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Exports, Margins and Productivity Growth: With An Application To the Canadian Softwood Lumber Industry

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Abstract

The softwood lumber industry is a major source of trade between Canada and the U.S.. This industry accounts for about 2% of Canadian manufacturing shipments and 80% of the output is exported to the United States. The purpose of this paper is to evaluate the allocative and dynamic efficiency of the Canadian softwood lumber industry by testing for the existence of price-cost margins and decomposing rates of total factor productivity (TFP) growth.

A dynamic model of multiple output production and investment is developed in which output is sold domestically and exported. Price-cost margins are parameterized through shadow prices that affect variable profit and thereby output supply and input demand functions. The model is applied to the Canadian softwood lumber industry. Price-cost margins are estimated for both domestic and export markets. The empirical results show that prices are equated to short-run marginal costs in both markets.

The traditional measure of TFP growth is decomposed into four elements; technological change, returns to scale, price-cost margins and capital adjustment. The decomposition is based on the variable profit function. The empirical results show that for the Canadian softwood lumber industry TFP growth has averaged 3% per year. In addition, unlike many other industries, softwood lumber did not suffer a productivity slowdown and the main element accounting for TFP growth was the rate of technological change.

J.E.L. Classification: D24, L73

1. Introduction*

The softwood lumber industry is a major source of trade between Canada and the United States. This industry accounts for about 2% of Canadian manufacturing shipments and 80% of the output is exported to the U.S.. Indeed, softwood lumber plays a large role in the free trade agreement between the two countries and continues to be a controversial industry (see for example, U.S. International Trade Commission [1985]). The first purpose of this paper is to develop and estimate a model in order to test the extent to which prices differ from marginal costs for Canadian softwood lumber sold domestically and exported to the U.S.. Significant margins imply that prices exceed marginal costs and therefore the industry is not competitive. In this model there are multiple products as softwood lumber sold domestically is not assumed to be identical or perfect substitutes with softwood lumber sold on foreign markets. Price-cost margins may differ across domestic and foreign markets.

The approach to modeling non-competitive behavior is based on duality theory.[1] Product and factor market decisions are interdependent and so non-competitive behavior in product markets also affects factor demands. Moreover, an analysis of non-competitive pricing is intimately tied to the equilibrium specification of product and factor market decisions. Suppose

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production occurs in the short run where short-run marginal cost exceeds long-run marginal cost. If product price equals short-run marginal cost then price to long-run marginal cost comparisons will lead to the erroneous conclusion that market power exists. Deviations from long-run equilibrium must be considered when testing for non-competitive behavior. In this paper non-competitive pricing is modelled in a dynamic cost of adjustment framework. Adjustment costs are incurred as capital accumulation occurs and marginal adjustment costs capture the deviation between short and long-run equilibrium.[2]

Price-cost margins are indicators of industrial efficiency pertaining to resource allocation. Another efficiency index that relates to the growth potential of an industry is total factor productivity (TFP) growth.[3] TFP growth is the difference between a weighted average of output and input growth rates. Traditional measures of TFP growth can be decomposed into technological change and returns to scale components. Based on a long-run total cost function, Denny, Fuss and Waverman [1981] have shown how traditional TFP growth measures are affected by price-cost margins, Bernstein and Mohnen [1991], using a short-run variable cost function, showed how capital adjustment influences TFP growth. In this paper a decomposition of TFP growth is based on a variable profit function that incorporates non-marginal cost pricing. The attraction of using a variable profit function in the parameterization of price-cost margins is that the margins simultaneously affect both output supplies and input demands. TFP growth is measured for the Canadian softwood lumber industry and the decomposition is in terms of four elements, technological change, returns to scale, price-cost margins and capital adjustment.

This paper is organized in the following manner. The second section develops the theoretical model. Section three relates to the empirical specification, estimation results on price-cost margins and marginal adjustment costs. The fourth section contains the derivation, measurement and decomposition of TFP growth. The last section concludes the paper.

2. The Theoretical Model

In general a production technology can be represented as,

$$(1) \qquad T(y(t),K(t-1),v(t),I(t),A(t)) = 0$$

where T is the transformation function, y is an l-dimensional vector of outputs, K is an m-dimensional vector of capital inputs, v is an n-dimensional vector of variable inputs (such as labor and materials), I is a vector of additions to capital inputs, and A is an indicator of the level of technology. T is twice continuously differentiable, increasing and concave in y and I, and decreasing and convex in K and v. Since the production process is defined over I, the gross investment vector, then there are adjustment costs associated with expanding the capital inputs. These costs are internal to the production process and are manifested by the foregone output when resources are diverted away from output production to capital expansion, (see

Morrison and Berndt [1981], and Mohnen, Nadiri and Prucha [1986]).

The accumulation of the capital stocks is governed by

$$(2) \qquad K(t) = I(t) + (I_m - \delta)K(t-1)$$

where I_m is the m-dimensional identity matrix and δ is the diagonal matrix of exogenous depreciation rates.[4]

Production decisions are determined by the maximization of the expected value of the flow of funds. The present value is given by

$$(3) \qquad J(t) = \Sigma_{s=t}^{\infty} E(t)\alpha(t,s)[P^T(s)y(s) - W^T(s)v(s) - Q^T(s)I(s)],$$

where E is the expectations operator conditional on information known in period t, P is the vector of product prices, W is the vector of variable input prices, Q is the vector of capital purchase prices. The superscript T represents vector transposition.

Production and investment decisions can be determined in two stages. The first stage relates to the short-run equilibrium in the product and variable factor markets. In this stage variable profit which is denoted by

$$(4) \qquad \pi^v = P^T y - W^T v$$

is maximized subject to the production technology (equation (1)) and conditional on the level and additions to the capital stocks.[5] In this model producers are not assumed to be price-takers in product markets. Price-setting ability is introduced through shadow (or marginal) prices.

$$(5) \qquad P^s = P(I_l + \Gamma)$$

where I_l is an identity matrix of dimension l, $\Gamma<0$ is a diagonal matrix of product price-marginal revenue proportions. The elements of Γ depend upon inverse price elasticities of product demand and conjectural elasticities of firm interdependence in product markets.

Diewert [1982] rigorously established that when Γ is a matrix of exogenous variables a monopolist in short-run equilibrium can be viewed as undertaking production decisions according to the maximization of variable profit evaluated at the prices given by equation (5). In this case the elements of Γ relate to the exogenous inverse price elasticities of product demand. The Diewert result was extended to an oligopolistic framework by Roberts [1984]. In this context the elements of Γ relate to the inverse price elasticities of product demand and the conjectural elasticities of firm interdependence in product markets. Diewert and Roberts refer to prices defined by equation set (5) as shadow prices and the variable profit evaluated at these prices as the shadow variable profit.

Maximizing shadow variable profit (which is $\pi^s = P^{sT}y - W^Tv$) leads to the shadow variable profit function which is denoted as

$$(6) \qquad \pi^s = \Pi^s(P^s, W, K, I, A).$$

By applying Hotelling's Lemma with respect to the shadow product prices and input prices (Diewert [1982]), short-run product supply and variable factor demand functions are

(7.1) $$y = \nabla\Pi^s_p(P^s, W, K, I, A)$$

(7.2) $$v = -\nabla\Pi^s_w(P^s, W, K, I, A).$$

These equations show that short-run production decisions depend on product shadow prices and variable factor prices, the levels and additions to the capital stocks and the indicator of technology.

There are a number of attractive features associated with the use of the shadow variable profit function to empirically analyze non-competitive behavior in product markets. First, non-competitive behavior in one market affects output supply and input demand functions relating to all markets in which firms operate. Any one shadow price affects the complete array of decisions affecting product supply and factor demand. Second, product demand functions do not have to be specified. Through the shadow prices, non-competitive behavior is parameterized by the elements of the Γ matrix. This feature is particularly attractive when products are exported, as demand functions do not have to be specified for each importing country. However, a difficulty with the use of the shadow variable profit function is that both price and conjectural elasticities cannot be identified. For example, without further information on price elasticities, it is not possible to identify the nature of firm interdependencies in product and factor markets. Nevertheless, the purpose of this paper is not to investigate the various types of firm interactions, but rather to determine whether decisions on product supply equate product prices to marginal costs. If shadow prices differ from market prices in product markets then product prices differ from marginal costs of production.

The second stage of production decisions pertains to the determination of the demand for the capital stocks. The equilibrium conditions relating to the capital stocks are found by using the shadow variable profit function (equation (6)) and the capital accumulation equations (equation set (2)). In this stage the shadow flow of funds

$$(8) \qquad J(t) = \Sigma_{s=t}^{\infty} E(t)\alpha(t,s)[\Pi^{s}(P^{s}(s),W(s),K(s-1),K(s) - (I_m - \delta) K(s-1),A(s)) - Q^{T}(s)(K(s) - (I_m - \delta)K(s-1))]$$

is maximized by selecting $K(s)$, $s=t,\ldots,\infty$. The Euler equations for this stage of production are

$$(9) \qquad E(s)[\nabla\Pi_k^s(s+1) - (I_m - \delta)\nabla\Pi_i^s(s+1)] + \alpha(s,s+1)^{-1}\nabla\Pi_i^s(s) - W_k(s) = 0$$

where $W_k(s) = \alpha(s,s+1)^{-1}Q(s) - (I_m - \delta)E(s)Q(s+1)$ is the vector of rental rates. Equation (9) points out that the expected marginal benefit of the capital stocks equals the marginal input cost. The marginal benefit consists of two components; the marginal profit and the reduction in marginal adjustment cost due to the undepreciated capital stocks brought forward to period s+1 from period s. The marginal capital input cost consists of two components; the rental rate and the marginal adjustment cost. Another way to view equation (9) is that the expected marginal benefit of the capital stocks is equated to the respective shadow rental rates. These shadow rental rates deviate from the market rental rates by marginal adjustment costs. If shadow rental rates equal market rental rates then expected marginal profits equal market rental rates. In this situation firms are in long-run equilibrium. However, the existence of marginal adjustment costs (or deviations between shadow and market rental rates) signify that firms are in short-run equilibrium.

It is important to account for both non-competitive behavior and the type of equilibrium. The reason is that it is possible to incorrectly infer that product market power exists in a situation where prices are above long-run marginal costs. Firms behaving competitively in the short-run set product prices to short-run marginal costs. These costs exceed long-run marginal cost because of the costs associated with capital adjustment. Indeed, by parameterizing the shadow variable profit function and the relationships between market and shadow prices, hypothesis tests relating to non-competitive behavior and short-run equilibrium can be undertaken.

3. Empirical Implementation and Estimation

The time series data for the estimation model relates to the Canadian shingle and shake industry (SIC 2511) and the sawmill and planing mill industry (SIC 2512).[6] In these industries over the sample period, 1963-1987, 82% of output is softwood lumber and of this percentage 79% is exported. The major share of exports go to the U.S..

The estimation of the model is carried out using industry data. In other words, deviations between shadow and market prices are measured for the softwood lumber industry. If all the firms in an industry equate shadow to market prices then at the industry level these same equalities will be satisfied. Hence unless firms exhibit non-competitive behavior and incur capital adjustment costs, the estimated model will not indicate inequalities between shadow and market prices. Hypothesis tests regarding deviations between shadow and market prices do not test whether product demand curves facing the industry are horizontal, but whether firms decisions equate product prices to marginal costs, and expected marginal profits to rental rates. The framework is useful in determining deviations between shadow and market prices in product markets, and deviations between short and long-run equilibrium.

In order to estimate the model (equations (6), (7) and (9)), a functional form for the shadow variable profit function must be specified. It is assumed that the function is translog (see Jorgenson [1986] and the references cited therein) which is a flexible functional form;

$$(10.1) \qquad \ln \pi^{s} = \beta_0 + \sum_{i=1}^{3} \beta_i \ln(P_i(1+\gamma_i)) + \beta_l \ln W_{ll} + \beta_K \ln K + \beta_a \ln A$$

$$+ .5\Big[\sum_{i=1}^{3}\sum_{j=1}^{3} \beta_{ij} \ln(P_i(1+\gamma_i))\ln(P_j(1+\gamma_j)) + \beta_{ll}(\ln W_l)^2$$

$$+ \beta_{KK}(\ln K)^2 + \beta_{aa}(\ln A)^2\Big] + \sum_{i=1}^{3} \beta_{il} \ln(P_i(1+\gamma_i))\ln W_l$$

$$+ \sum_{i=1}^{3} \beta_{iK} \ln(P_i(1+\gamma_i))\ln K + \sum_{i=1}^{3} \beta_{ia} \ln(P_i(1+\gamma_i))\ln A$$

$$+ \beta_{lK} \ln W_l \ln K + \beta_{la} \ln W_l \ln A + \beta_{Ka} \ln K \ln A$$

where $\beta_{ij} = \beta_{ji}$, π^s is shadow variable profit normalized by the price of the wood input, P_i, i=1,2,3 are the three output prices normalized by the price of the intermediate input, where the first output is domestic softwood lumber, the second output is exported softwood lumber and the third output is other lumber products, $\gamma_i < 0$, i=1,2,3 are the deviations between shadow and market product prices, (γ_i are the elements of Γ in equation (5)), W_l is the price of the labor input normalized by the price of the intermediate input, which is essentially the wood input, K is the capital stock, A is the indicator of technology, which is a time trend. The deviations between shadow and market prices are parameterized by γ_i, and for other lumber products, which is a heterogenous category representing hardwood lumber, shakes, shingles and wood chips, which accounts for only 18% of output, $\gamma_3 = 0$.

Marginal adjustment cost is assumed to be zero when net investment is zero so that in long-run equilibrium there is no difference between the shadow and market rental rates for capital (see Morrison and Berndt [1981], Mohnen, Nadiri and Prucha [1986]). Thus the adjustment cost function is specified as,

$$(10.2) \qquad c^{a} = .5\beta_{ii}(\Delta K)^{2},$$

where c^{a} is capital adjustment cost.[7]

From equation (10.1), the short-run equilibrium conditions (equations (7.1) and (7.2)) are

$$(11) \quad s_{i}^{s} = \beta_{i} + \sum_{j=1}^{3}\beta_{ij}\ln(P_{j}(1+\gamma_{j})) + \beta_{il}\ln W_{l} + \beta_{ik}\ln K + \beta_{ia}\ln A$$

where $s_{i}^{s} = P_{i}^{s}y_{i}/\pi^{s}$ $i = 1,2,3$ are the shadow revenue-shadow variable profit components and $s_{j}^{s} = -W_{j}v_{j}/\pi^{s}$ is the negative of the labor cost-shadow variable profit component. The parameterization of the deviations between shadow and market product prices cause the equilibrium conditions to be nonlinear in the parameters.[8]

To complete the characterization of equilibrium, from equation set (10), the Euler equation (9) can now be written as,

$$(12) \qquad E(s)\Big[\beta_{K} + \beta_{KK}\ln K(s+1) + \sum_{i=1}^{3}\beta_{iK}\ln(P_{i}(s+1)(1+\gamma_{i})) + \beta_{lK}\ln W_{l}(s+1)$$

$$+ \beta_{Ka}\ln A(s+1)]\pi^{s}(s+1)/K(s) + E(s)\beta_{ii}\Delta K(s+1) - (1+r(s))\beta_{ii}\Delta K(s)$$

$$- W_{K}(s) = 0,$$

where $\alpha(s,s+1)^{-1} = (1+r(s))$, r is the discount rate. The parameter β_{ii} represents the short-run deviation between the shadow and market rental rates for the capital input.

In order to estimate equation set (10), (11) and (12), shadow variable profit is replaced by $\pi^{v}(1 + \Sigma_{i=1}^{3}\gamma_{i}s_{i} + \Sigma_{j=1}^{m}s_{j})$ where $s_{i}, i = 1,2,3$ are the revenue variable profit components, and s_{j}, $j = 1,m$ are the negative of the labor and wood cost variable profit components. In addition, in the definition of s_{i}^{s}, P_{i}^{s} is replaced by $P_{i}/(1+\gamma_{i})$. These substitutions mean that the equilibrium conditions become nonlinear in the variable profit components. Error terms appended to equation set (10) and (11) represent optimizing and technology errors. The error term added to equation (12) is a conditional expectation error which arises when the conditional expectation of the future values of the variables in (12) is replaced by their predicted values. All errors are assumed to have zero expected value, and positive definite contemporaneous variance-covariance matrix. With respect to equation (12), the zero expected value assumption means that expectations are rational.

The estimator used for equations (10), (11), (12) is the generalized method of moments estimator developed by Hansen [1982] and Hansen and Singleton [1982]. This estimator is equivalent to the three stage least squares estimator if the random errors are conditionally homoscedastic (see

Pindyck and Rottemberg [1982]). The endogenous variables in the estimation model are variable profit, the four variable profit components (defined for domestic softwood lumber, softwood lumber exports, other lumber, and the labor input) and the capital input. The instrumental variables that are used are the lagged capital stock, lagged relative product and labor input prices, and the time trend.[9]

First, the model is estimated with $\gamma_i<0$, i = 1,2 so that non-competitive behavior exists in both the domestic and export markets for softwood lumber. Next the model is estimated for non-competitive behavior in either the domestic market or the export market, and then competitive behavior is assumed in both markets. In addition, in order to test for the constancy of the margin parameters the sample is split in 1973. This year corresponds to the major oil shock experienced in the Canadian economy. Estimating the model to allow for two different sets of γ parameters over the sample period yields the test statistics of 0.621, 0.252 and 2.097 for each of the alternative competitive hypotheses shown in table 1. These test statistics are calculated for each row in table 1 as the difference in objective functions between the constant and varying margin models. The critical values of the distribution with 2 and 1 degrees of freedom (which relate to the number of parameter restrictions) are $\chi^2_{.025,2} = 7.378$ and $\chi^2_{.025,1} = 5.024$. Thus the null hypothesis that there is no difference in the margin parameters over the sample period cannot be rejected. This is a strong conclusion and emerges from the result that the γ parameters are not statistically different zero over the sample period.

The softwood lumber industry prices competitively in both domestic and export markets. This result can be seen from table 1. From the column with constant margins, the test statistic of 4.189 relates to the null hypothesis concerning competitive pricing against the alternative hypothesis of non-competitive pricing. The test statistics is distributed as a chi-square with two degrees of freedom . The value of the test statistic is less than the critical value of the distribution. Thus the null hypothesis of competitive domestic and competitive export product markets cannot be rejected. In addition, the non-competitive model nests both the competitive and partially competitive models. Clearly, by the nesting of the models, all partially competitive models are also rejected. It is interesting to note from table 1 how little the values of the objective function change as more competitive behavior is introduced into the model.

The estimation results for the competitive model are presented in table 2. The standard errors of the estimates are small relative to the parameter estimates. The standard errors of each of the equations are also relatively small. The estimates generated positive variable profit, capital input and variable profit components at each point in the sample for both industries. The estimated variable profit function is also convex in the product and variable factor prices at each point in the sample.

The estimate of β_{ii} found in table 2 show that the softwood lumber industry is not in long-run equilibrium. The estimate of the adjustment cost parameter is positive and statistically different from zero. Indeed, with respect to the capital input there are significant marginal adjustment costs

Table 1: Tests of Non-Competitive Behavior in Softwood Lumber Markets

	Margins Constant			Margins Vary		
	Rest.*	Obj.*	Stat.***	Rest.	Obj.	Stat.
Non-Competitive Domestic and Non-Competitive Export	N.A.	68.802	N.A.	N.A.	68.181	N.A.
Non-Competitive Domestic and Competitive Export	1	72.819	4.017	2	72.567	4.386
Competitive Domestic and Non-Competitive Export	1	71.230	2.428	2	69.133	0.952
Competitive Domestic and Competitive Export	2	72.991	4.189	4	72.991	4.810

* Means restrictions and refers to the number of parameter restrictions

** Means the objective function and refers to the minimized weighted sum of squares of the errors for the system of equations

*** Means the test statistic and refers to the difference in the objective function values between the unrestricted and restricted models

Table 2: Estimation Results: Competitive Model

Parameter	Estimate	Standard Error
β_0	-1.215	1.000
β_1	2.277	0.151
β_2	-1.629	0.513
β_3	-0.912	0.223
β_l	0.551	0.438
β_K	0.801	0.279
β_a	0.811 E-01	0.656 E-02
β_{11}	0.680	0.753 E-01
β_{22}	-0.777 E-01	0.330
β_{33}	0.679	0.043
β_{ll}	0.119	0.136
β_{KK}	-0.105	0.040
β_{12}	-0.183 E-02	0.125
β_{1l}	-0.241	0.063
β_{1K}	-0.240	0.022
β_{2l}	0.065	0.197
β_{2K}	0.469	0.074
β_{3l}	-0.352	0.019
β_{3K}	0.201	0.031
β_{lK}	-0.205	0.063
β_{la}	-0.168 E-01	0.154 E-02
β_{ii}	0.420 E-03	0.448 E-04

Equation	Standard Error
Variable Profit	0.197
Domestic Softwood	0.102
Export Softwood	0.134
Other Lumber	0.885 E-01
Labor	0.172
Capital	0.995 E-01
Objective Function	72.997

so that the shadow rental rate exceeds the market rental rate on capital. Table 3 shows the deviation between the shadow and market rental rates. The wedge is defined by the ratio of the marginal adjustment cost to the market rental rates. On average for a $1 spent on the capital input, marginal profit exceeds the rental rate by $0.26 in the softwood lumber industry.

Therefore, the estimation results point out that there are no differences between product prices and marginal costs in the Canadian softwood lumber industry. In addition, this industry is not in long-run equilibrium as there are significant marginal costs of adjustment that cause the marginal profitability of capital to exceed the rental rate. Thus, this industry behaves competitively in the short-run, prices are equal to short-run marginal costs. However, these costs are inclusive of marginal adjustment costs, and therefore exceed apparent marginal costs derived under the mistaken assumption that the industry is in long-run equilibrium.

4. Total Factor Productivity Growth and Decomposition

An important measure of innovative or dynamic efficiency is defined by the rate of TFP growth. In Canada, as well as other countries, (see for example Jorgenson et. al. [1990], Denny et. al. [1992] and Morrison [1992]) many industries experienced a TFP growth slowdown in the seventies and eighties. Different reasons for the productivity slowdown centre on declining rates of technological change, rising input prices (such as energy), decreases in scale economies, increases in adjustment costs

Table 3: Deviation Between Shadow and Market Rental Rates on Capital;

Period	$\beta_{ii}\Delta K/W_k$
1963-70	0.1321
1971-79	0.3658
1980-87	0.2935
Mean	0.2621
Standard Deviation	0.1760
Minimum	0.0637
Maximum	0.5595

associated with capital expansion, and declining margins in product markets. TFP growth rates are calculated for the softwood lumber industry. Moreover, these rates are decomposed into technological, scale, adjustment and margin components (the latter is zero because the industry is competitive) in order to determine the contribution to TFP growth over time.

The traditional measure of TFP growth is defined as,

$$(13) \qquad TFPG = \sum_{i=1}^{l} \left[P_i y_i / R \ (d\ln y_i/dt) \right] - \sum_{j=1}^{n} \left[W_j v_j / c \ (d\ln v_j/dt) \right] - \sum_{k=1}^{m} \left[W_k K_k / c \ (d\ln K_k/dt) \right]$$

where $R = \sum_{i=1}^{l} P_i y_i$ is total revenue, and $c = \sum_{j=1}^{n} W_j v_j + \sum_{k=1}^{m} W_k K_k$ is total cost. Using the shadow variable profit function defined by the right side of (6) and the definition of shadow variable profit, then

$$(14) \qquad 0 = \left[\sum_{i=1}^{l} s_i^s (d\ln y_i/dt) + \sum_{j=1}^{n} s_j^s (d\ln v_j/dt) - \sum_{k=1}^{m} (\partial \ln \pi^s / \partial \ln K_k)(d\ln K_k/dt) - \partial \ln \pi^s / \partial t \right],$$

where, as defined after equation set (11), s_i^s $i=1,\ldots,l$ are the shadow revenue-shadow variable profit components, and s_j^s $j=1,\ldots,n$ are the negatives of the variable cost-shadow variable profit components, also $\ln A = t$ where A is the indicator of technology and t is the time trend.

By adding equations (13) and (14) and with further manipulation, productivity growth becomes,

$$(15) \quad TFPG = (1-\rho_y^{-1})\left(\sum_{i=1}^{l} s_i^s / \sum_{h=1}^{l} s_h^s\right)(d\ln y_i/dt) + z_v + \sum_{i=1}^{l}\left[s_i / \sum_{h=1}^{l} s_h - s_i^s / \sum_{h=1}^{l} s_h^s\right] + \left(\rho_y^{-1} / \sum_{i=1}^{l} s_i\right) \sum_{k=1}^{m}\left[W_k K_k/\pi^s - \partial\ln\pi^s/\partial\ln K_k\right] \left[\left(\sum_{j=1}^{n} W_j v_j/c\right)(d\ln v_j/dt) + \left(\sum_{g=1}^{m} W_g K_g/c\right)(d\ln K_g/dt) - d\ln K_k/dt\right],$$

where ρ_y is the degree of returns to scale and z_v is the rate of technological change. Equation (15), shows the decomposition of TFP growth based on the shadow variable profit function. Measured TFP growth is calculated from the right side of equation (15), using the parameter estimates from table 2 to find the fitted values of shadow variable profit, the shadow variable profit components and the components of variable profit, along with the values of the exogenous variables.

Equation (15) shows that there are four parts to the decomposition of TFP growth. First, if ρ_y=1, then under constant returns to scale there is no scale effect on TFP growth. Second, if z_v=0 then there is no technological change effect on TFP growth. Third, if market and shadow product prices are equal so that $s_i^s = s_i$ $i=,\ldots,l$, then there are no price-cost margin effects on TFP growth. Fourth, if the market and shadow prices of capital inputs are equal, in other words $W_k = \partial\pi^s/\partial K_k$ $k=1,\ldots,m$, then there are no capital adjustment effects on TFP growth.

From the estimation results for the Canadian softwood lumber industry, we have already established that there are no differences between market and shadow product prices. Thus there are no price-cost margin effects on TFP growth. Next, the significant adjustment cost parameter (β_{ii}) from the regression results means that the percentage increase in variable profit due to capital expansion does not equal capital cost per dollar of variable profit. Thus from equation (15) there is a capital adjustment component to TFP growth. The first column of table 4 shows the capital adjustment term as the differential between percentage increase in variable profit and capital cost per dollar of variable profit. A 1% capital expansion generates, on average, a capital adjustment term of 0.08%. The two remaining components of TFP growth relate to scale and technological change.

The degree of returns to scale based on the transformation function (given by (1)) is,

$$(16) \qquad \rho_y = -(\sum_{j=1}^{n} T_j v_j + \sum_{k=1}^{m} T_k K_k) / \sum_{i=1}^{l} T_i y_i \ .$$

In equilibrium for output supply, $\lambda T_i = P_i^s$ $i=1,\ldots,l$, and for variable factor demand $\lambda T_j = -W_j$ $j=1,\ldots,n$, where λ is the Lagrangian multiplier. In addition, for the capital inputs, $\partial \ln \pi^s / \partial \ln K_k = -\lambda T_k K_k / \pi^s$ $k=1,\ldots,m$. Substitute these equalities into the right side of equation (16) and use the definition of the shadow variable profit components, then

$$(17) \qquad \rho_y = (-\sum_{j=1}^{n} s_j^s + \sum_{k=1}^{m} \partial \ln \pi^s / \partial \ln K_k) / (\sum_{i=1}^{l} s_i^s)$$

The estimates of returns to scale are presented in the second column

Table 4: Capital Adjustment, Returns to Scale and Rates of Technological Change

Period	Capital Adj.	RTS	RTC
1963-70	0.0223	1.2228	0.0245
1971-79	0.0815	1.2386	0.0233
1980-87	0.1318	1.2648	0.0226
Mean	0.0754	1.2407	0.0235
Std. Deviation	0.0596	0.0202	0.0010
Maximum	0.2371	1.2796	0.0249
Minimum	0.0114	1.2101	0.0221

of Table 4. There are increasing returns to scale in the Canadian softwood lumber industry. On average returns to scale are around 1.24 and the estimate is very stable throughout the sample period. Thus, in short-run equilibrium there are scale economies along with competitive pricing in product markets.

Next, from the transformation function, the definition of the rate of technological change is,

$$(18) \qquad z_v = T_t / \left(\sum_{j=1}^{n} T_j v_j + \sum_{k=1}^{m} T_k K_k \right).$$

In terms of the shadow variable profit function, with $\partial \ln\pi^s/\partial t = -\lambda T_t/\pi^s$ then

$$(19) \qquad z_v = (\partial \ln\pi^s/\partial t) / \left(-\sum_{i=1}^{n} s_j^s + \sum_{k=1}^{m} \partial \ln\pi^s/\partial \ln K_k \right).$$

The rates of technological change estimated for the softwood lumber industry are presented in the third column of table 4. These rates averaged 2.35 per cent, and were very stable over the sample period. Compared to the rates of technological change for other Canadian manufacturing industries (see Bernstein and Mohnen [1991], and Morrison [1992]), the softwood lumber lumber industry exhibited one of the highest rates of technological change over the period from the mid 1960's to ther mid 1980's.

The rate and decomposition of TFP growth are presented in table 5. The rate of TFP growth has averaged 3.2% per year for the softwood lumber industry over the last two decades. In addition, average annual TFP growth

Table 5: Total Factor Productivity Growth

and its Decomposition

	TFPG	Returns To Scale	Technological Change	Capital Adjustment
1963-1970	0.0308	0.0147	0.0245	-0.0084
1971-1979	0.0324	0.0157	0.0223	-0.0056
1980-1987	0.0345	0.0174	0.0226	-0.0055
Mean	0.0324	0.0157	0.0235	-0.0067
Std. Deviation	0.0018	0.0013	0.0010	0.0014
Maximum	0.0363	0.0177	0.0249	-0.0034
Minimum	0.0297	0.0136	0.0221	-0.0088

rates have been very stable, with no slowdown during the 1970's and 1980's. In terms of a comparison of TFP growth rates to other U.S., Japanese and Canadian industries (see Jorgenson et. al. [1990], Denny et. al. [1992], and Morrison [1992]), the Canadian softwood lumber industry generally exhibitted a relatively higher and more stable growth rate. From table 5, the major reason for the consistently high TFP growth rate is due to the rate of technological change in the industry. Technological change, on average, accounted for about 73% of TFP growth over the last three decades. The remaining contribution was due to the small degree of increasing returns to scale. Furthermore, the softwood lumber industry paid a price for having an insufficient capital stock relative to the long-run quantity. Marginal adjustment costs caused TFP growth rates to decrease by about 1% per year during the 1960's and about 0.5% per year over the last two decades.

6. Conclusion

A dynamic model with multiple products incorporating price-cost margins in domestic and export markets was developed and applied to the Canadian softwood lumber industry. Price-cost margins were parameterized as deviations between shadow and market prices. It was found that competitive behavior occurred in both domestic and export markets.

The dynamic nature of the model arises from the existence of adjustment costs associated with the capital input. Adjustment costs cause deviations from long-run equilibrium. Indeed, it was estimated that the softwood lumber industry was in short-run equilibrium. It was estimated that the marginal profit of capital is about 25 per cent greater than the rental rate in the softwood lumber industry.

TFP growth was measured and decomposed for the softwood lumber industry. The average rate of TFP growth was 3.2% per year over the last three decades and the major contributing element to TFP growth arose from the rate of technological change. Capital adjustment costs also affected TFP growth. These costs led to around a 0.5% per annum decline in the rate of TFP growth.

Data Appendix

The data were obtained from Statistics Canada, for the period 1963-1987. There are three products, softwood lumber exports, softwood lumber sold domestically, and other lumber products (shakes, shingles and wood chips). Output data is obtained from Statistics Canada Catalogues 35-204 and 65-202. Output quantities are shipments and output prices are defined as revenues divided by quantities.

There are two variable factors, labor and wood. The labor input is defined in terms of millions of man hours and the after tax wage rate is defined as dollars per man hour. The intermediate input quantity and after tax price are defined in a similar manner to the output prices and quantities.

The quasi-fixed factor is a Tornqvist index of machinery, structures, and land. Statistics Canada provided the unpublished capital stock data which consist of gross and net end of year stocks in current and 1971 dollars. The capital purchase prices are defined as the ratio of current to constant dollar gross stocks. The after tax rental rate is constructed from the before tax purchase price of capital, the corporate income tax rate, the investment tax credit rate, the capital cost allowance rate, a long term interest rate, and the capital depreciation rate. The tax, allowance, and credit rates are obtained from the Canada Gazette and Statistics Canada catalogue 13-211. In addition, the interest rate is taken to be the average of monthly average yields of Government of Canada bonds with 10 or more years maturity. The rate is obtained from the Bank of Canada Review.

Footnotes

1 There have been some studies that have applied duality theory to the analysis of price-cost margins for a variety of industries and sectors; Appelbaum [1979] for the U.S. crude petroleum and natural gas industry, Appelbaum and Kohli [1979] for the Canadian manufacturing sector, Appelbaum [1982] for the U.S. rubber, textiles, electrical and tobacco industries, Roberts [1984] for the U.S. coffee roasting firms, Bernstein and Mohnen [1991] for the Canadian chemical, electrical, and non-electrical machinery industries, and Morrison [1992] for the U.S., Canadian and Japanese manufacturing sectors.

2 See the papers by Morrison and Berndt [1981], and Mohnen, Nadiri and Prucha [1986] on the existence of capital adjustment costs for U.S. and European manufacturing sectors.

3 There are different interpretations and various ways to measure total factor productivity growth (see Diewert [1989]).

4 It is assumed that the service flow of a quasi-fixed input is proportional to the stock.

5 The notation (t) is generally omitted for simplicity.

6 The data are described in the data appendix.

7 Equations (10.1) and (10.2) can be combined into a single function by renormalizing the β_{ii} parameter to reflect that the shadow variable profit function is defined in terms of the natural logarithms of the variables.

8 The wood cost component equation can be eliminated by the fact that the absolute value of shadow variable profit components sum to unity.

9 The model is estimated as a set of implicit equations using the Time Series Processor software under the nonlinear three stage least squares procedure. The instruments are standard ones selected in this context (see Pindyck and Rottemberg [1982]). Other instruments such as the lagged deflator for gross domestic product, the lagged wage rate for the manufacturing sector, and a moving average of interest rates for long term government bonds were used in the estimation. The main conclusion with respect to non-competitive bahavior and equilibrium were unaffected.