of labor strikes in British Columbia in 1975 and 1986. Unlike past studies, output and roundwood prices were treated as jointly dependent with input and output volumes.[8]

Time-series data including annual observations from 1962 to 1995 for each of the three Canadian regions were used in the estimation of the model. Data for prices and quantities of output, roundwood, and labor were obtained from Statistics Canada. Capacity as described in Adams and Haynes (1996) was used as a proxy for capital stock, representing maximum service output of the stock. The price index for variable inputs was a national producers' selling price index. Further discussion of the data can be found in the Appendix.

Relations for the three regions were estimated using iterative nonlinear three stage least squares with a set of

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[3] Output response can be examined by means of the cost function. Chambers (1982) presents an approach for this, but output must be treated as jointly dependent in estimating the cost function. This was not the case in any of the cost function studies considered in this paper.

[4] Mohr (1980) describes the approach, noting that this is a necessary but not a sufficient condition for concavity.

[5] Determined to be homogeneous in timber species and production facilities.

[6] See Lau (1978) and Chambers (1988) for treatments of the properties of the normalized profit function.

[7] Linear homogeneity of the ordinary profit function in all prices is assured by normalization.

[8] Constantino and Haley (1988) noted that these prices should be treated as endogenous but abandoned the approach in the face of deteriorating estimation results.

Table 2. Coefficient estimates for profit function model of Canadian softwood lumber industry.

Coefficient	BCC	INT	EAST	Coefficient	BCC	INT	EAST
α_0	–100.56 (–3.00)	23.49 (2.11)	10.33 (2.37)	β_{KT}	–0.04 (–0.57)	–2.62 (–2.24)	–0.47 (–1.45)
β_O	–2.32 (1.52)	–2.93 (–4.48)	–0.32 (–0.46)	β_{TT}	0.00 (0.27)	0.59 (2.53)	0.05 (1.15)
β_W	8.77 (2.12)	13.63 (2.74)	0.10 (0.05)	β_{KK}	–3.42 (–2.76)	3.27 (2.26)	1.03 (1.72)
β_L	0.51 (0.72)	–5.17 (–1.32)	–8.33 (–3.43)	β_{DS75}	–0.93 (–6.54)	–1.33 (–4.14)	
β_{OO}	0.66 (4.96)	0.89 (4.39)	0.80 (3.13)	β_{DW75}	–0.53 (–3.71)	–1.27 (–3.93)	
β_{WW}	1.88 (2.82)	1.59 (3.09)	3.08 (3.14)	β_{DL75}	1.77 (7.93)	2.04 (4.35)	
β_{LL}	0.30 (4.63)	0.35 (1.63)	0.06 (0.16)	β_{DS86}	0.86 (3.72)	2.19 (4.67)	
β_{OW}	–0.98 (–4.11)	–1.05 (–3.67)	–1.00 (–2.31)	β_{DW86}	0.33 (6.99)	0.31 (3.71)	
β_{OL}	–0.11 (–2.60)	–0.14 (–2.57)	–0.20 (–1.67)	β_{DL86}	0.16 (3.51)	0.26 (3.14)	
β_{WL}	0.13 (1.15)	–0.08 (–0.64)	0.29 (1.04)	ρ_π	0.80	1.25	0.44
β_{OK}	0.90 (2.86)	1.09 (5.79)	0.16 (0.53)	ρ_O	0.76	0.76	1.02
β_{WK}	–2.08 (–3.12)	–2.02 (–5.74)	–0.21 (–0.35)	ρ_W	0.89	0.99	1.03
β_{LK}	–0.37 (–2.80)	–0.23 (–2.92)	–0.01 (–0.09)	ρ_L	1.02	0.96	0.98
β_{OT}	0.02 (0.93)	–0.09 (–1.37)	0.15 (0.19)	R^2_π	0.58	0.87	0.86
β_{WT}	–0.10 (–1.92)	0.22 (1.05)	0.03 (1.51)	R^2_O	0.56	0.98	0.95
β_{LT}	0.05 (2.11)	0.13 (2.04)	0.10 (1.51)	R^2_W	0.65	0.98	0.95
β_T	0.26 (0.36)	3.36 (1.40)	0.11 (0.26)	R^2_L	0.86	0.82	0.76
β_K	35.67 (2.81)	–13.10 (–2.31)	–2.73 (–1.47)				

Note: Asymptotic *t* statistics are given in parentheses. β_{ij}, coefficient; ρ_i, first-order autocorrelation correction coefficient; R^2, pseudo-R^2 calculated as the square of the correlation coefficient between the actual and predicted values; *O*, output; *W*, roundwood input; *L*, labor; *K*, capital stock, *T*, time trend representing technological level. The β_{DPY} indicate dummy variables for British Columbia labor strikes for quantities *P* = *S* (output), *W* (wood), *L* (labor) and years *Y* = 1975 and 1986 in the output supply and two factor demand equations.

Table 3. Marshallian elasticities from profit function model of Canadian softwood lumber industry.

	BCC	INT	EAST
e_{OO}	0.84 (3.61)	0.38 (3.13)	0.65 (2.74)
e_{OW}	–0.46 (–3.30)	–0.13 (–2.97)	–0.24 (–2.16)
e_{OL}	–0.11 (–2.48)	–0.06 (–2.50)	–0.09 (–1.63)
e_{WO}	0.78 (3.27)	0.26 (2.84)	0.47 (2.13)
e_{WW}	–0.55 (–2.52)	–0.12 (–2.65)	–0.42 (–2.74)
e_{WL}	–0.08 (–1.14)	–0.02 (0.64)	–0.08 (–1.02)
e_{LO}	0.42 (2.40)	0.24 (2.27)	0.34 (1.62)
e_{LW}	–0.18 (–1.13)	0.04 (0.63)	–0.15 (–1.02)
e_{LL}	–0.80 (–4.05)	–0.58 (–1.61)	–0.05 (–0.16)

Note: Ratios of the elasticities to their estimated standard errors are given in parentheses. *O*, output; *W*, roundwood input; *L*, labor.

instruments including exogenous variables together with the lagged values of all endogenous variables for all regions.[9] Durbin–Watson statistics from initial estimates showed signs of autocorrelation in all regions. As a result, first-order autocorrelation terms (ρ) were added to each equation.

Results

Parameter estimates, asymptotic *t* ratios and goodness-of-fit statistics for the equations are given in Table 2. For the quadratic functional form, the Hessian matrix of second-order partial derivatives contains only constants (the estimated coefficients), and hence, its curvature properties are global. Eigenvalues of the Hessian for each system were checked and found to be non-negative in all cases. Thus the Hessians are positive semi-definite and the functions convex at all points. Marshallian (output adjusted) own-price and cross-price elasticities were computed as

[6]
$$e_{ij} = \beta_{ij}\,\frac{p_j/p_n}{x_i}, \qquad \text{for } i,\ j = o,\ w,\ l$$

Values were calculated at the sample means and appear in Table 3 together with ratios of the elasticities to their estimated standard errors.[10] All elasticities were found to be in the inelastic range. Estimates for the EAST region were less precise in many cases than their western counterparts. Output supply was most responsive to prices in BCC and least responsive in the INT. Wood price changes had a greater effect on output level than labor price in all three regions. Cross-price elasticities were small in all regions, suggesting low substitutability between factors. Factor demands in BCC were most responsive to changes in their own prices. The INT region showed a limited response of wood demand to wood price, yet labor demand was fairly responsive to labor price. The situation in the EAST is the opposite with a low own-price elasticity of labor demand but a moderate wood demand response to own-price changes.

A comparison of Marshallian elasticities with those from prior studies that used profit functions is given in Table 4. Estimates of unconditional elasticities are limited, the largest

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[9] Coefficient estimates were obtained by means of the SHAZAM (1997) econometrics package.

[10] The Marshallian elasticities for labor consist of a ratio of stochastic variables, while those for output and wood comprise a product and a ratio. Thus, elasticity variances were calculated using the first order Taylor series approach described in Miller et al. (1984). Since Table 3 presents point estimates, variances and covariances of price and quantity terms we computed from trend-adjusted series.

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Table 4. Comparison of Marshallian elasticities from current and past profit function studies.

Study	e_{OO}	e_{OW}	e_{OL}	e_{WO}	e_{WW}	e_{WL}	e_{LO}	e_{LW}	e_{LL}
Canada									
Baker 1989	0.63	–0.17	–0.57	0.01	–2.01	–0.90	0.44	–3.18	–2.30
BCC									
Adams and Haynes 1996	0.94	–0.60	–0.99						
Baker 1990	14.30	–8.80	–4.40	14.00	–8.50	4.50	18.40	11.80	–6.80
Constantino and Haley 1988	1.11	–0.93	–0.39	1.50	–1.43	–0.48	1.42	–1.10	–0.74
Current study	0.84	–0.46	–0.11	0.78	–0.55	–0.08	0.42	–0.18	–0.80
INT									
Adams and Haynes 1996	0.45	–0.24	–0.26						
Baker 1990	3.70	–2.40	–1.20	4.40	–3.00	2.10	4.60	4.40	–2.00
Current study	0.38	–0.13	–0.06	0.26	–0.12	0.02	0.24	0.04	–0.58
EAST									
Adams and Haynes 1996	0.49	–0.34	–0.41						
Baker 1990, Quebec	1.90	–2.30	–1.10	3.00	–3.70	1.30	3.90	3.70	–2.30
Baker 1990, Ontario	11.90	–10.20	–3.70	13.50	–11.60	4.40	12.40	11.10	–4.40
Bernard et al. 1997, Quebec	1.02 to 1.03	–0.09 to –0.32			–0.19				
Bernard et al. 1997, Ontario	2.12 to 2.41	–0.15 to –0.63			–0.39				
Current study	0.65	–0.24	–0.09	0.47	–0.42	–0.08	0.34	–0.15	–0.05

Note: For Bernard et al. (1997), *W* refers to all variable inputs. Multiple values refer to kiln dried and air dried grades. For Adams and Haynes (1996), *L* refers to labor or all non-wood variable factors depending on the study. *O*, output; *W*, roundwood input; *L*, labor.

number coming from two studies by Baker (1989, 1990). The Baker (1990) study, however, yielded elasticities far higher than any reported elsewhere in the literature for either the United States or Canada. Apart from this study, there is some concurrence on own-price elasticities of lumber supply by region but wide divergence on cross-price and factor-demand elasticities. In all regions, Adams and Haynes (1996) report own-price supply elasticities that are similar to those of the present study, yet find output to be more responsive to labor (non-wood factor) price changes. In the BCC, Constantino and Haley (1988) also found a supply elasticity similar to the present study, yet with the exception of the own-price of labor their factor demands are more responsive to all price changes. Bernard et al. (1997) found supply to be elastic with respect to its own price in both Quebec and Ontario. This may reflect their treatment of supply by grade category (air and kiln dry) rather than the all grade aggregates used in other studies.

Since the largest number of past studies of the Canadian industry have employed cost functions, constant output elasticities are needed to compare results. Hicksian (constant output) elasticities (e_{ij}^{c}) for the response of the *i*th factor demand to a change in the price of factor *j* can be determined from Marshallian elasticities as

$$[7] \qquad e_{ij}^{c} = e_{ij} - \frac{e_{oj}e_{io}}{e_{oo}}, \qquad \text{for } i,\ j = w,\ l$$

where *o* is output.

Hicksian demand elasticities along with ratios to their approximate standard errors are shown in Table 5.[11] A comparison of the Hicksian demand elasticities from the current and prior studies is given in Table 6. Past studies generally do not report error measures for their elasticity estimates. Apart from the Baker (1990) study, estimates of the Hicksian own-price elasticity of labor demand from past studies fall in a fairly restricted interval for BCC (–0.24 to –0.31), INT (–0.31 to –0.36), and EAST (–0.42 to –0.44). Our estimates are higher than these ranges for the BCC and INT but not significantly different from zero in the EAST. The dispersion of past estimates for wood own-price demand elasticity is also fairly narrow for the BCC (–0.07 to –0.17) and INT (–0.07 to –0.18) and somewhat wider for the EAST (–0.06 to –0.51). In this case our estimates fall within or just below these ranges.

Table 5. Hicksian elasticities and estimated ratios to their standard errors.

	BCC	INT	EAST
e_{WW}	–0.12 (–1.78)	–0.03 (–1.41)	–0.25 (–2.39)
e_{WL}	0.02 (0.76)	0.06 (2.44)	–0.01 (–0.17)
e_{LL}	–0.75 (–4.51)	–0.55 (–1.55)	–0.01 (–0.02)
e_{LW}	0.05 (0.76)	0.13 (2.44)	–0.02 (–0.17)

Note: Ratios of the elasticities to their estimated SEs are given in parentheses. *W*, roundwood input; *L*, labor.

The differences between Marshallian and Hicksian elasticities of factor demand, $e_{ij} - e_{ij}^{c} = e_{oj}e_{io}/e_{oo}$, are the output adjustment effects. These are summarized in Table 7. In effect they represent the underestimate of the factor demand response to a change in factor price that would be associated with the use of conditional factor-demand elasticities as derived in most previous studies using cost functions. In the present case, they are large in both absolute and relative terms for wood and labor own-price changes in BCC and for

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[11] Variances for Hicksian elasticities and Morishima elasticities of substitution were calculated based on the assumption that all elements of the elasticity other than the estimated parameters are nonstochastic.

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Table 6. Comparison of Hicksian elasticities from current and past studies.

	Hicksian elasticities			
Study	e^{c}_{WW}	e^{c}_{WL}	e^{c}_{LL}	e^{c}_{LW}
Canada				
Baker 1989[a]	–2.01	–0.89	–1.91	–3.06
Constantino and Townsend 1986	–0.30		–1.14	
Martinello 1985	–0.37	0.00	–0.24	0.00
Nautiyal and Singh 1985	–0.44	0.14	–0.48	0.30
Singh and Nautiyal 1986	–0.69	0.77	–0.86	0.13
BCC				
Baker 1990[a]	0.12	8.81	–1.14	23.12
Constantino and Haley 1988[a]	–0.17	0.05	–0.24	0.09
Current study	–0.12	0.02	–0.75	0.05
Martinello 1987	–0.07	0.04	–0.31	0.14
Meil and Nautiyal 1988	–0.08	0.08	–0.27	0.19
INT				
Baker 1990[a]	–0.15	3.53	–0.51	7.38
Current study	–0.03	0.06	–0.55	0.13
Banksota et al. 1985	–0.07	0.03	–0.36	0.02
Martinello 1987	–0.15	0.01	–0.32	0.03
Meil and Nautiyal 1988	–0.18	0.14	–0.33	0.26
Meil et al. 1988	–0.11	0.23	–0.31	0.12
EAST				
Baker 1990, Quebec[a]	–0.03	8.60	–0.54	21.73
Baker 1990, Ontario[a]	–0.07	3.04	–0.04	8.42
Current study	–0.25	–0.01	–0.01	–0.02
Meil and Nautiyal 1988, Quebec	–0.17	0.18	–0.44	0.25
Meil and Nautiyal 1988, Ontario	–0.09	0.13	–0.42	0.20
Bernard et al. 1997, Quebec[a]	–0.06 to –0.19			
Bernard et al. 1997, Ontario[a]	–0.51 to –0.39			

Note: For Bernard et al. (1997) range is for air dry and kiln dry grades. *W*, roundwood input; *L*, labor.

[a] Values are calculated for this comparison and did not appear in the original papers.

Table 7. Output adjustment effect: difference between Marshallian and Hicksian elasticities.

	BCC	INT	EAST
e_{WW}	–0.43	–0.09	–0.17
e_{WL}	–0.10	–0.04	–0.06
e_{LL}	–0.23	–0.08	–0.13
e_{LW}	–0.05	–0.04	–0.05

Note: Output adjustment effects are computed as $e_{ij} - e^{c}_{ij}$. *W*, roundwood input; *L*, labor.

Table 8. Morishima elasticities of substitution.

	BCC	INT	EAST
σ^{m}_{WL}	0.77 (4.71)	0.61 (1.74)	–0.01 (–0.02)
σ^{m}_{LW}	0.18 (2.61)	0.15 (3.18)	0.23 (1.23)

Note: Ratios of the elasticities to their estimated standard errors are given in parentheses. *W*, roundwood input; *L*, labor.

wood own-price changes in the EAST. Relative differences are large for eastern labor elasticities as well, but these are imprecisely estimated.

As an indicator of factor substitution, we compute the Morishima elasticity of substitution (MES) rather than the Allen–Uzawa partial elasticity of substitution (AES) as has been customary in earlier cost function approaches. Chambers (1988) notes that the MES is potentially a "…much more economically relevant concept than the Allen elasticity since it is an exact measure of how the *i*, *j* input ratio responds to a change in w_j." Blackorby and Russell (1989) point out that MES has a natural asymmetry, unlike the AES, since its value depends on whether it is the price of factor *i* or factor *j* that is changing.

Morishima elasticities of substitution were calculated as

$$[8] \qquad \sigma^{m}_{ij} = e^{c}_{ij} - e^{c}_{jj}, \qquad \text{for } i, j = w, l$$

Results are presented in Table 8 along with ratios of the elasticities to their approximate standard errors.[11] The elasticities indicate wood and labor are substitutes (MES > 0) in the BCC and INT. In the EAST, complementary (MES < 0) behavior is found if the price of labor changes, but these elasticities are not significantly different from zero.

A comparison of Morishima elasticities of substitution in the current and prior studies is given in Table 9. The AES estimates from prior studies have also been included. Regional results from the present study fall in a relatively narrow range for labor use when the price of wood changes

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Table 9. Comparison of Morishima elasticities of substitution from current and past studies.

Study	MES[a]		AES[b]
	σ^{m}_{WL} [c]	σ^{m}_{LW}	σ^{a}_{LW}
Canada			
Baker 1989	1.02[d]	–1.05[d]	
Martinello 1985	0.24[d]	0.37[d]	0.00
Nautiyal and Singh 1985	0.62[d]	0.74[d]	0.60
Singh and Nautiyal 1986	1.63[d]	0.82[d]	0.24
BCC			
Baker 1990	9.95[d]	23.01[d]	
Constantino and Haley 1988	0.29[d]	0.26[d]	
Current study	0.77	0.18	
Martinello 1987	0.35[d]	0.21[d]	0.20
Meil and Nautiyal 1988	0.36[d]	0.27[d]	0.28
INT			
Baker 1990	4.04[d]	7.53[d]	
Current study	0.61	0.15	
Banksota et al. 1985	0.39[d]	0.09[d]	0.06
Martinello 1987	0.34[d]	0.17[d]	0.05
Meil and Nautiyal 1988	0.47[d]	0.44[d]	0.42
Meil et al. 1988	0.54[d]	0.23[d]	0.36
EAST			
Baker 1990, Quebec	9.14[d]	21.76[d]	
Baker 1990, Ontario	3.08[d]	8.49[d]	
Current study	–0.01	0.23	
Meil and Nautiyal 1988, Quebec	0.62[d]	0.42[d]	0.46[d]
Meil and Nautiyal 1988, Ontario	0.56[d]	0.29[d]	0.35

[a] MES, Morishima elasticity of substitution.

[b] AES, Allen–Uzawa partial elasticity of substitution.

[c] *W*, roundwood input; *L*, labor.

[d] Values were not calculated in the original study.

(0.18, 0.15, 0.23) and lie within or close to the range of calculated MES from past studies (ignoring Baker 1990). Most past studies find the response of wood use to change in labor price to be larger than the labor–wood elasticities, and this is true in our results as well (except in the EAST, where estimated standard errors are large). Values of the wood–labor elasticity in the current study are larger that past findings in the BCC and INT.

Past econometric studies have typically presented elasticities calculated at the sample means only. Figure 1 shows the own-price supply and demand elasticities from the present study for the three regions for the period 1963–1995. It is evident from the graph that the BCC supply and wood demand relations have become more elastic, while the INT and EAST have become less elastic. Labor own-price elasticities appear to be moving upward slightly in all regions. The statistical significance of these trends was examined by fitting a simple time trend regression line through the elasticity data using ordinary least squares. All slope coefficients were found to be significant at the 99% level with the exception of the BCC own-price supply elasticity, which was significant at the 95% level.

In contrast to the eastern provinces, BCC has experienced declining softwood roundwood supplies and sharply higher wood prices, particularly in the last 10 years of the data sample.[12] Its share of national output has fallen, while the shares of the INT and EAST have risen. Given the linear forms of our factor demand functions, this translates directly into higher demand elasticities. Declining BCC lumber output and higher lumber prices (at least through the end of the data sample) yield similar results for the region's lumber supply elasticity.

The existence of these trends in elasticities may have important implications for policy analysis. Consider the imposition of a tariff on softwood lumber exports to the United States and its provincial or regional impacts within Canada. The sample mean values of own-price supply elasticities are 0.84, 0.38, and 0.65 in the BCC, INT, and EAST, respectively (from Table 3). In 1995 these elasticities were 1.26, 0.33, and 0.32, respectively. Extending the methods of Adams et al. (1986), the mean values imply an elasticity of Canadian excess or export supply of 0.52, while the 1995 estimates yield 0.42 for the same elasticity.[13] Thus, at the national level, shifts in regional shares of lumber output from BCC to the other regions largely offset the elasticity trends. Tracing the impacts of a tariff-induced price change back to the regional level, however, would yield markedly different results in the BCC and EAST using the sample mean versus the trend elasticities.

Discussion

Despite its importance in understanding producer response to tariffs, to market shifts (such as the decline in U.S. public harvest), and to an array of domestic forest policy measures, few studies have examined the own-price elasticity of Canadian lumber supply over the past two decades (Table 4). Including the present study (and omitting Baker (1990)), supply elasticity estimates for the western regions fall in the ranges, 0.84–1.11 for BCC and 0.38–0.45 for INT. The band may be somewhat broader for the EAST, 0.49–0.65 or 2.41, depending on treatment of the grade-based elasticities from Bernard et al. (1997). Producers in the BCC, which have experienced contracting output, declining rates of capacity utilization, and loss of market share to other regions, appear from these results to be most sensitive to price. Elasticities are somewhat lower in the INT and EAST, which have undergone rapid capacity expansion and enjoy high operating rates.

Supply elasticity estimates for key U.S. regions, as the primary market competitors, offer a useful comparison with these Canadian results. Bernard et al. (1997) estimate the

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[12] Miller (1994) reports both declining allowable annual cuts (AAC) since 1990 and sharply declining harvest since 1987. As in the case of the National Forests in the United States, it appears that there is a large discrepancy between the official harvest limit (AAC) and volumes that can actually be harvested.

[13] Assuming a single international (Canadian–U.S.) market for softwood lumber, the elasticity of Canadian export supply to the United States is the weighted average of the regional output supply elasticities less the elasticity of Canadian domestic demand. Weights are the regional shares in total Canadian output and the ratio of Canadian consumption to total Canadian output. We assume an elasticity of domestic demand of –0.2 for the example.

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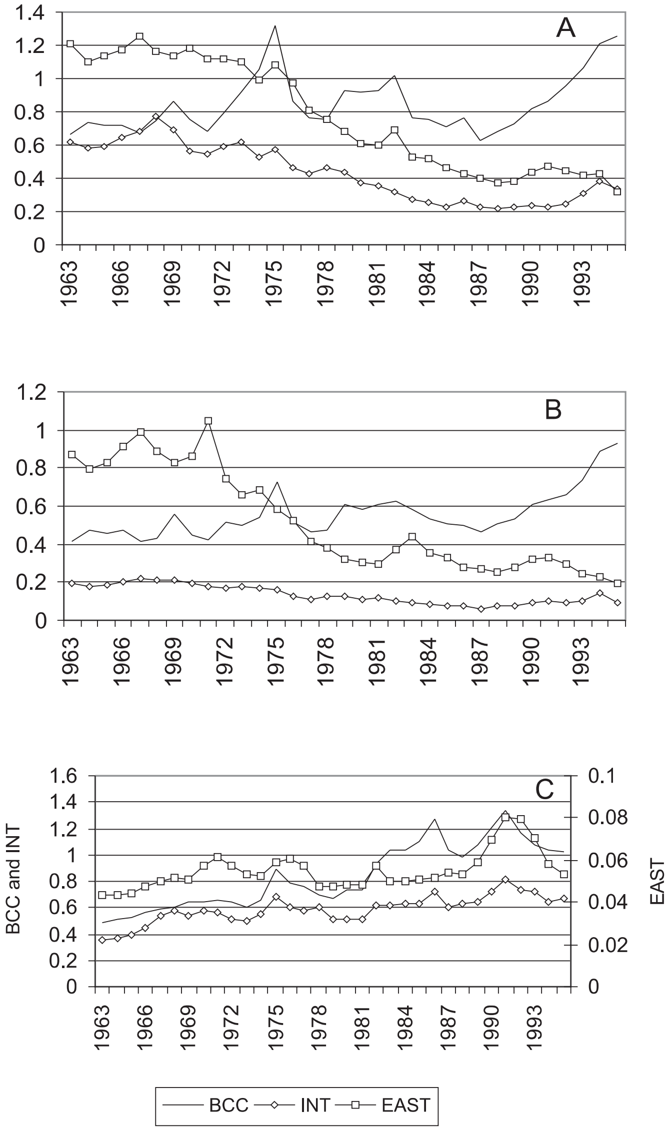
Fig. 1. (A) Lumber own-price supply elasticities, 1963–1995. (B) Roundwood own-price demand elasticities, 1963–1995. (C) Labor own-price demand elasticities, 1963–1995.



supply elasticity of U.S. Northeast kiln dried production at 0.27. Supply elasticities from Adams and Haynes (1996) for all softwood output fall in the range 0.34–0.79 for the U.S. West (the lower value from western Oregon and Washington, the higher from California) and 0.94–0.96 for the U.S. South. In a study from a decade earlier, Adams et al. (1986) found elasticities ranging from 0.24 to 0.46 for the U.S. West and 0.51 for the South, in all not greatly different in their range from our Canadian results.

Apart from Baker (1990), only the present study and Constantino and Haley (1988) have developed estimates of Marshallian own- and cross-price factor demand elasticities at the regional level. These few results suggest the same regional pattern of own-price elasticities for wood and labor demand as found for supply. In the far larger group of Hicksian estimates (Table 6), however, this regional pattern does not emerge. Virtually all of the Hicksian results, including our own, do indicate though that the own-price elasticity of labor demand is higher than that for wood. Hicksian elasticities from the present study generally fall on the upper or lower bounds of the range of past results. Apart from methodological differences, this may reflect the addition of at least 10 years of observations to our data sample. Finally, for some regions and factors, we find a large output adjustment effect indicated in the differences between Marshallian and Hicksian elasticities.

Our findings also suggest that there have been fairly steady trends in Marshallian lumber-output-demand, roundwood-demand, and labor-demand elasticities in the sector over the past two decades. Labor-demand elasticities have risen in all regions, while output- and roundwood-demand elasticities have increased in the BCC but fallen elsewhere. In the BCC this pattern might be observed if log supply were to decline (envisioned as a “backward” shift in price–quantity space), as seems to have been the case, raising wood costs, lowering lumber output, and raising lumber prices. In other regions, lumber output and log demand elasticities might decline in the face of rising output with a positive (“outward”) shift in log supply with little increase in log or product prices.

Factor substitution in the current and previous studies was compared by means of the Morishima elasticity of substitution (Table 9). Again, our results appeared to be on the boundaries of the ranges of past results, being somewhat higher (excepting the non-significant EAST results) in the case of wood-use response to labor price, σ^{m}_{WL}, and at the low end for labor response to wood price, σ^{m}_{LW}. Analysis of current and past results using the MES also indicated a fairly clear asymmetry in factor substitution responses with σ^{m}_{WL} at least as large as σ^{m}_{LW} in all but two reported cases (excepting Baker): the wood–labor factor intensity appears to be more sensitive to changes in labor price than is the labor–wood intensity to changes in wood price.

There are a number of potentially fruitful avenues for future research to test and extend the findings of the present study. Two aspects seem particularly important. The treatment of chips as a fixed by-product of lumber production in this and many past studies is less than satisfactory, particularly in light of the revenue generated by chip sales. Tests for jointness in production seem warranted, but data on chip output will require some improvement before this can be undertaken with confidence.[2] The concentration of work using only two flexible functional forms (quadratic and translog; see Table 1) is also of concern. Numerous studies have shown that findings can vary markedly with alternative forms. Estimates with other forms (e.g., the generalized McFadden or generalized Leontief) would be particularly useful for assessing the finding of elasticity trends in the present study and asymmetry in factor demand responses to own- and cross-price changes.

Acknowledgements

This research was supported in part by the USDA Forest Service, Pacific Northwest Research Station, Portland, Oreg., and the Forest Research Laboratory, College of Forestry, Oregon State University, Corvallis.

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Appendix

Lumber output

Lumber production data were collected from *Sawmills, Planing Mills, and Shingle Mills* (Statistics Canada 1962–1982), *Wood Industries* (Statistics Canada 1985–1994), and *Canadian Forestry Statistics* (Statistics Canada 1962–1995). Species breakdown of hardwood and softwood lumber for all industries found in *Canadian Forestry Statistics* (Statistics Canada 1962–1995) was applied to the SIC 2512 numbers. For the period 1979–1984, only the all-industry production is reported. To obtain estimates of SIC 2512 output for that period, SIC 2512 production was regressed on all industry output using data from 1962 through 1978. Resulting coefficients of determination (R^2) were 0.984, 0.993, and 0.992 for BCC, INT, and EAST, respectively. No survey was issued for 1987 and 1991. Data were taken from *Selected Forestry Statistics Canada* (Candian Forestry Service 1987–1996), with the British Columbia coast and interior breakdown based on percentages of production as reported in *Sawmills and Planing Mills* (Statistics Canada 1962–1999).

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Lumber price

Lumber price is composed of two parts: softwood lumber price and chip value per unit of lumber output. Mill level softwood lumber prices were estimated as the average value of shipments. Value data for 1985 and volume data for 1987 were not available. Prices were interpolated for these years using the lumber selling price index reported in *Selected Forestry Statistics Canada* (Canadian Forest Service 1987–1996).

Chip value per unit of lumber produced for 1962–1984 was estimated as the ratio of the total value of chip shipments to total lumber production in each region. Unit chip values in the EAST are based solely on Quebec and Ontario. Data for 1985–1994 are taken from the TAMM data set (Adams and Haynes 1996).

Sawlog input

Softwood lumber recovery rates for 1965–1984 were estimated as the ratio of softwood lumber output to softwood log input. Softwood sawlog input for the remaining years in the sample was computed by dividing the softwood lumber output in each year by the average recovery rate from the 1965–1985 period.

Sawlog price

Softwood sawlog price is the average expenditure on softwood roundwood per unit of total roundwood purchased. Volume data for 1987 and 1991 were interpolated.

Labor input and wage

Labor input data were taken as the number of total employees in all activities and wage as the average total salary and wage payments per employee.

Other variable input price

The price of other variable inputs was approximated with the all Canada industrial selling price index as reported in the *International Financial Statistics Yearbook* (IMF 1979–1997).