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PRODUCTION STRUCTURE AND THE AUSTRALIAN SAWMILLING INDUSTRY*

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This paper examines the production structure of the Australian sawmilling sector over the period 1950-51 to 1984-85 using a translog cost function. The results show that the sawmilling industry is best represented by a production function which does not have any restrictions on functional form. Inputs, including capital, labour, materials and energy, are generally found to substitutable for one another, although the degree of substitutability is small. There have been economies of scale in the Australian sawmilling industry, and technological change has been capital and energy-using, and labour and materials-saving.

Introduction

The sawmilling industry in Australia has gone through a cycle of rapid growth in the post-war period. Annual output rose from 2.9 million m^3 in 1951 to a peak of 3.7 million m^3 by the mid-1960s before easing to around 3.0 million m^3 in the 1980s. Although output volumes peaked in the mid-1960s, this is also when the sawmilling industry began a period of rapid technological expansion, as indicated by levels of capital investment. Capital investment in sawmills and the accompanying capital expenditure per unit output from 1951 to 1985 are shown in Figure 1. Sawmill capital stock remained under $100 million until the 1970s when investment picked up and subsequently grew to more than $400 million. With the increase in capital, and with static or declining output, there was a corresponding rise in associated capital expenditures, or user cost, per unit output of sawn timber.

Over the entire study period there has also been a decline in the numbers employed in the sawmilling sector. As employment declined, productivity as measured by annual output per employee rose. Total employment and annual output per employee over the period 1951-1985 are shown in Figure 2. Productivity in terms of output per employee can be seen to have risen about 50% or 50 m^3/employee.

* I would like to thank two anonymous referees for their valuable comments.

FIGURE 1
Capital Expenditure

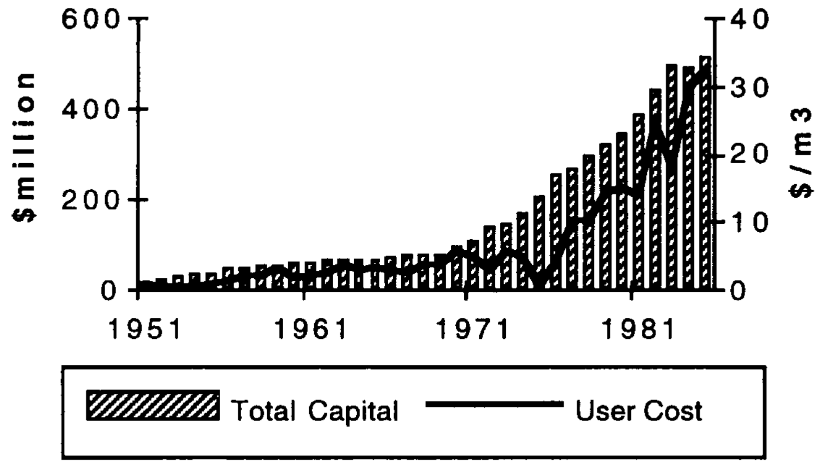


FIGURE 2
Sawmill Productivity

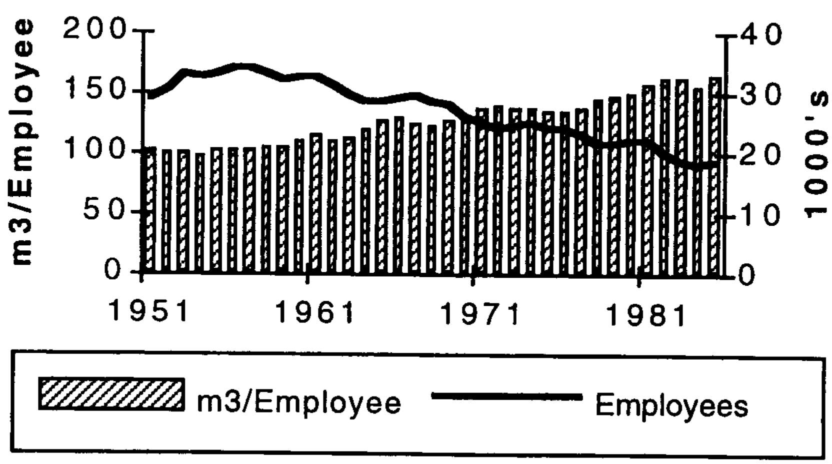


FIGURE 3
Sawmill Numbers and Size

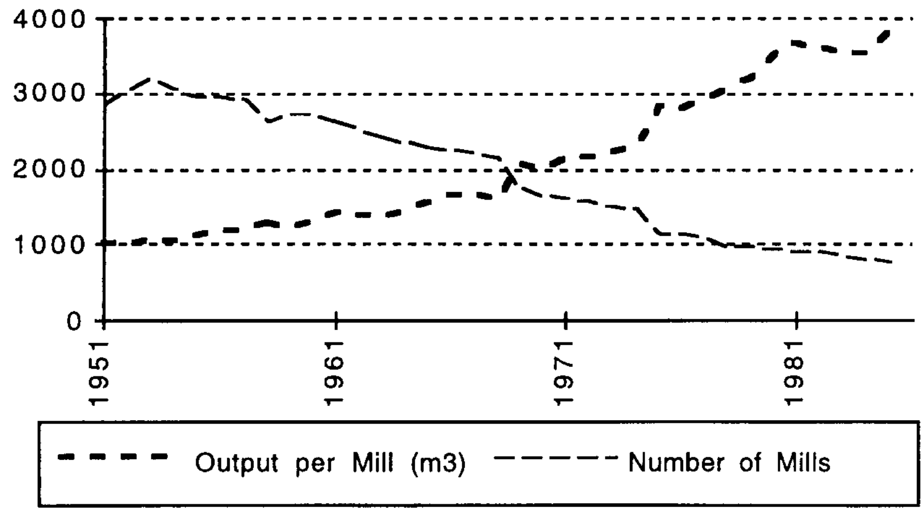
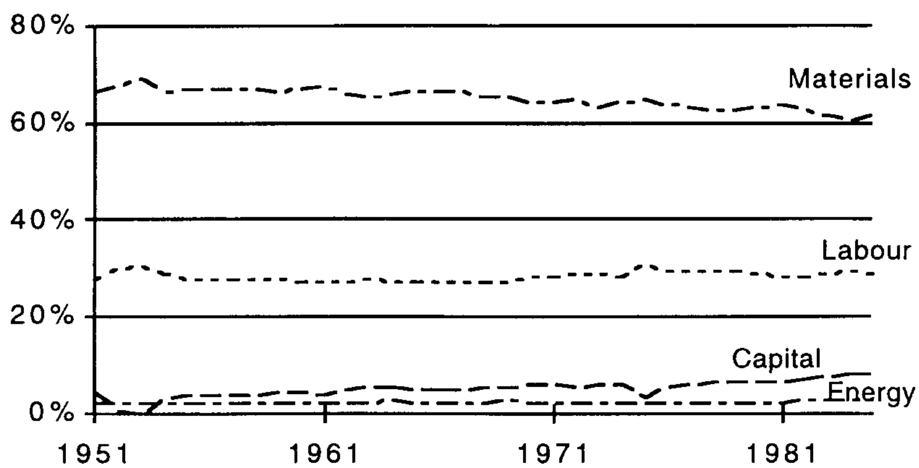


FIGURE 4
Input Shares



As well as the changes which have been occurring with individual inputs, sawmills have been responding to relative changes in the prices of inputs and the applicability of new technology. One way that this is reflected is in the changes in the size of sawmills. Over the entire study period the number of mills declined and output per mill rose. As is shown in Figure 3, the number of mills declined by almost 75% between 1951 and 1985. Annual output per mill doubled from 1000 to 2000 m^3 between 1951 and 1971, and then doubled again by 1985.

Another way that changes to relative input prices and technology are reflected is in the changes in cost shares of inputs over time, or the relative shares of total expenditure. Cost shares for capital, labour, materials and energy are illustrated in Figure 4. The sawmilling industry has been reducing the share of materials, which in this study is largely made up of log costs, and increasing the share of capital. Labour and energy's shares have remained relatively constant.

While the information in Figures 1 through 4 is informative, it is limited in usefulness for identifying the actual structure of the sawmilling sector. For example, a typical interpretation of a rise in capital expenditure accompanied by a decrease in employment is that there has been a substitution of capital for labour, or an increase in the capital intensity of the manufacturing process. If this was the case, then it could be expected that capital's share of total expenditures would be increasing at the expense of labour's share. However, examination of the shares of total expenditure of capital and labour in Figure 4 instead shows that although capital's share of expenditures has been rising, labour's share has remained relatively constant, and that only the share of materials costs has been declining. This illustrates the problem of studying structural or productivity changes by relying on observation since the change is not the result of a simple occurrence. Observed productivity changes are the end result of responses to changes in relative factor prices, the level of output, raw material bottle-necks and biased technological change. Factor prices for materials, labour, energy and capital have been increasing in real terms over time and relative to one another and, as mill sizes have increased, it has become possible to take advantage of scale economies.

The estimation of a production or cost function is a useful tool for overcoming the problems of casual observation, and providing for a better understanding of the production structure of an industry. It provides quantitative insights into the substitution possibilities between inputs, economies of scale and the impact of technological change. The purpose of this paper is to study the structure of the Australian sawmilling industry using an estimation of a cost function. Most studies which have applied this technique to the sawmilling industry have been done for Canada (Nautiyal and Singh 1985, Singh and Nautiyal 1986, Banskota *et al* 1985 and Martinello 1987) and the U.S. (Stier 1980,1985). One study has been done for the Tasmanian sawmilling industry (Campbell and Jennings 1990).

The Theoretical Model

It is assumed that the Australian sawmilling industry is characterised by a twice-differentiable production function, $Q = Q(K,L,M,E)$, where Q is output and K, L, M and E are inputs of capital, labour, materials and energy respectively. If prices are exogenous, and firms minimise costs, then the duality principles of economic theory can be applied to derive a cost function which will reflect the production technology (Varian 1984). The dual cost function can be characterised by the form, $C = C(P_K, P_L, P_M, P_E, Q, T)$, where C is total cost of production, P_K, P_L, P_M and P_E are prices of capital, labour, materials and energy respectively, Q is output, and T is technological change.

The specific functional form used for this study is the flexible translog function. The advantage of using the translog function is that estimates of the elasticities of substitution and technological change bias can be obtained even though it may not be possible to specify an exact form for the production function. The translog function also has other desirable properties. The elasticity of substitution does not need to be restricted to any particular value, or to be restricted to any particular value over time, the assumption of constant returns to scale is not necessary, the bias of technological change can be calculated rather than be assumed to be Hicks-neutral and the rate of technological progress can be estimated.

The translog cost function used in this paper is similar to those used by Nautiyal and Singh (1985,1986), Singh and Nautiyal (1986), Banskota, Phillips and Williamson (1985), Martinello (1987) and by Sherif (1983) in studies of the pulp, paper and sawmilling industries in Canada and by Stier (1980,1985) for the United States. The unrestricted model takes the following form.

$$(1)\qquad lnC = a_o + a_Q lnQ + \frac{1}{2} a_{QQ}(lnQ)^2 + a_T T + \frac{1}{2} a_{TT}(T)^2$$
$$+\sum_{i=1}^{4} \beta_i \, lnP_i + \frac{1}{2} \sum_{i=1}^{4}\sum_{j=1}^{4} \cdot \beta_{ij} \, lnP_i \, lnP_j$$
$$+\sum_{i=1}^{4} d_{iQ} \, lnP_i \, lnQ + \sum_{i=1}^{4} g_{iT} \, lnP_i \, T \qquad i,j = K,L,M,E$$

To ensure that the underlying production function conforms to the theory of production, certain restrictions must be placed on the parameters of the cost function. Symmetry requires that $\beta_{ij} = \beta_{ji}$ for $i,j = K,L,M,E$, and linear homogeneity in prices requires the following restrictions

$$\Sigma_i a_i = 1$$

$$\Sigma_i \beta_{ij} = \Sigma_i d_{iQ} = \Sigma_i g_i T = 0.$$

These restrictions imply that a proportional increase in expenditure on all factors must also cause a proportionate change in output, and that a proportionate change in all factor prices will not change the relative quantities of each factor used.

By assuming competitive factor markets and cost minimisation by firms, Shephard's Lemma can be used to obtain $(\partial C/\partial P_i) = X_i$, the demand for the i^{th} input. For a logarithmic cost function

$$(2) \qquad \frac{\partial lnC}{\partial lnP_i} = \frac{(P_i \cdot X_i)}{C} = S_i$$

where S_i is the cost share of the i^{th} factor. By differentiating the logarithm of the cost function with respect to the logarithm of each input price, the factor cost share or input-demand equations can be derived.

$$(3) \qquad S_i = \beta_i + \sum_{i=1}^{4} \beta_{ij}\, lnP_i + d_{iQ} lnQ + g_{iT}T \qquad i,j = K,L,M,E$$

While it would be reasonable to assume that the prices of capital, labour and energy reflected competitive factor markets, this is less likely to be the case for materials, which for this study is largely logs. For log inputs, prices are influenced by government agencies which can act as local monopolists or have wider impacts on prices, particularly at a state level (O'Regan and Bhati 1991, Byron and Douglas 1981). This will not affect the results as long as the observed price of logs is a market clearing price, in which case any particular price and quantity combination will still represent a point along the factor demand curve (Campbell and Jennings 1990).

The system of share equations contains all of the information required to estimate the substitution and price elasticities of factor demand. Uzawa (1962) has shown that the partial elasticity of substitution between factors i and j (μ_{ij}) can be derived from the cost function according to

$$\mu_{ij} = \frac{(C)(C_{ij})}{(C_i)(C_j)}$$

where the subscripts indicate partial derivatives of the cost function $(\partial C/\partial P)$ with respect to the i^{th} and j^{th} inputs ($i,j = K,L,M,E$). For the translog, Berndt and Wood (1975) and Binswanger (1974) have shown that,

$$(4) \qquad \mu_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^{\,2}} \qquad i = K,L,M,E \qquad i \neq j$$

$$(5) \qquad \mu_{ij} = \frac{\beta_{ij}}{S_i \cdot S_j} + 1 \qquad i,j = K,L,M,E$$

and that the price elasticities of demand, E_{ij}, are given by,

$$(6) \qquad E_{ii} = \mu_{ii} \cdot S_i \qquad i,j = K,L,M,E$$

$$(7) \qquad E_{ij} = \mu_{ii} \cdot S_j$$

Neutral or non-neutral technological change is incorporated in this model by letting T represent any of the factors which cause neutral and non-neutral efficiency differences. If all g_{iT} are zero ($i = K,L,M,E$), then time alone would not affect factor shares (Binswanger 1974). If g_{iT} is greater than zero, the share of the i^{th} factor would rise given constant factor prices. This type of technological change is non-neutral, or factor i-using. A non-neutral efficiency difference in the Hicksian sense is one in which the isoquant does not shift inwards homothetically, and the factor ratio does not stay constant even with constant factor prices. For example, if the capital-labour ratio is rising, the efficiency gain must be labour-saving, implying that the labour share declines at a constant factor price ratio. In terms of this model, the bias of technological change (w_i) is given in percentage terms by the following equation (Stier 1980).

$$(8) \qquad w_i = \frac{\partial S_i}{\partial T} \cdot \frac{1}{S_i}$$

where $(\partial S_i/\partial T) = g_{iT}$. If $(w_i < O)$ then technological progress is factor i-saving, if $(w_i = O)$ then it is factor i-neutral and if $(w_i > O)$ then it is factor i-using.

Estimation Technique

The system of cost share equations forms a singular system because the cost shares always add to unity. One equation must then be dropped from the system to permit estimation. It has been shown by Berndt and Wood (1975) that any of the share equations can be dropped arbitrarily and the parameters associated with the missing equation estimated residually. This requires that the errors in each equation are homoskedastic and non-autocorrelated, and that there is non-zero correlation between contemporaneous error terms across equations. The energy equation has been dropped, and the resulting cost and share equations are,

$$(9) \qquad lnC = a_{o*} + a_Q lnQ + \frac{1}{2} a_{QQ}(lnQ)^2 + a_T T + \frac{1}{2} a_{TT}(T)^2$$

$$+ \sum_{i=1}^{3} \beta_i \, lnP_i + \frac{1}{2} \sum_{i=1}^{3} \sum_{j=1}^{3} \cdot \beta_{ij} \, lnPi{*}lnPj{*}$$

$$+ \sum_{i=1}^{3} d_{iQ} \, lnP_i{*}lnQ + \sum_{i=1}^{3} g_{iT} \, lnPi{*} \, T \qquad i,j = K,L,M$$

$$S_K = \beta_K + \sum_{i=1}^{m} \beta_{Ki} lnP_i{*} + d_{KQ} lnQ + g_{KT} T$$

$$S_L = \beta_L + \sum_{i=1}^{m} \beta_{Li} lnP_i{*} + d_{LQ} lnQ + g_{LT} T \qquad i = K,L,M$$

$$S_M = \beta_M + \sum_{i=1}^{m} \beta_{Mi} lnP_i{*} + d_{MQ} lnQ + g_{MT} T$$

where P_i * equals (P_i/P_E) and a_O* equals ($a_O + 1/2lnP_E$). P_i * and a_O* are derived by setting $\beta_E = (0 - \beta_K - \beta_L - \beta_M)$ in equation (1) and rearranging the remaining terms.

The translog function permits estimation of the cost function without placing any a priori restrictions on the structure of that function. The model selection procedure involves testing different hypotheses about the structure of the underlying production function through the placement of restrictions on the parameters of the model. This creates new models which are nested in the unrestricted model. The restrictions deal with assumptions such as the effects of scale economies, input substitution or the effects of technological change. The validity of different restrictions can be tested by comparing the restricted and unrestricted models using the likelihood ratio test.

For example, nested assumptions about the form of technological change can be examined. The presence of technological change can be tested ($a_T \neq 0$) as well as the assumption of a constant rate of technological change ($g_{TT} = 0$). Hicks-neutral technological change can be tested by setting $g_{iT} = 0$. Alternatively, nested assumptions about scale economies can be tested. These include the hypothesis that the cost function is homothetic ($d_{iQ} = 0$) or that it is homogeneous and exhibits constant returns to scale ($d_{iQ} = 0$, $a_{QQ} = 0$). It is also possible to test the hypothesis that the cost function is unitary elastic ($\beta_{ij} = 0$). In this case the assumption is that there is constant substitution between inputs. The combination of the homogeneity and unitary elasticity assumptions leads to the Cobb-Douglas production function ($d_{iQ} = 0, a_{QQ} = 0, \beta_{ij} = 0$).

The various restrictions form a sequential order of nested models within the unrestricted model that are created by gradually imposing restrictions. The presence of both a time trend variable and an output variable complicates the nesting procedure because they are not intuitively nested. It is often difficult to separate the effects of returns to scale and technological change since their estimates are not independent of each other (Martinello 1985). Thus there is a problem of either reasonably splitting total factor productivity between scale economies and technological change or determining whether one or the other more adequately explains producer behaviour. Banskota (1984) integrated the two in an arbitrary fashion which first examined homotheticity, and then Hicks-neutral technological change. The method used here is to make the nesting initially two-tracked, one based on scale economies and the other on technological change. The testing is conducted between a particular hypothesis and the one immediately preceding it. In a testing procedure which starts with an unrestricted model and gradually imposes restrictions, the hypothesis test ceases when the first hypothesis is rejected.

The optimal procedure for estimation of the translog cost model is to jointly estimate the total cost function and the cost-share equations as a multivariate regression system (Christensen and Greene 1976). Although the translog cost model can be estimated directly using ordinary least squares, the large number of regressors (many of which are second order terms) introduces the risk of multicollinearity. Estimation as a system of equations reduces possible multicollinearity problems and provides many additional degrees of freedom without adding any unrestricted regression coefficients (Nautiyal and Singh 1986). The system of equations was estimated using Seemingly Unrelated Regressions (SUR) on Time Series Processor (TSP) software.

Data

Annual data covering the period 1950-51 to 1984-85 from the Australian Bureau of Statistics (ABS) were used for the estimations. The manufacturing industry census was not carried out in 1970-71 and no statistics are available for that year so data for that year has been interpolated. After 1984-85, detailed manufacturing industry censuses were only done in 1986-87 and 1989-90 so 1984-85 was used as the final year of the study.[1]

The total cost of production is calculated from the following equation.

$$C = P_K \cdot K + P_L \cdot L + P_M \cdot M + P_E \cdot E.$$

The total cost of labour, materials and energy is published annually along with employment. The price of labour (P_L) is derived by dividing the total wage bill by total employment The price of materials (P_M) is represented by an index of wood costs.[2] The energy price (P_E) is an aggregate of electricity, coal, wood, oil and natural gas prices. The electricity and natural gas prices were taken from the annual reports of Electricity Supply Association of Australia and the Gas and Fuel Corporation of Victoria, respectively. The remaining prices were calculated implicitly from details of expenditures and quantities consumed in the manufacturing statistics. The Divisia index (Diewert 1976) was used to create the aggregate energy price.

For the period 1950-51 to 1967-68, the census of manufacturing provides estimates of the book value of land and buildings, and of plant and machinery at the end of the year, but not investment or disposal of assets. The quantity of capital for this period was thus taken directly from the book value. This included capital owned by firms and the imputed value

[1] Manufacturing data for the period 1950-51 to 1967-68 was in the old classification of Australian Factory Statistics and was published in Report No. 27, Sawmilling. In 1968 the ABS adopted the Standard Industrial Classification (SIC). Data for the period 1968-69 to 1984-85 was obtained from SIC No. 2531, Log Sawmilling and SIC No. 2532, Resawn and Dressed Timber. Both of these were combined to match the earlier statistical series. These later statistics are published by the ABS in *Manufacturing Establishments, Details of Operations by Industry Class*. Output is sawn wood in cubic metres, and was obtained from AFC (1989) and Wilson (1969).

[2] For the period to 1968-69, the index was calculated implicitly from data provided in the ABS publication *Rural, Non-Primary Industries Bulletin*. For the remaining period, the ABS publishes an index of the costs of materials used in manufacturing, one of which is a forestry and fishing index. The index is a value-weighted index of which forestry is about 84 percent of the weighting.

of capital rented by firms. This approach to estimate capital stocks contains some problems in that book values fail to take account of inflation, and they will reflect a divergence between economic and accounting depreciation rates. For the period 1968-69 to 1984-85 the data changed to net investment in each of these two capital categories along with payments for rental of capital. The value of the capital stock for 1968-69 to 1984-85 was based on increments to the book value of capital in 1967-68. Each year, constant dollar net investment and the imputed value of rental capital were added and depreciation was deducted.

The expenditure on capital stock services is calculated as a user cost of capital (UC) and in this paper is defined as:

$$(10) \qquad UC = (r + g_n - dP_{nt}/P_{nt})\, P_{nt}\, K_{nt}$$

where r is the interest rate on 10-year government bonds, g is the declining balance depreciation rate for capital n, dP_{nt}/P_{nt} is the annual rate of change in price of capital n, P_{nt} is the price of capital n, and K_{nt} is the quantity of capital n. Two user costs were calculated with this formula, one for buildings and land, and one for plant and machinery. The imputed asset value of rental capital is also obtained from this formula. The price of capital for each class of asset is calculated as the value of capital services (UC) divided by the quantity of that capital. The total value of capital services was calculated as the user cost of capital from (10) plus rental expenditures. The price index for capital (P_K) was calculated as a divisia index using the three classes of capital.

Estimation Results

The estimated parameters and values of the log likelihood functions from the nested models are presented in Table 1. Along with these values are presented the calculated Chi-squares and their respective critical values for each model. By comparing the calculated and critical Chi-square values it is observed that neither the Hicks-Neutral nor Homothetic models are accepted at the 99 percent confidence level. Since the rejection of a restriction implies rejection of nested models, no further tests are necessary. These results indicate that the sawmilling industry in Australia is best represented by a model which has no restrictions on the production function.

The regularity conditions of a well-behaved cost function, homogeneity in prices, positivity and concavity (Varian 1984) were examined for the unrestricted model. Linear homogeneity in prices was imposed a priori and thus this condition is satisfied. The positivity condition is satisfied if the fitted cost shares for each observation are positive. This condition was found to be met at every point. Concavity requires that the principal minors of the Hessian matrix of the second order partial derivatives be negative definite (i.e., alternate in sign starting with negative). This condition is satisfied for the mean values, but is only satisfied for 18 out of 35 of the individual observations. An equivalent test of concavity is that the symmetric matrix of Allen Partial Elasticities of Substitution

TABLE 1
Test Statistics for Model Selection

Coefficient	Unrestricted	Hicks-Neutral	Homothetic	Hicks-Neutral and Homothetic	No Technological Change	Homogeneous	Unitary Elastic (Cobb-Douglas)
a_O	3.157	-6.044	-0.167	-7.846	3.432	5.384**	5.384**
a_Q	2.434	18.670	5.631	20.486	2.812		
a_{QQ}	-1.656	-14.929	-2.368	-15.446	-1.969		
a_T	0.005	-0.065**	-0.003	-0.071**			
a_{TT}	0.002*	0.005**	0.003**	0.005**			
β_K	0.115**	0.185**	0.026**	0.056**	0.061**	0.061**	0.061
β_{KL}	0.361**	0.315**	0.261**	0.251**	0.251**	0.250**	0.250**
β_M	0.503**	0.465**	0.680**	0.068**	0.665**	0.666**	0.666**
β_{KK}	0.012**	0.008**	0.012**	0.006*	0.010**	0.009**	
β_{KL}	-0.006**	-0.001	-0.010**	-0.006**	-0.008**	-0.008**	
β_{KM}	-0.006**	-0.006**	-0.002	0.0003	-0.003	-0.002	
β_{LL}	0.040**	0.047**	0.014	0.032**	0.032**	0.033**	
β_{LM}	-0.024	-0.042**	0.006	-0.023**	-0.023**	-0.023**	
β_{MM}	0.033+	0.049**	-0.002	0.023**	0.029**	0.029**	
d_{KQ}	-0.073**	-0.109*					
d_{LQ}	-0.076**	-0.060					
d_{MQ}	0.148**	0.178**					
g_{KT}	0.002**		0.002**				
g_{LT}	-0.001**		-0.001				
g_{MT}	-0.001+		-0.002**				
Number of Restrictions	0	3	3	3	2	2	6
Log of Likelihood Function	442.74	406.98	426.82	389.38	389.38	383.88	324.97
Critical* X^2	—	11.35	11.35	11.35	11.35	9.21	16.81
Calculated* X^2	—	71.53	31.85	74.88	74.88	11.00	117.46

For coefficients, **, * and + indicate significant at the 99,95 and 90 percent levels of confidence respectively. Critical value for X^2 is 99 percent level.

(*AES*) be negative semi-definite (Nautiyal and Singh 1986). A necessary condition for the matrix to be negative semi-definite is that all of the own AES be negative. When this condition is met then the derived demand curves will be downward sloping. This condition is satisfied for the model. Overall, on the basis of all the required conditions, the estimated model is a reasonable representation of a well-behaved cost function.

Discussion

Elasticities of demand with respect to own prices and prices of other inputs have been calculated from the parameter estimates in Table 1, and are given in Table 2. Own price elasticities of demand show the expected negative sign, and in each case demand was shown to be inelastic with respect to the input's own price. The cross elasticities indicate that all inputs were substitutes, except for labour and energy, and in all cases were inelastic. The substitution relationships between capital, labour and materials were similar to results for the Canadian sawmilling industry found by Banskota *et al* (1985), Nautiyal and Singh (1985) and Singh and Nautiyal (1986), and for the U.S. sawmilling industry by Stier (1980). The results differ somewhat from those for the Tasmanian sawmilling industry found by Campbell and Jennings (1990). In this latter study, materials, which is largely comprised of wood costs, was found to be a slight complement to energy and capital. In this study materials were found to be substitutes with energy and capital, and in the case of a response to a change in the price of materials, both energy and capital were found to be much more responsive than was found by Campbell and Jennings (1990). The differences may arise for two reasons, one because the present study uses aggregate Australian data which reflects a different industry structure to the Tasmanian industry, and because this study covers both sawmilling and resawing, rather than just sawmilling.

TABLE 2
Price Elasticities*

	Price of Capital	Price of Labour	Price of Materials	Price of Energy
Capital	–0.69	0.14	0.53	0.02
Labour	0.02	–0.58	0.56	–0.01
Materials	0.04	0.24	–0.30	0.02
Energy	0.05	–0.13	0.55	–0.47

* At mean values 1950-51 to 1984-85

In general though, the low elasticities show that the sawmilling industry has limited opportunities to respond to rising prices for a particular input by substituting another input for it. Of all the inputs, materials showed the highest cross elasticities with respect to changes in its own price and in the price of labour. The industry's main substitution opportunity was thus to compensate for rising wood prices by becoming less wood intensive and more capital, labour and energy intensive. This result would be expected given the changes observed in the sawmill industry. These include an increase in the lumber recovery factor, or recovery of saw output from a given log input over time, and the increased 'value-adding' applied to any given log input such as drying and dressing.

The accepted model rejects homotheticity ($d_{iQ} \neq 0$) and shows that as scale is changed the relative shares of the inputs in the production process are also changed. For the Australian sawmilling industry, it is shown that an increase in scale resulted in a smaller share for capital and labour, and a larger share for materials and energy. This result is consistent with the greater automation and the relatively higher throughput of raw material associated with increasing scale. Christensen and Greene (1976) have shown for the translog cost function that scale economies are derived by calculating scale elasticities (*SE*). For the translog cost function, *SE* is expressed as a percentage.

$$SE = 1 - \frac{\partial lnC}{\partial lnQ} = 1 - (a_Q + a_{QQ}\, lnQ + \Sigma d_{iQ}\, ln\, P_i)$$

where $i = K,L,M,E$.

A positive value for *SE* indicates economies of scale and a negative value indicates diseconomies of scale (Singh and Nautiyal 1986). The interpretation of scale economies for the translog cost function is in terms of total cost changes as output is varied. If the rise in total costs is more than proportionate relative to a rise in output then there are diseconomies of scale (negative value) and if less than proportionate then there are economies of scale (positive value).

As can be seen from Table 3, the scale economy values were positive for each year of the series. These results suggest that the Australian sawmilling industry operated under economies of scale over the entire study period. In other words, the industry was operating on the downward sloping portion of the long run average cost curve where average costs decline as output is increased. The implication of this is that the industry was on average, operating in an environment where there were cost advantages to increasing the scale of the business. The declining value of SE over time indicates that scope for making economies of scale had been declining over time.

The positive economies of scale is similar to the result of 1.49% found by Campbell and Jennings (1990) for the Tasmanian industry although the size of scale economies found in this study are lower, averaging 0.56%. Banskota *et al* (1985) found small scale economies for the Alberta sawmilling industry (0.023–0.089), and Singh and Nautiyal (1986) found somewhat larger economies (0.944–1.043) for the Canadian sawmilling industry. These are interpreted as being on the flat and the downward sloping portions of the relevant average cost curves respectively. A possible reason for the difference between the results in this study and those of Campbell and Jennings (1990) is in the structure of the sawmilling industry in Tasmania versus that of the average Australian sawmill industry. The most important component of the difference would be the dominance of relatively small hardwood sawmills found in Tasmania compared to the national average which has a large softwood component, much of which is already in large mills. An analysis of the Victorian sawmilling industry by Kennedy and Hourigan (1985) found that the average size of a hardwood sawmill should change from an average of 5000 m^3 per annum to an apparent economic size of between 11,000 and 15,000 m^3 per annum. This could be interpreted as simply suggesting that there were economies of scale to be exploited, as the results of this study would support, but this interpretation is complicated by an additional issue of the type of technology which would be used in the move from an average mill size of 5,000 to 15,000 m^3 per annum.

TABLE 3
Scale Economies

Year	Scale Economies	Year	Scale Economies
1950-51	0.35	1968-69	0.74
1951-52	0.20	1969-70	0.63
1952-53	0.33	1970-71	0.67
1953-54	0.47	1971-72	0.59
1954-55	0.61	1972-73	0.66
1955-56	0.68	1973-74	0.63
1956-57	0.69	1974-75	0.36
1957-58	0.63	1975-76	0.47
1958-59	0.61	1976-77	0.46
1959-60	0.71	1977-78	0.39
1960-61	0.78	1978-79	0.44
1961-62	0.66	1979-80	0.52
1962-63	0.58	1980-81	0.58
1963-64	0.65	1981-82	0.54
1964-65	0.74	1982-83	0.37
1965-66	0.78	1983-84	0.28
1966-67	0.76	1984-85	0.39
1967-68	0.68		

A change in technology would mean a move to a different long run cost curve rather than the exploitation of scale economies with the existing technology, or movement along the old cost curve. Information about changes in technology are provided by parameters estimated in the translog cost function. The accepted model includes a parameter for technological change (a_T) which indicates that technological change had taken place, but the parameter is not statistically different from zero. A constant rate of technological change ($a_{TT}= 0$) was also rejected. Hicks-neutral technological change ($g_{iT}= 0$) was rejected in all cases implying that technological change has changed factor shares. The bias of technological change, calculated from Equation (8), is given in Table 4.

TABLE 4
Technological Change Bias

Capital	.039
Labour	–.005
Materials	–.002
Energy	.025

At average factor shares and using equation (8), the results show that the bias of technological change had been capital and energy-using, at 0.039% and 0.025% annually. Thus if the relative prices of inputs had remained constant, technological change would have increased the share of expenditures of capital and energy over time. Over the 35 year period covered by the study, capital's share rose by 1.39% and energy's by 0.9% due to this bias. The bias of technological change had been labour and materials-saving, at –0.005% and –0.002% annually. Over the 35 year period covered by the study, labour's share had declined by 0.18% and material's by 0.05% due to this bias. Although not large, these results would be expected given a pattern of technological change in the sawmilling industry which had seen capital being spent in a way that increased log throughput per mill, lifted sawn recovery logs and which did this with a smaller labour force.

Summary

The purpose of this paper has been to quantify the structure of the Australian sawmilling sector through an econometric study of the industry's production structure. This has been done with the use of a translog cost function. The results show that the production structure of the sawmilling industry in Australia over the period 1950-51 to 1984-85 appears to be best represented by a production function which does not assume homotheticity, homogeneity, unitary elasticity or Hicks-neutral technological change. Inputs were found to be generally substitutable for one another, the exception being a complementary relationship between labour and energy. Although cross-price elasticities show that no substitution possibilities were large, the greatest substitution possibilities existed between materials and both capital and labour. This suggests that capital and labour were changed in ways which were more efficient in material use, and thus would lower production costs. Although inputs can be substituted, price elasticities were small, indicating that there was only limited potential for producers to respond to rising input prices by changing input combinations and factor shares.

There were economies of scale in the sawmilling industry although these declined over time. This appears to be the way in which the sawmilling industry reduced costs given the lack of substitutability of inputs. Over time, technological change also occurred in the industry which was capital and energy-using, and labour and materials-saving. These results are not unique to the forest industry and reflect trends across all industries in developed nations towards capital and energy intensive processes.

A factor which complicates a study like this in Australia is the presence of two distinct sectors in sawmilling, hardwood and softwood. This contrasts with Canada and the U.S. which have most of their sawmilling capacity producing softwoods under similar species, technology and economic conditions. In Australia, hardwood and softwood sawmills have developed along similar but divergent patterns, particularly in response to differences in raw material availability and quality, and this has important implications for the way that they operate. The hardwood sawmilling industry has traditionally consisted of small mills with an average annual output of only 5000 cubic metres (Crow and Kennedy 1984, Tasmanian Yearbook, Queensland Yearbook), and in most States is dependent on public forests for log supplies. Access to public logs has generally been on short-term and often informal arrangements, and there can be problems with transferring harvesting rights. This has created what is believed to be a sub-optimal level of capital stock in the hardwood sawmilling industry because firms were reluctant or unable to invest in large mills (*Victoria: Timber Industry Strategy* 1986). The hardwood resource is also highly variable in its quality and thus requires relatively labour-intensive processing (Kennedy and Hourigan 1985). In contrast, the softwood industry operates from a base of large tracts of private and public plantations dedicated to log production. As a result, the softwood industry operates on a much larger scale than the hardwood industry, with mills that are 8 to 20 times larger. With a uniform resource, softwood mills are generally highly automated and relatively capital intensive compared to hardwood mills.

Not only are there differences in the way hardwood and softwood sawmills have developed, each is adapting to different resource pressures. The hardwood sawmilling industry has had to adapt to a gradual decline in the availability of native hardwoods while the softwood sawmilling industry has faced an increase in the availability of plantation softwoods (FAFPIC 1985). The decline in hardwood availability has largely been due to the exhaustion of old growth timber and a shift to the second rotation resource. In addition, there have been major withdrawals from the commercial forest land base as parks and reserves have been expanded. The decline in hardwood availability has been more than offset by a large increase in softwood sawlog supply from plantations. Softwood sawlog availability is expected to rise by nearly 50% or 2 million m^3 by the end of the current decade (AFC 1989).

Given the likely structural differences between the hardwood and softwood sawmilling industries, the ideal approach would be to try and model each separately. Since statistics are not collected on the basis of hardwood and softwood, but only for sawmilling as whole, this is not possible. A reasonable approximation would be to separately model the sawmilling industry in each state and compare them on some subjective estimate of the relative presence of hardwood and softwood sawmilling in each. This could capture much of the difference between the two industries since some states are much more heavily weighted to one or the other. A study of the sawmilling industry on a state basis would also help to capture the differences in state government policies governing log allocation and the effect this has on production structure. With state governments owning or administering a large part of log supply in each state as a monopolist or oligopolist, and the virtual absence of interstate flows of logs, differences in state government policies regarding log allocation will likely create structural differences in the sawmilling industry in each state. Estimation and comparison at a state level for each of the states is thus a likely direction for future research. The national-level results of this paper and those for Tasmania from Campbell and Jennings' 1990 study will provide an interim base for policy-makers.

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