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THE UNIVERSITY OF ALBERTA

AN ECONOMETRIC ANALYSIS OF LOGGING IN ALBERTA

by

DONALD L. HAID

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

FOREST ECONOMICS

DEPARTMENT OF RURAL ECONOMY

EDMONTON, ALBERTA

SPRING 1986

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled AN ECONOMETRIC ANALYSIS OF LOGGING IN ALBERTA submitted by DONALD L. HAID in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in FOREST ECONOMICS.

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Date. MARCH 18, 1986 ....

ABSTRACT

The purpose of this thesis is to analyze the production structure of the logging sector of the Alberta forest industry. The problems of wood supply, employment stability, technological progress and competitiveness are economic in nature and have a significant impact on the forest industry. Econometric analysis of production structure facilitates development of a quantitative description of industry structure. The quantitative structural model provides a framework from which economic issues concerning logging may be addressed.

The description of structure was accomplished through the use of a flexible form production model. A transcendental logarithmic cost function consisting of the real prices of capital, labour, fuel and wood inputs was utilized in the analysis. Use of the translog cost function permitted specification of a number of nested models. Tests of parameters of nested models revealed that the production structure was best represented by a nonhomothetic, non-neutral technical change translog cost function.

Estimation of scale and output parameters indicated that technical change was capital using and labour, fuel and wood saving. Scale was found to be capital and labour using and wood and fuel saving. Comparative static results indicated input demand was highly inelastic in all cases. Significant substitution relationships were observed between capital and labour.

The results obtained from the parameter estimates of the model have policy implications beyond direct economic interpretation. The inelasticity of input demand is typical of primary industries. The forest industry is characterized by instability of forest product prices. The relative insensitivity of input demand to price changes may cause the logging sector to be significantly affected by price instability. Alberta stumpage policy changed during the period of this study. Crown dues, previously adjusted according to market prices, were institutionally fixed after 1976, causing a distortion of economic indicators. Inflexibility of the wood price forces output price changes to be absorbed among other inputs, possibly contributing to price instability. Current appraisal methods in Alberta are ineffective in capturing the price of timber and should be reevaluated by policymakers. The results show that a shift away from labour is occurring in logging. Technical change and substitution elasticities indicate that capital is being substituted for labour. Scale effects may offset labour losses through employment increases that occur with industry expansion. Government frequently promotes large scale capital investment in the forest industry that may contribute to industry development and efficiency. However, existing employment levels may only be preserved rather than increased by this action.

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I. INTRODUCTION

This study contains an econometric analysis of logging production in Alberta. Its purpose is to identify, describe and measure in economic terms those criteria that characterize the Alberta logging industry. A transcendental logarithmic cost function was utilized in the economic analysis. This flexible form cost function allowed a variety of models to be tested and facilitated the selection of a model most representative of the production structure of the Alberta logging industry.

Logging is that aspect of the forest industry concerned with the location of merchantable standing timber and its harvest. This includes felling, limbing, decking and hauling of raw timber. Road layout and construction is frequently included with logging as well. Logging is the first step in any of the industrial processes associated with the forest industry. Since logging is an essential phase in all forest industries, the role of this primary industrial activity within the forest industry is highly significant.

Forests in the province of Alberta cover approximately 53 percent of the provincial area and are estimated to contain 57,000 million cubic feet of growing stock (Ondro and Williamson, 1982). Alberta is Canada's fourth largest province in terms of productive forest area and merchantable volume. Consequently, Alberta has the forest resource potential to make it a major force in the Canadian forest industry and to make forestry a major force in the provincial economy.

The forest industry has, historically, played a major role in Canadian economic development and prosperity. Today, its role is no less significant. In 1980 the total value of exports by the forest industry was nearly 13 billion dollars, accounting for 17 percent of the nation's total exports (Williamson, 1983). Of the total direct employment in the forest industry, logging accounts for one fifth of the total. This tends to understate the importance of logging. Although it employs relatively few, it supports other forest industry jobs which in turn generate other indirect employment outside of the forestry sector.

A. JUSTIFICATION AND PROBLEM STATEMENT

Economic analysis of the logging sector is warranted by the importance of the forest industry to the Canadian and Alberta economies and by the lack of past research in this area. Previous studies have tended to focus on the manufacturing activities associated with the forest industry and only approached logging as an afterthought.[1] Thus, there is a legitimate need for more detailed study of the logging sector.

The perceived need for economic research in the forest industry and the logging sector in particular is reinforced by the timber supply crisis currently facing the Canadian forest industry. The contentious issue of timber supply has

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[1]A recent example of this treatment of logging can be found in a paper by Martinello (1984)

received attention in both academic and political arenas. This problem has strong economic implications and the area where these problems initially surface is the logging sector. Declining economically accessible supply forces wood input costs upward and causes production to expand intensive and extensive margins (B.C. Ministry of Forests, 1980). Alberta currently does not face a shortfall in supply because of its short logging history and above average regeneration record. However, the timber supply situation may change in the future, making declining economic supply an issue of present and future concern. There are problems facing the logging sector which are economic in nature. Inadequate past research in this area further compounds these problems due to a lack of information and understanding. There is a need for research in this area. Economic analysis of forest industry structure has been identified as an area of research need for western Canada and particularly the province of Alberta (Phillips *et al*., 1984).

This thesis contains a microeconomic analysis of logging production in Alberta through time. The study is a step toward meeting the need for economic analysis of the forest industry and will provide a structural profile of the logging sector of the forest industry. This study is similar in method and intent to Banskota's (1984) study on sawmill production structure in Alberta. These two studies offer comparable results and together provide insight into a major portion of the Alberta forest industry.

B. THE ALBERTA FOREST INDUSTRY

In Alberta, the forest resource, despite its dominance of the landscape, takes a back seat to petroleum and agriculture in terms of economic importance and public awareness. The role of forestry is an important one that can be increased in significance through continued development of the forestry sector.

The direct contribution of the logging industry to the economy of Alberta is small in terms of gross domestic product. Logging is a primary industry involving simple resource extraction and has limited potential for value added because logs, as the final output of the sector cannot be significantly improved. The indirect impact of logging to the economy of Alberta has a much greater significance. The forest industry (which obtains its wood inputs from the logging sector) accounts for 20 percent of the value added in the manufacturing industries which in turn account for 8.9 percent of the Alberta gross domestic product (Ondro and Williamson, 1982, pp. 99-103). In comparison the petrochemical industry accounts for 18.9 percent of the manufacturing contribution to gross domestic product. Thus, the logging industry plays a significant but indirect role in the Alberta economy in terms of value added and gross domestic product.

Logging, in terms of employment, is significant both directly and indirectly.

> "Total direct employment by the forest industry (in 1978-79) was 1,915 person years in logging and 4,502 person years in manufacturing. An additional 9,003 jobs were supported by the industry" (Ondro and Williamson, 1982).

Although the impact of the forest industries on employment is small relative to the total workforce of 915,000 persons, many of the jobs occur in communities which are partially or wholly dependant on the forest industry.

Despite the importance of forest industry in the economies of Canada and Alberta, studies of the economic dynamics of these industries have been limited in both scope and number. In Alberta studies by Ondro and Williamson (1982), Bigsby (1983), Williamson (1983), and Banskota (1984) have contributed to knowledge of the subject. However, these studies have focused on the manufacturing side of the industry, particularly sawmilling. Economic analysis of logging in Alberta has been lacking in the past and to date no microeconomic analysis of the structure of the logging sector has been performed. This study will utilize neoclassical microeconomic theory and current production analytical techniques to fill this void in the present state of knowledge about the logging sector of the Alberta forest economy.

C. METHODOLOGY

Production economics is concerned with resource allocation in terms of optimal combinations and levels of resource inputs in a production process. It examines production choices and how these choices are influenced by changes in technical and economic circumstances (Beatie and Taylor, 1985). Neoclassical production theory postulates that output is produced by combining inputs in some process. This study assumes that logging output is a function of the inputs labour, capital, fuel, and standing timber.

Production economics is a study of optimizing behavior. A primal setup of a production system involves the explicit solution of an optimization problem such as determining the profit maximizing level of output. Duality is a mathematical relationship, whose discovery is attributed to Shephard (1953), which allows one to obtain the same results from the partial differentiation of an indirect objective function as from the primal optimization problem. For example the dual of the primal of profit maximization would be cost minimization.

Duality allows the use of input expenditure data in the solution of a cost function which is the dual of a production function. Expenditure data has many advantages in terms of quality and availability of data as well as certain favorable statistical properties. This study utilizes input expenditure data in determining the production structure of the Alberta logging industry.

The specification of an appropriate functional form to model the production process is an important aspect of any production analysis. In this study a transcendental logarithmic or translog function was selected to represent the production structure of the Alberta logging industry. This function was chosen for its flexible form characteristics and its lack of restrictions in the specification of a production structure. It was selected over more traditional forms such as the Cobb Douglas or Constant Elasticity of Substitution production functions because of its superior statistical qualities and more realistic implications when applied to the real world.

Appropriate econometric techniques were utilized in the estimation and testing of the translog models developed in the analysis.

D. OBJECTIVES OF THE STUDY

The purpose of this study is to develop an econometric analysis of logging in Alberta based on time series data and to interpret the results developed therein. The analysis requires the specification of a cost function for the industry and the estimation of the parameters of the cost function. Developed from this analysis will be comparative static results in the areas of input price elasticities, elasticities of substitution, and technical change over time.

The specific objectives of this thesis are:

1. To assemble existing time series data on the logging industry;
2. To put these data in an index form to facilitate estimation;
3. To use econometric techniques on a translog cost functional form to estimate parameters;
4. To derive returns to scale, input demand, factor substitution, technical change and productive efficiency measures; and
5. To interpret results in terms of industry structure and policy implications with emphasis on stumpage valuation.

E. OUTLINE OF THE THESIS

This thesis is divided into six chapters. Chapter two contains the theoretical framework upon which the analysis is based. Economic theory and modelling methods are discussed, evaluated and compared in this chapter. The data employed in the analysis is presented in the third chapter which includes a description of the data used, the sources from which they were obtained, and some of the techniques used in developing the data according to the specific needs of the models. Chapter four outlines the application of economic theory in empirical estimation. The actual methodology employed in the analysis is described in this section. The results of the analysis are presented and discussed in chapter five. Chapter six provides an interpretation of the results obtained and an identification of the meaning of the various findings both from economic and policy viewpoints. The sixth chapter also concludes the thesis. It cortains highlights of the most significant findings, resulting conclusions and suggested areas of further research.

II. THEORETICAL FRAMEWORK

The analytical techniques used in this thesis are derived from the neoclassical theory of the firm. This mainstream school of microeconomic thought considers the firm as a technical unit which produces commodities. The production of these commodities occurs through the transformation of inputs to outputs. The transformation process is subject to technical constraints and its specification is known as the production function. The production function is a mathematical expression of the relationship between quantities of inputs used and quantities of output produced. Specifications of the production function can range from a single point to a variety of different functions to a system of equations. This study is concerned primarily with one specification of the production function, the translog. However other widely studied functional forms are also discussed.

A. NEOCLASSICAL PRODUCTION THEORY

In neoclassical microeconomics, the production of outputs as a function of inputs can be written as

$$Q = f(X_1, \ldots X_n) \tag{1}$$

where Q is output and X_n's are inputs. This production function is subject to a budget constraint

$$C = \sum_{i=1}^{n} P_{x_i} X_i + b \tag{2}$$

where C is the cost of production, P_{x_i} is the price of input X_i and X_i is the quantity of input i and b is the cost of any fixed inputs.

Constrained optimization of the production process can occur as an output maximum or a cost minimum. The firm is generally free to vary the levels of both cost and output and hence the objective of the firm is the maximization of profit rather than the solution of constrained maximum and minimum problems. Total revenue for the firm is given as the product of quantity of output produced (Q) and the fixed unit price received (P). Profit is the difference between the firms total revenue and total cost. Thus profit (π) is expressed as

$$\pi = P \cdot Q - C \tag{3}$$

or substituting from equations (1) and (2)

$$\pi = P \cdot f(X_1, \ldots X_n) - \sum_{i=1}^{n} P_{x_i} X_i - b \tag{4}$$

Setting the partial derivatives of π with respect to inputs equal to zero,

$$\partial \pi / \partial X_i = P \cdot f_i - P_{xi} \tag{5}$$

and moving input price terms to the right

$$P \cdot f_i = P_{xi} \tag{6}$$

yields the first-order conditions for profit maximization. Each input is utilized up to the point where the value of its marginal product equals its price when these conditions are met. Second-order conditions require that the principal minors of the relevant Hessian determinant alternate in sign (Henderson and Quandt, 1980, p. 79). The second-order conditions require that the production function be strictly concave in the neighborhood of a point at which the first order conditions are satisfied. If the production function is strictly concave then the point at which the first order conditions are satisfied is a unique profit maximizing solution.

The firm's input demand is derived from the underlying demand for the output produced. The input demand functions are obtained by solving the first-order conditions (equation 6) for input quantities as a function of input and product prices. The input demand functions for the producer are analagous to ordinary demand functions in many ways. Satisfaction of the first order conditions indicates homogeneity of degree zero in input and output prices

(Henderson and Quandt, 1980, p.80). Elasticities may be defined for each of the inputs with respect to each of the prices. The rate of change of the producers purchases of an input with respect to changes in its price will always be negative, and the producers input demand curves are always downward sloping. Thus it is possible to specify derived demand functions for the inputs of production from the demand for the final products.

Production structure, defined by a production function, mathematically represents the relationship between the multiple inputs in the production process and the final output product. The relationships between inputs and outputs are affected by many factors. Dominant among these are the prices of inputs and outputs which influence the behavior of the rational profit maximizing producer. Other important factors influencing production relationships are scale and technology.

The concept of returns to scale refers to the size of the proportional change in output caused by a proportioal change in inputs. Returns to scale are categorized as being increasing, constant or decreasing. The effect of scale on input usage can be determined when output terms are included in the specification of the production function. Scale may be input using, neutral or saving depending on the sign and value of the output parameters. The specification of the production function may also restrict production structure to constant returns to scale (as is often the case with the

Cobb-Douglas production function) although many production functions allow returns to scale to vary. The restriction of homotheticity in production (which is discussed in a subsequent section of this chapter) allows returns to scale to vary but fixes it at one level over the entire production period.

Hence, the specification of a functional form to model production influences the number of economic variables that are allowed to vary.

B. PRODUCTION FUNCTIONAL FORM

The microeconomic analysis of firm and industry structure can adopt a wide variety of functional forms. Past research has favoured a few popular specifications of the production function. These include the Cobb Douglas, the Leontief or Fixed Factor, and the Constant Elasticity of Substitution production functions. These functions are classified as inflexible form production functions. They are considered to be inflexible because of *a priori* restrictions on parameter estimates and on other comparative static measures that limit the testing of different hypotheses within the models. The source of the inflexibility in these production functions is their representation of production possibility frontiers which are additive and homogeneous (Christensen *et al.*, 1973) and that these properties restrict the results obtained from the production functions.

The Fixed Factor or Leontief production function is the most restricted of the forms discussed. The elasticity of substitution is zero for this function thereby allowing no substitution among inputs. As its name suggests, the production process requires a fixed proportion of factor inputs and hence this form is extremely inflexible.

The Cobb Douglas specification is perhaps the oldest and most widely used production function form. This form is founded on the relationship of total wages paid as some proportion of output. This linearly homogeneous production function also allows for increasing, decreasing or constant returns to scale. However, the elasticity of substitution is restricted to unity. Thus the Cobb Douglas form does not allow complementarity among inputs thereby permitting a substitute relationship only among all inputs.

The Cobb Douglas form was relatively unchallenged in production economics until the early 1960's when Arrow *et al.*, (1961) first published the Constant Elasticity of Substitution,CES, functional form. The CES production function sets a constant but unconstrained value on the elasticity of substitution. Hence, the elasticity of substitution, while not restricted to unity, as in the Cobb Douglas case is limited to a single or constant value. While being an improvement the CES production function is still regarded as restrictive and inflexible. The CES function unlike the Cobb Douglas is non linear and hence more difficult to estimate. Arrow *et al.*, (1961) demonstrated that the Cobb Douglas and Leontief production functions were special cases of the CES where the elasticity of substitution was restricted to unity or zero. The apparent superiority of the CES over the other forms led to its adoption in econometric analyses of the 1960's. However, despite its advantages, the CES function was still an inflexible production function.

The variation in microeconomic systems over time makes flexibility a desirable characteristic for any function that attempts to model the system. In the case of production functions, the production structure is rarely known in advance and hence flexibility of structure is advantageous. Minimization of the number of *a priori* restrictions that affect parameter estimates and other economic indicators is also useful. Thus, there are advantages to the use of flexible functional forms over the inflexible forms previously discussed.

The traditional production functions of the past have been giving way to more flexible functional forms for more than a decade. The development of these flexible form production functions arises from production possibilities that have the restrictions of additivity and homogeneity removed. This enables the specification of production functions that

1. have fully flexible elasticity of substitution;
2. allow the specification of complementary elasticities; and

3. allow for the hypothesis testing of variations of the model nested within the production function (e.g. homotheticity and technical change).

Flexible form production functions that are common in the literature include: the translog, the generalized Cobb Douglas, the generalized Leontief and the quadratic. The translog is perhaps the most widely applied of these forms and is the functional form utilized in this study.

C. COST AND PRODUCTION

The concept of a cost has always been of concern in production theory. In a production process, rational economic behavior suggests the selection of an input bundle which minimizes the cost of producing each possible output. This fundamental duality between cost functions and production possibilities has many favourable properties particularly when subjected to econometric estimation procedures. The theory of establishing the dual relations between cost functions and production functions was introduced to economics by Shephard (1953) but was not applied to empirical data until the 1960's when Nerlove (1963) employed the Cobb Douglas case in a study of returns to scale in electric utilities.

The principle advantage of using cost functions is avoidance of the problem of deriving demand systems from production possibilities. In addition, the cost function and its derivatives can define the reduced form of the model in many circumstances (Fuss and McFadden, 1978).

The use of cost functions in the specification of production structure is contingent upon the satisfaction of certain regularity conditions. A well behaved neoclassical cost function satisfies the following conditions (Banskota, 1984):

1. strictly positive;
2. linearly homogeneous;
3. concave; and
4. continuous such that first and second partial derivatives exist.

The satisfaction of these mathematical conditions constrains the production technology inferred from the cost function. Consequently, satisfaction of the conditions of well behaved cost functions requires the imposition of restrictions on the production technology to which the cost function applies.

To illustrate these restrictions, consider a single output, multi input cost function of the form:

$$C=C(P_i, Y, t) \tag{7}$$

The Y refers to the single output of wood, t represents time and C represents cost. The P_i's refer to the input prices for labour (L), capital (K), standing timber (W), and fuel (F). The restrictions imposed *a priori* on this cost function to satisfy regularity conditions are as follows:

1. The adding up condition requires the sum of input costs to be equal to total costs such that

$$\sum_{i=1}^{n} P_i \; X_i \; (P_i, Y) = C(P_i, Y) \tag{8}$$

2. The Cournot aggregation condition, which allows a change in the ith input price leading to a reallocation of total cost without violating the adding up condition, can be written as

$$\sum_{i=1}^{n} P_j \; \partial X_i (P_i, Y)/\partial P_i \; + X_i \; = 0 \tag{9}$$

3. The Engel condition, which states that a reallocation of cost will still maintain the adding up condition, is expressed as

$$\sum_{i=1}^{n} P_i \; \partial X_i (P_i, Y)/\partial C_i \; = 0 \tag{10}$$

4. The symmetry condition, which requires equality between the cross second order partial derivatives such that

$$\partial^2 C(P_i, Y)/(\partial P_i \; \partial P_j) = \partial^2 C(P_i, Y)/(\partial P_j \; \partial P_i) \tag{11}$$

D. TRANSCENDENTAL LOGARITHMIC COST FUNCTION

The translog functional form was pioneered by Christensen *et al.*, (1971) and first applied to production analysis in 1973 in a benchmark study titled "Transcendental Logarithmic Production Frontiers" (Christensen *et al.*, 1973). In this study Christensen *et al.* exploited the duality between quantities and prices in production to develop a translog production frontier and a translog price frontier. Definition of a translog cost function was possible from the translog price frontier. The superior characteristics of cost functions (discussed in the previous section) justified their application to the analysis (Binswanger, 1974).

The non-homothetic, single output, multi-input translog cost function, augmented to incorporate technical change through the inclusion of time (t) as an argument, can be written as

$$\ln C = \alpha_0 + \beta_Y \ln Y + \beta_t t + \sum_{i=1}^{n} \beta_i \ln P_i +$$

$$1/2 \sum_{i=1}^{n} \sum_{j=1}^{m} \beta_{ij} \ln P_i \ln P_j + \sum_{i=1}^{n} \beta_{iY} \ln P_i \ln Y +$$

$$\sum_{i=1}^{n} \beta_{it} \ln P_i t + 1/2\beta_{tt} t^2 + 1/2\beta_{YY} (\ln Y)^2 \quad (12)$$

where i=1 to n and j=1 to m

for all i,j = L,K,W,F

The β's are the parameters of the cost function to be estimated, Y represents the output term and the inputs are as defined previously. The translog cost function is a quadratic function having interaction terms (β_{ij}) and square terms (β_{tt} and β_{YY}). The cost function is constrained to homogeneity of degree zero in input prices through the imposition of the following restrictions:

1. $\sum_{i=1}^{n} \beta_i = 1$

2. $\sum_{i=1}^{n} \beta_{ij} = \sum_{i=1}^{n} \beta_{ji} = 0$

3. $\sum_{i=1}^{n} \sum_{j=1}^{m} \beta_{ij} = 0$

4. $\sum_{i=1}^{n} \beta_{iy} = 0$

5. $\sum_{i=1}^{n} \beta_{it} = 0$ and,

6. $\beta_{ij} = \beta_{ji}$ (13)

In general these restrictions are maintained hypotheses of the translog cost function and as such are imposed prior to the actual estimation of the parameters.

Share Equations

Cost minimizing derived demand equations for the various inputs can be derived from the translog cost function (12). This derivation is accomplished through the differentiation of equation (12) with respect to input prices via Shephard's lemma (Shephard, 1953):

$$\partial \ln C/\partial \ln P_i = \partial C/\partial P_i \cdot P_i/C = X_i P_i/C = S_i \quad (14)$$

where S_i represents the share of the ith input in total cost. The derived demand equations (14) are also known as the share equations and can be written in terms of the parameters of equation (12) as

$$S_i = \alpha_0 + \sum_{j=1}^{m} \beta_{ij} \ln P_j + \beta_{iy} \ln Y + \beta_{it} t \quad (15)$$

These share equations are frequently used in estimation because of their relative simplicity in comparison with the cost function particularly when models with many inputs are used.

Substitution and Price Elasticities

The elasticity of substitution between two factors is defined as the elasticity of the ratio of the factors with respect to the marginal rate of technical substitution between them (McFadden, 1978b). Hence, this elasticity is an index of the sensitivity of cost minimizing factor input proportions to changes in relative factor prices. The elasticity of substitution (σ) can be defined in terms of the derivatives of the translog cost function. However, when the production process has more than two inputs, the elasticity of substitution becomes more complex as the number of inputs increases. Thus, in the n input case, partial elasticities of substitution are estimated. The most widely applied form is the Allen-Uzawa partial elasticity of substitution (Binswanger, 1974). Defined in terms of the translog cost function, equation (12), these elasticities can be written as

$$\sigma_{ii} = (\beta_{ii} + S_i^2 - S_i) / S_i^2 \qquad (16)$$

for the own input case, and

$$\sigma_{ij} = 1 + (\beta_{ij} / S_i S_j) \tag{17}$$

between inputs, for all i,j and i≠j.
S_i represents the share of the ith input and the β's represent the parameters of the translog cost function in all cases.

The elasticities of substitution represent the sensitivity of the change in total cost occuring when the quantity of input i changes due to a change in the price of factor j while all other prices and output are held constant (Banskota, 1984). Negative values of (σ) indicate complementarity among inputs while positive values indicate substitutability.

The elasticities of substitution are affected by the separability of inputs in the production process. The extent of separability among inputs (weak or strong) has specific implications regarding the partial elasticities of substitution and consequently the relationships between inputs. Separability is discussed further in a subsequent section of this chapter.

In addition to the Allen partial elasticities of substitution, the price factor demand elasticities (η) offer important economic information. These are defined as

$$\eta_{ii} = \sigma_{ii} S_i \tag{18}$$

for the own-price factor demand elasticity and,

$$\eta_{ij} = \sigma_{ij} S_i \tag{19}$$

for cross-price factor demand elasticity for all i,j and i≠j.

The own-price elasticities will all be of negative sign except in the case of the inferior input. Cross-price elasticities indicate the change in the demand for input i caused by a change in the price of input j while all other prices and output are held constant. As defined by equation (19), these elasticities are proportional to the substitution elasticities (σ_{ij}). Consequently, these cross-price elasticities also indicate complementarity or substitutability.

Homotheticity and Non-Homotheticity

Shephard (1953) defined a homothetic function as a function which is a positive monotonic transformation of a linear homogeneous function. All homogeneous cost functions are homothetic. However, not all homothetic cost functions are homogeneous (Banskota, 1984, p. 26).

Homotheticity in production functions and their dual cost functions ensures that all isoquants are radial blow ups from the origin of a given isoquant defining the production process. As a result, the expansion path of production is a ray from the origin. Further, the distance between isoquants changes as the level of output increases along the cost-minimizing expansion path. Homothetic production technologies can exhibit increasing, decreasing or constant returns to scale depending on the slope of the ray defining the expansion path. However, because the expansion path is constrained to linearity, returns to scale remain constant over changing levels of output as are the marginal rates of technical substitution.

Homotheticity can further be dissected into strongly homothetic and weakly homothetic. A production function, such as the one defined by equation (12), is homothetic if it can be separated into two parts such that

$$C = c(P_i) \cdot g(Y) \tag{20}$$

When this relation is applied to the translog case there are two economic properties implicit in this condition (Denny and May, 1978). First, the ratio of any two factor demand (share) equations is independent of the output level. Second, the elasticity of total or average cost with respect to output is independent of factor prices. A production technology that satisfies both of these conditions is said to be strongly homothetic while a production function that satisfies only the first condition is said to be weakly homothetic. Strong homotheticity is achieved by restricting the coefficients of the input output price parameters, $\beta_{iy} = 0$ thereby prohibiting the possibility of any output effects in production. Hence, changes in the level of output have no effect on the demand for inputs. The presence of the restriction for weak homotheticity in the translog cost function (12) implies that $\beta_{iy} = \beta_i \delta_y$ for all i, where δ is an unknown constant. Weak homotheticity of the production structure implies that input prices are weakly separable from output.

Homotheticity in production is a rather restrictive condition. Non-homothetic production technology has many structural characteristics which are less restrictive than in the homothetic case. The expansion path implicit in a non-homothetic cost function is non linear, enabling the marginal rate of technical substitution to vary over changing levels of output. In addition, the two economic properties, observed in the homothetic translog cost function (the ratio of share equations being independent of output and the elasticity of cost with respect to output being independent of factor prices) are reversed. Consequently, the ratio of any two factor share equations is not independent of the level of output and the cost elasticities with respect to output are not independent of factor prices.

The ratio of factor share equations for the translog cost function is written as

$$S_i / S_j = (\beta_i + \sum_{i=1}^{n} \beta_{ij} \ln P_i + \beta_{iy} \ln Y + \beta_{it} t) /$$

$$(\beta_j + \sum_{j=1}^{m} \beta_{ij} \ln P_j + \beta_{jy} \ln Y + \beta_{jt} t) \quad (21)$$

Equation (21) is non linear however, the individual share equations are linear.

The second property of cost elasticities, in which they are dependent on factor prices, can be used to make inferences regarding scale economies. Scale economies (SE) can be defined as unity minus the total cost elasticity with respect to total output. This relation is written as

$$SE = 1 - \partial \ln C / \partial \ln Y \quad (22)$$

where the total cost elasticity with respect to total output is defined as

$$\partial \ln C / \partial \ln Y = \beta_y + \beta_{yy} \ln Y + \sum_{i=1}^{n} \beta_{iy} \ln P_{it} + \beta_{it} t \quad (23)$$

Thus, scale economies are not independent of factor prices for the non-homothetic translog cost function. This relation implies that firms can be constrained by factor prices when expanding production output (Denny, 1974).

Scale economies as defined in equation (23) are interpreted as scale diseconomies for negative values of SE and scale economies for positive values of SE. SE must be interpreted with care, however, because SE as defined in equation (23), is not independent of the technical change parameter. Hence the two are not separable and observed cost reductions cannot be singularly attributed to technical change or to scale economies.

The non-homothetic case in production cost functions is distinctly superior to the homothetic case. This advantage is largely due to the less restrictive nature of the production technology defined by the non-homothetic case.

Separability

The property of separability among inputs is an important feature in production analysis. Separability in cost functions allows the specification of a cost function in terms of subcost functions. Independence between the marginal rates of substitution of pairs of factors in the separated group and factors outside of that group is implicit in the property of separability (Denny and Fuss, 1977). Alternatively stated, the Allen partial elasticities of substitution between a factor in the separable group and some factor outside the group are equal for all factors in the group (Denny and Fuss, 1977). An advantage of separability is that it permits the use of aggregated data in the absence of acceptable disaggregated data. However, the restrictions placed on the elasticities of substitution are a disadvantage.

There are two testable forms of separability commonly found in the literature (Denny and Fuss, 1977; Banskota, 1984; Berndt and Christensen, 1973). These are strong and weak separability. Weak separability allows input use between a cost function and a sub-cost function to be related, but only in a fixed manner. Weak separability defined in terms of the translog cost function previously discussed involves restricting parameters such that

$$\beta_{ij} = \beta_i \rho_j \tag{24}$$

where ρ is some unknown constant. Weak separability also suggests that the marginal rate of technical substitution between inputs in a subcost function is independent of input use in another subcost function.

Strong separability implies total independence between the separated group and the remaining inputs. Hence, changes in the price of the non-separable inputs will have no impact on the demand for the separated input. The relationship of strong separability can be identified by restricting the parameters of the previously described translog cost function such that

$$\beta_{ij} = 0 \tag{25}$$

Technical Change

Technical change refers to the improvement of production processes over time. Neoclassical theory describes technical change as an inward shift of isoquants while inputs and outputs are held constant. Sources of technical change include technological advancements through research and development, accumulated experience, improved management expertise and the passage of time. Technical change manifests itself in the form of reduced use of one or more inputs to achieve the same output level prior to the change or, conversely, as increased output levels from unchanged input levels. Technical change is said to be biased in a Hicksian sense if the relative proportions of inputs change. Technical change is said to be Hicks neutral if all inputs are reduced proportionately to produce the same output level.

The non-homothetic cost function described in equation (12) utilizes a time variable (t) as a proxy for technical change. Technical change is best interpreted from factor shares rather than factor proportions or the overall translog cost relationship. In terms of equation (15), defining factor shares, the β_{it} coefficient is the technical change parameter. Technical change, which is Hick's neutral, occurs when the marginal rates of technical substitution between inputs are constant over increasing output levels. Technical change is said to be factor i saving in a Hicksian sense if the marginal rate of technical substitution of input i for j declines over time. Similarly the technical change is factor i using if the marginal rate of technical substitution of i for j shows an increase over time. Thus, in terms of the given translog cost function and share equations, technical change is said to be factor i using where

$$\partial S_i/\partial t = \beta_{it} > 0, \tag{26}$$

factor neutral where

$$\partial S_i/\partial t = \beta_{it} = 0, \tag{27}$$

and factor saving where

$$\partial S_i/\partial t = \beta_{it} < 0. \tag{28}$$

Neoclassical microeconomic theory provides the foundation upon which the analytical techniques used in this study are based. The methodology used in determining estimates of the different economic indicators described herein is documented in the fourth chapter. The next chapter describes the data which will be used in conjunction with the estimation methods to develop results that can be evaluated in terms of theoretical expectations.

III. THE DATA SET: COLLECTION AND TRANSFORMATION

The translog model and estimation technique utilized in this study require a data set consisting of input price indexes as well as output and total cost data. This chapter contains the sources of the secondary data, their transformation and aggregation into indexes and the indexing procedure used. Estimation of the model utilizes a sixteen annual observation time series covering the years of 1966 through 1981. The data were obtained from two sources, Statistics Canada and Alberta Energy and Natural Resources. The length of the time series was constrained only by problems of data availability and compatibility over time.

A. DATA AQUISITION DIFFICULTIES

Although logging in Alberta is among the oldest and most primary of the provinces industries, it has only been chronicled in economic terms during the last 30 years. Throughout this brief history, a number of inconsistencies in the kinds of economic data collected have occurred to significantly reduce the amount of compatible data available.

Aquisition of data covering the province of Alberta was the major difficulty encountered in the data search. Statistics Canada has been collecting and publishing forestry data for over 40 years. However, they have tended to consider the west as two entities British Columbia and the Prairie Provinces. The majority of data from the 1960's is aggregated over the three prairie provinces. No separate provincial breakdowns are available.

Another area of difficulty in data aquisition concerned financial information related to the logging sector. Capital proved to be a particularly difficult input to obtain information on. Financial data were generally lacking and those which did exist were unavailable for reasons of confidentiality.

The traditional inadequacies associated with secondary data were abundant in this study. These included incompleteness of time series, changes in classification criteria over time, and levels of abstraction and aggregation which were unsuitable for the model.

However all of these difficulties proved surmountable. In some cases assumptions regarding data were required as were extrapolations and disaggregation. Despite the difficulties encountered, the data are used with reasonable confidence.

B. DIVISIA PRICE INDEXES

The method utilized in this analysis requires production factor inputs to be represented as price indexes corresponding to each of the inputs capital, labour, wood and fuel. There are a variety of functional forms to consider for the determination of price indexes. The use of a flexible form model (the translog) in estimation makes it advantageous to use an indexing procedure which is compatible.

The literature[2] reveals that many index number formulas represent particular production functions. The Laspeyres index (the most common index form) is exact for a linear production function which specifies *a priori* that all factors are perfect substitutes in the production process (Christensen, 1975). Clearly these restrictions of linearity and perfect substitutability are not compatible with the flexible form translog cost function.

The Divisia price index has many desirable properties and has been implemented in a majority of translog production and cost studies[3]. The continuous Divisia price index is written as

$$\partial \ln P_{it} = \Sigma_t S_{it} \partial \ln p_{it} \qquad (29)$$

where i represents the input, t is the number of periods, S_{it} represents the share of the ith input, P_{it} is the divisia index of input i, and p_{it} denotes the price of the ith input.

The discrete approximation of the Divisia price index known as the Tornqvist index can be written as

$$\ln P_t - \ln P_{t-1} =$$

[2]see Christensen (1975) and Diewert (1976) for more detailed discussions on index numbers.
[3]see Fuss (1977), Diewert (1976), and Christensen (1975).

$$\sum_{i=1}^{n} W_{it} (\ln p_{it} - \ln p_{it-1}) \tag{30}$$

where $W_{it} = (1/2)(S_{it} + S_{it-1})$ are time varying weights.

The discrete Divisia or Tornqvist index is superior to other index forms for a number of reasons. First, the weights (W_{it}) utilized in this form are flexible (i.e. not fixed), permitting variation in the expenditure pattern when input prices change. Implicit in this property is the absence of *a priori* restrictions placed on input substitution relationships. Secondly, the Divisia index corresponds to the translog functional form. Diewert (1976) has shown that the Divisia index is exact for a homogeneous translog production function which can provide a second order approximation to a twice differentiable homogeneous production function. Diewert defined index numbers, such as the discrete Divisia, which meet this criteria as "superlative".

The use of an index form such as the Divisia is essential for inputs that are aggregates of sub-categories of inputs. An example of this is the fuel input which is an aggregate of all the categories of fuels consumed by the logging sector. Divisia indexing is not essential for single input items. However, consistency must be maintained over all the inputs being indexed. Thus, the most appropriate indexing form for all the inputs in this analysis is the discrete Divisia price index.

C. INPUT PRICE INDEXES

Price of Labour

The price of labour was determined using data found in Statistics Canada's logging publication series (catalogue 25-201). Quantity of labour is expressed in terms of paid man hours devoted to logging in Alberta. The expenditure on labour was represented by the total wages paid for logging in Alberta. The total wage bill was deflated to real dollars using a GNE deflator[4]. The price of labour was then determined by dividing the real wage bill by the man hours paid. The price index of labour was then calculated using the Divisia indexing procedure as contained in the Shazam econometrics package available from the University of Alberta, Computing Services.

The data used to represent the expenditure and quantity of labour reflect only the labour input directly related to the production process. Owners or partners and workers involved in non-logging activities are excluded. The contribution of non-logging employees, although small, is essential for overall operations. However, usable data on this component of labour was not available and therefore excluded. Hence, the labour data used may understate the labour input somewhat.

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[4]The GNE deflator is available from a wide variety of sources however, the one utilized in this analysis was obtained from Agriculture Canada's Handbook of Food Expenditures, Prices and Consumption.

Man hours paid data used to represent quantity of labour can lead to an underestimate of the actual price of labour. Banskota (1984) observed that, when overtime work is taken into account man hours paid will exceed the actual hours worked according to the proportion of overtime wages to regular wages. For example, if a worker puts in two hours of time-and-a-half overtime, the man hours paid will be three hours for two hours of actual work. The use of this type of data may introduce some bias into determination of the price of labour. In times of high demand for forest products the number of overtime hours will increase but the price of labour will also increase during these periods as well. Consequently, any bias introduced should be slight. While this type of data may not be considered ideal, no data regarding worked (as opposed to man hours paid) were available in any form for Alberta logging. Further, this inadequacy of the data is of diminished significance as the bias caused by overtime applies throughout the time period. Hence, the proportion of overtime to regular hours of work in logging is assumed to be relatively constant throughout the time series.

Despite these drawbacks, the data are used with confidence because of their consistency of behavior and sources over the time period. Statistics Canada has not altered classification of labour data over the period in question. Further, the data concern only the component of labour directly related to logging production and not data indirectly related to non-logging labour activities that would otherwise provide background noise in the analysis.

Price of Capital

Measurement of the factors of production should, in theory, be in terms of services of the input per unit time (Intriligator, 1978 p. 262). Capital services have traditionally been difficult to measure and data on capital services difficult to obtain. In the absence of the ideal, (a measure of capital services), the usual procedure is to measure capital value and then deflate by a price index; in some sense this should measure the level of capital stock. This level is then adjusted by a utilization rate which gives the capital measure (Varian, 1978 p. 119).

The literature on production analysis of the forest industry contains a variety of different formulations of capital. An attempt was made to use a capital price index formulation similar to one used by Banskota (1984) or Martinello (1984). However, this attempt was abandoned for a number of reasons[5]. First, insufficient data were available to formulate capital in this manner. Measures of corporate tax rates, taxes paid by the Alberta logging industry and depreciation of logging capital were not available for

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[5]Martinello and Banskota employed elaborate indexes measuring the service prices of different forms of capital. These formulations required extensive financial data in areas such as the effective corporate tax rate, depreciation for different forms of capital, capital gains, investment tax credits, rates of return, inflation rates, etc. For further discussion of these formulations see Martinello, 1984, p. 9 and Banskota, 1984, p.70.

Alberta over the time period. Second, there was a lack of data reliability. There is no market for capital services as for the other inputs. Producers are owners of capital and capital services are either self generated or obtained from other firms. Capital exists as part of a capital stock and tends to be available in indivisible units. Services from capital as well as depreciation occur as a flow over time. These stocks and flows are affected by tax policies, interest rates, market conditions and rates of depreciation. These factors can ultimately influence the price of capital. However, accurate determination of these influences can be rather difficult. Methods determining a price of capital vary widely in the literature,[4] yet none has emerged as the best or correct method of determining a price index of capital services.

The price of capital will be determined, therefore, in a more simplistic manner in this analysis. A more simplistic approach to capital is assumed to be no less reliable than the complex formulations. This statement increases in validity as the quality and availability of data required in the complex capital formulations declines. The realities of the Alberta logging industry reinforce this premise. Logging has made a relatively small contribution to the industrial base of Alberta until quite recently. Consequently, the relative size of capital stock and services has been quite

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[4]For examples of different capital formulations see Banskota (1984), Martinello (1984), Christensen and Jorgenson (1969), and Hall and Jorgenson (1967).

small. Until the 1970's much of the logging in the province was undertaken by small independant operators whose capital input was smaller than their larger current counterparts. Therefore, to effectively capture the capital services used by the small scale operators, a more simplistic, less corporate-oriented capital price formulation is preferred. Formulation of a capital price in this analysis will incorporate the elements of capital outlined by Varian (1978, p. 119).These elements are capital stock, a deflator and a utilization rate.

The price of capital was determined in the following manner. The quantity of logging capital was calculated as a percentage of capital stock. Capital stock for logging was available from the Alberta Bureau of Statistics publication of Alberta Economic Accounts. The percentage represents the change in capital stock and was set at five percent. The purpose of the data is to capture changes in the price of capital throughout the time period. By maintaining a constant percentage over the time period the capital stock is allowed to vary over time.

The annual expenditure on capital was obtained from the capital and repair expenditures for logging published by Statistics Canada (catalogue number 25-201). This source lists expenditures as an aggregate for the prairie provinces. In order to isolate the Alberta component of capital and repair expenditures, capital was proportionately allocated according to the number of logging establishments.

Therefore, a ratio of the number of logging establishments in Alberta to the total for the prairie provinces was determined for each year of the time period. This ratio was multiplied by total capital and repair expenditure for the prairies yielding the capital and repair expenditures for Alberta. A GNE deflator was used to convert both the quantity and price of capital to real dollars. This deflator was considered more appropriate than a CPI which is more applicable for output prices. The real quantities and prices of capital were then combined to develop a discrete Divisia price index of capital using the Divisia indexing procedures available on the Shazam econometrics package.

Price of Wood

In Alberta, as in the rest of western Canada, the majority of the timber occurs on Crown land. The Crown, as landowner, delegates the responsibility of management of the forests to the Alberta Forest Service. The responsibilities of the forest service include arrangement for timber disposal as well as determination and collection of appropriate dues for the resources harvested. The dues charged by the Forest Service for timber harvested represent a cost to log producers. These dues take the form of stumpage charges,permit fees, protection charges etc. The expenditure by producers for the wood input is represented by the fees collected by the province. This information is available from the annual reports of Alberta Energy and

Natural Resources (formerly Alberta Department of Lands and Forests). Timber receipts are included in the "statement of receipts from income accounts" in their annual reports. The net timber receipts (which include dues, permit fees, protection and damage charges as well as refunds) represent expenditure on wood input by producers for this analysis, that is, this account effectively represents the total cost to the producer of the standing timber resource.

The quantity of timber harvested by the logging industry is simply the annual cut or actual harvest (as opposed to the annual allowable cut) for a given year. These data were obtained from the Alberta Forest Service, Timber Management Branch and are expressed as total annual harvest in cubic metres. The expenditure on wood was converted to real terms using the same GNE deflator and Divisia indexing procedure as used for the previous inputs.

Price of Fuel

Logging production processes utilize a variety of different machines and consequently consume a variety of different fuels. In order to represent fuel as a production input aggregation of these fuels according to some common unit is necessary. Since energy output is common to all fuels, conversion of fuel quantities to BTU's is a logical step (Banskota, 1984; Taher, 1983). The factors used to convert fuel quantities into BTU's are listed in Table 3.1.

TABLE 3.1 : FUEL CONVERSION FACTORS

FUEL TYPE	BTU CONVERSION FACTORS
Electricity	.003412 MBTU/MKWH
Liquified Petroleum Gases	99.5287 MBTU/gal
Natural Gas	875.5 MBTU/MCF
Gasoline	29.8636 MBTU/gal
Diesel and other Oil Fuels'	44.713 MBTU/gal

Abreviations: MBTU = thousands of BTU

MKWH = thousands of kilowatt hours

MCF = thousands of cubic feet

gal = imperial gallons

'An aggregate conversion factor based on the conversion factors for kerosene, light oil, heavy oil, diesel and the proportion of each fuel type from the total for oils from 1975 to 1981.

Data used to determine the price index of fuel input for logging were obtained from two separate Statistics Canada publications. Data covering Alberta logging fuels were not available for the entire time period. However, data on national logging fuel consumption were available from Statistics Canada. Thus, the proportion of fuel consumed for logging in Alberta to fuel consumed for logging in Canada was assumed to be constant. Data covering Alberta fuel consumption were obtained from Statistics Canada catalogue number 57-208 and covered the years 1975 to 1981. These data were used to determine the proportion of Alberta consumption to the rest of Canada. Data covering logging fuel consumption for all of Canada were obtained from the Statistics Canada logging publication (catalogue number 25-201). Therefore, it was possible to extrapolate Alberta fuel consumption for the years 1966 to 1975 from the national data.

The data set initially developed contained quantities for and expenditures on many different fuels. These fuels were natural gas, gasoline, diesel and other oils, liquified petroleum gases and electricity. The quantities were converted to BTU's, the expenditures were deflated to real terms and the Divisia indexing procedure was applied. Expenditures on diesel, other oils and gasoline represented approximately 90 percent of the total expenditure on fuel. As a result, a separate fuel data set comprised of gasoline and diesel only was developed and Divisia indexes calculated.

Between the two fuel index alternatives, the diesel and gasoline based index performed better in estimation. Logging is dominated by the cutting, skidding and hauling of logs and these activities require gasoline and diesel type fuels. The inclusion of other fuels reported for logging contributed to multicollinearity and decreased the significance of many of the estimates. Consequently, the gasoline and diesel index was ultimately used to represent the price of fuel in the analysis.

Output and Total Cost

The total annual volume of timber harvested in the province represents the output of the logging industry and constitutes an argument in translog production and cost functions. This output term is represented by harvest volume obtained from the Timber Management Branch, Alberta Forest Service. The quantity of wood is also used in the determination of the price of wood.

The total cost of production is the sum of the expenditures for the four inputs. Expenditures are the product of price and quantity of each input. Input cost shares are defined as the ratio of individual input expenditures to total cost.

All of the inputs, output, and total cost data as described in this chapter are used, along with the translog cost function, to develop parameter estimates for the model.

The methods of estimation used are discussed in the following chapter.

IV. ESTIMATION METHODS AND SIGNIFICANCE

A. PARAMETER ESTIMATION

The model utilized in this study is a four input non homothetic translog cost function. In its most unrestricted form this model includes technical change and output parameters in the specification of the cost function. The complete model has 21 parameters and is written as

$$\ln C = \alpha_0 + \beta_Y \ln Y + \beta_t t + \sum_{i=1}^{n} \beta_i \ln P_i +$$

$$1/2 \sum_{i=1}^{n} \sum_{j=1}^{m} \beta_{ij} \ln P_i \ln P_j + \sum_{i=1}^{n} \beta_{iY} \ln P_i \ln Y +$$

$$\sum_{i=1}^{n} \beta_{it} \ln P_i t + 1/2\beta_{tt} t^2 + 1/2\beta_{YY} (\ln Y)^2 + \mu_i \quad (26)$$

for all i,j = L,K,W,F

where L is labour, K is capital, W is wood and F is fuel.

The estimated translog cost function (equation 26) differs from the theoretical cost function (chapter 2) by a disturbance term (μ_i). This error term captures any deviations from the cost minimizing combinations of inputs which may occur due to changing input prices, technical change, contractual obligations etc. Production is assumed, however to move towards optimal input combinations over time.

The translog cost function parameters can be estimated using ordinary least squares (OLS) subject to the conditions of OLS. These assumptions are quite restrictive and are violated in the presence of heteroscedasticity, autocorrelation and multicollinearity in the estimation procedures. Thus, the use of OLS is restricted to data and models that perform in an ideal or near ideal manner[7].

Estimation of the complete translog cost function on the other hand can give rise to problems arising out of data requirements. The translog cost function, as specified for this analysis, has 21 parameters and, hence, requires a minimum of 21 observations in the data set for estimation of the full cost function. The use of the share equations in the estimation enables estimation of the parameters of the cost function without the large data requirement. This is more realistic in terms of the data available (a time series of 16 oservations).

The theoretical framework section of this analysis contained the derivation of input cost share equations from the translog cost function. The estimation of the share equations is written as

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[7]Rockel and Buongiorno (1982) used OLS to estimate translog cost functions in the absence of input cost share data and encountered problems of efficiency of estimation and multicollinearity. Also see Banskota (1984) p.40 and Madalla (1977) for further discussion of the problems observed in the estimation of translog cost functions using OLS.

$$S_i = \alpha_0 + \sum_{j=1}^{m} \beta_{ij} \ln P_j + \beta_{iY} \ln Y + \beta_{it} t + \mu_i \qquad (27)$$

for all i,j=K,L,W,F

These equations provide useful information on the behavior of the various inputs in the production process as well as reduction in the number of parameters to be estimated. Reducing the number of parameters to be estimated is accomplished by standardizing the factor shares and converting all input prices to relative prices (i.e. dividing the factor share equations by one of the factor shares). The number of share equations in the system are reduced by one thereby significantly reducing the number of parameters to be estimated.

The share equations exist as a simultaneous system of equations and, as such, are closely related to each other by the cross-equation parameters and the error terms. This two-way causality among parameters violates the assumption of OLS requiring independence between the explanatory variables and the disturbance term (Koutsoyiannis, 1977 pp. 331-336). In this situation, the explanatory variables are not truly exogenous and consequently OLS yields estimators that are biased and inconsistent. Therefore, estimation methods other than OLS must be employed for the estimation of the translog cost function and its share equations.

There are a number of estimation methods that attempt to overcome the problem of simultaneous equation bias. These include single equation methods such as indirect least squares (ILS), instrumental variables (IV), two-stage least squares (2SLS), and limited information maximum likelihood (LIML) as well as system methods such as three-stage least squares (3SLS) and full information maximum likelihood (FIML).

The method utilized in this analysis was a three-stage least squares (3SLS) estimation. This technique estimates a two-stage least squares (2SLS) estimator for each equation of the system and examines the cross correlation between the error terms of the equations to develop a seemingly unrelated regression (SUR) estimate of the system. The SUR system of equations is characterized by a zero mean and non-zero variances and covariances of the disturbance term. The discovery of this type of system is generally attributed to Zellner (1962). Estimation of a SUR system is accomplished by deleting one of the share equations and then applying the generalized least-squares method (GLS). The SUR technique provides efficient estimators. In general, the efficiency gain tends to be higher as the disturbance or error terms of the equations of the system become increasingly correlated (Judge *et al.*, 1982). If the disturbance terms are unrelated, the SUR results will be identical to those obtained by OLS. Thus, the greater the simultaneous equation bias in the system, the greater the efficiency of the SUR estimator. A 3SLS estimation procedure, as described above, is available in the SHAZAM econometrics package offered by University of Alberta Computing Services. It was used for this analysis.

The methodology described above permits estimation of the system of share equations alone or estimation of the complete system (consisting of the share equations and the cost function). The principle advantage of estimating the complete system is that the scale parameters β_{1Y} and β_{tY} which appear only in the nonhomothetic cost function are estimated. These terms are excluded when the share equations alone are estimated. Estimates of these scale parameters are useful in the interpretation of the results and hence, the complete equation system is estimated in order to estimate all parameters.

The problem of increased data requirements in estimating the unrestricted cost function (discussed above) necessitates estimation of the cost function in successive stages. Each stage tests the significance of a particular feature (nonhomotheticity, technical change, and scale effects) and enables the results to be inferred to the 21 parameter unrestricted model. Consequently, the 21 parameters of the unrestricted model are all estimated but without the use of a single-equation estimation.

B. HYPOTHESIS TESTING AND PARAMETER SIGNIFICANCE

Comparison of the various models, each with different restrictions, is achieved through the sequential testing of nested models. The nonhomothetic, non-neutral technical change translog cost function, with homogeneity in input prices and with imposed symmetry restrictions, represents the most complex and unrestricted production structure among the models evaluated. Parameters of the fully unrestricted model cannot be estimated at one time due to limitations in the size of the data set. This model is, however, the maintained hypothesis of this study and its results are inferred from the various nested models for which parameter estimation is possible.

Testing is conducted in a decreasing order of restrictiveness because of the impossibility to estimate the parameters of the complete unrestricted model directly. Estimation begins with the homothetic, Hick's neutral model and sequentially removes the restrictions of homotheticity and Hicksian neutrality in subsequent estimations. Thus, three models have parameters estimated: a restricted model which is homothetic and Hick's Neutral and two unrestricted models, one nonhomothetic and one with non neutral technical change[8].

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[8]The sequential removal of restrictions on the translog model involves setting all βit's and βiy's equal to zero for the homothetic, Hick's Neutral restricted model. For the nonhomothetic unrestricted model the βiy parameters are estimated and the βit parameters are restricted to zero while the unrestricted non neutral technical change model permits the estimation of the βit parameters and restricts the βiy parameters to zero. Thus the most unrestricted model, the nonhomothetic, non neutral translog cost function, allows the estimation of all parameters.

C. TEST STATISTICS

The comparison of the various nested models was accomplished through the use of two different tests. The log likelihood ratios for the models were evaluated and F-tests were conducted. The restricted-unrestricted F-tests were employed to test the significance of the particular structural feature in the nested models. R^2 and Durbin-Watson statistics were also used to evaluate the results of the different models. The parameters estimated were also tested individually for significance using a T-test.

The log likelihood ratio calculated for each of the models provides an indication of the overall strength of the relationship represented by the model. When comparing the likelihood values of the different nested models, the highest log likelihood values indicate the best representation of production structure by that model.

The use of restricted-unrestricted F-tests allows the comparison of two models, one restricted (for example homothetic) to a model with the restriction removed. The restricted case is the maintained hypothesis and rejection of the hypothesis indicates that the structural feature represented in the unrestricted model is significant and improves the estimation.

R^2 measures the explanatory power of the estimates of the model. It is the proportion of total variance explained by the regression. R^2 can be useful in comparing the various nested models however caution must be exercised as R^2 may increase when variables unrelated to the regression are added. Durbin-Watson statistics are calculated for each of the nested models. The Durbin-Watson test determines if autocorrelation is present in the estimation.

All of the estimation techniques and test statistics discussed in the previous sections are avilable on the SHAZAM econometrics package available through the University of Alberta Computing Services. Hence, the model estimates are readily available for interpretation as are the test statistics which allow one to determine if the estimates and their implications are significant.

V. RESULTS

The translog model of logging production developed in chapter two, estimation methods described in chapter four and the data set described in chapter three are used to obtain results representing the production structure of the Alberta logging industry. These results are described in this chapter and are prefaced by a description of the input price indexes and factor shares over the study period. A number of economic indicators are calculated in addition to the parameters estimated in the models. These include elasticities of substitution, own and cross-price demand elasticities as well as technological change biases and scale effects for the time period. The statistical significance of each parameter estimated is tested and documented. Furthermore, the significance of the different forms of the model (i.e. nested models such as homothetic and nonhomothetic etc.) are tested.

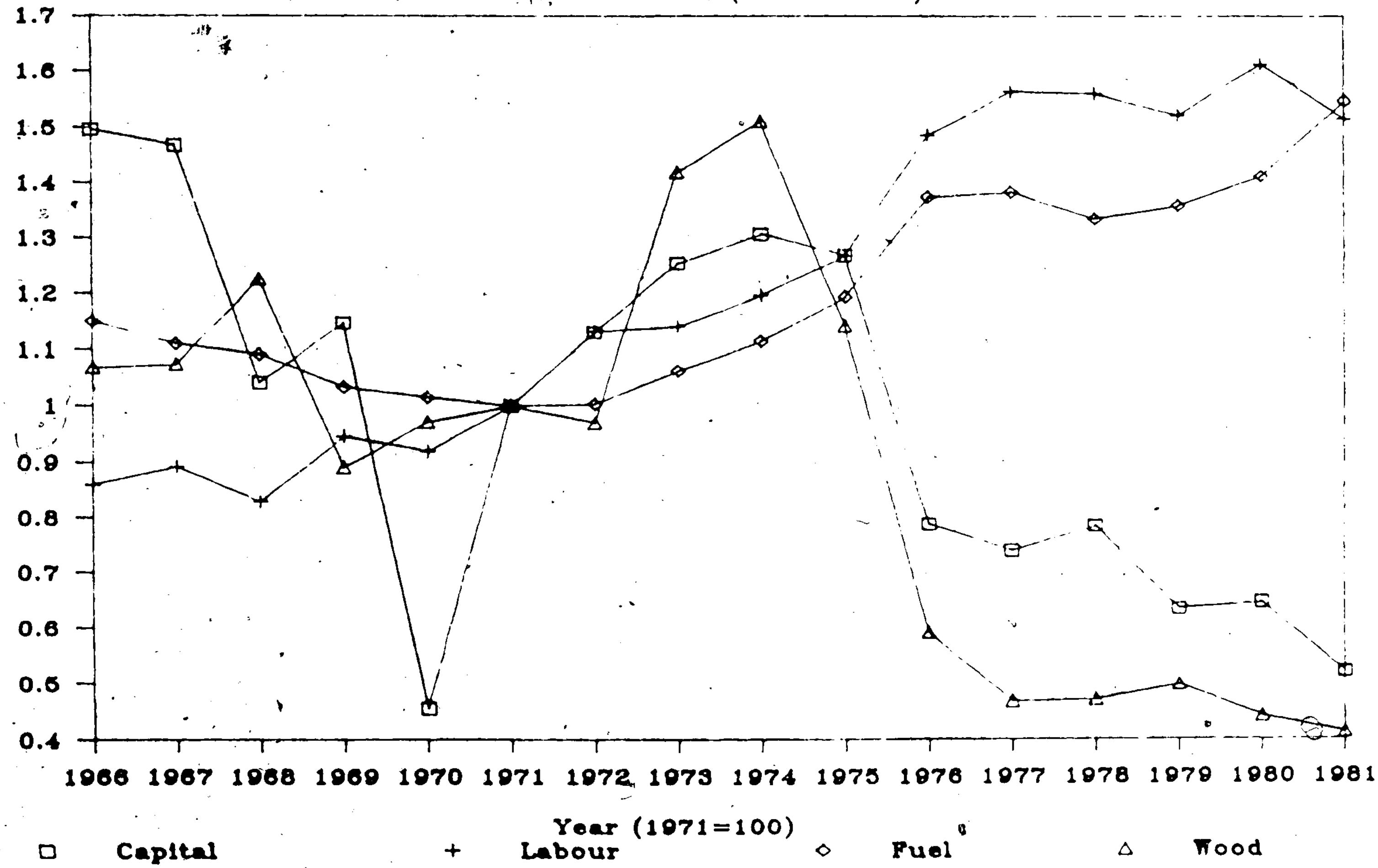
A. INPUT PRICE INDEXES AND FACTOR SHARES

The Divisia price indexes developed for each input are based on real, rather than nominal data. The removal of inflationary effects allows one to observe any input price changes or trends more accurately. The movement of input prices over the period of 1966 to 1981 is graphically displayed in Figure 5.1.

Real prices of capital and wood declined over the study period whereas real prices of labour and fuel were higher at

Figure 5.1 Logging Input Price Indexes

Alberta 1966 - 1981 (real dollars)



the end of the time period. All inputs displayed increasing price trends over the period, 1972 to 1975. This result corresponds to the period of the oil embargo and ensuing price instability.

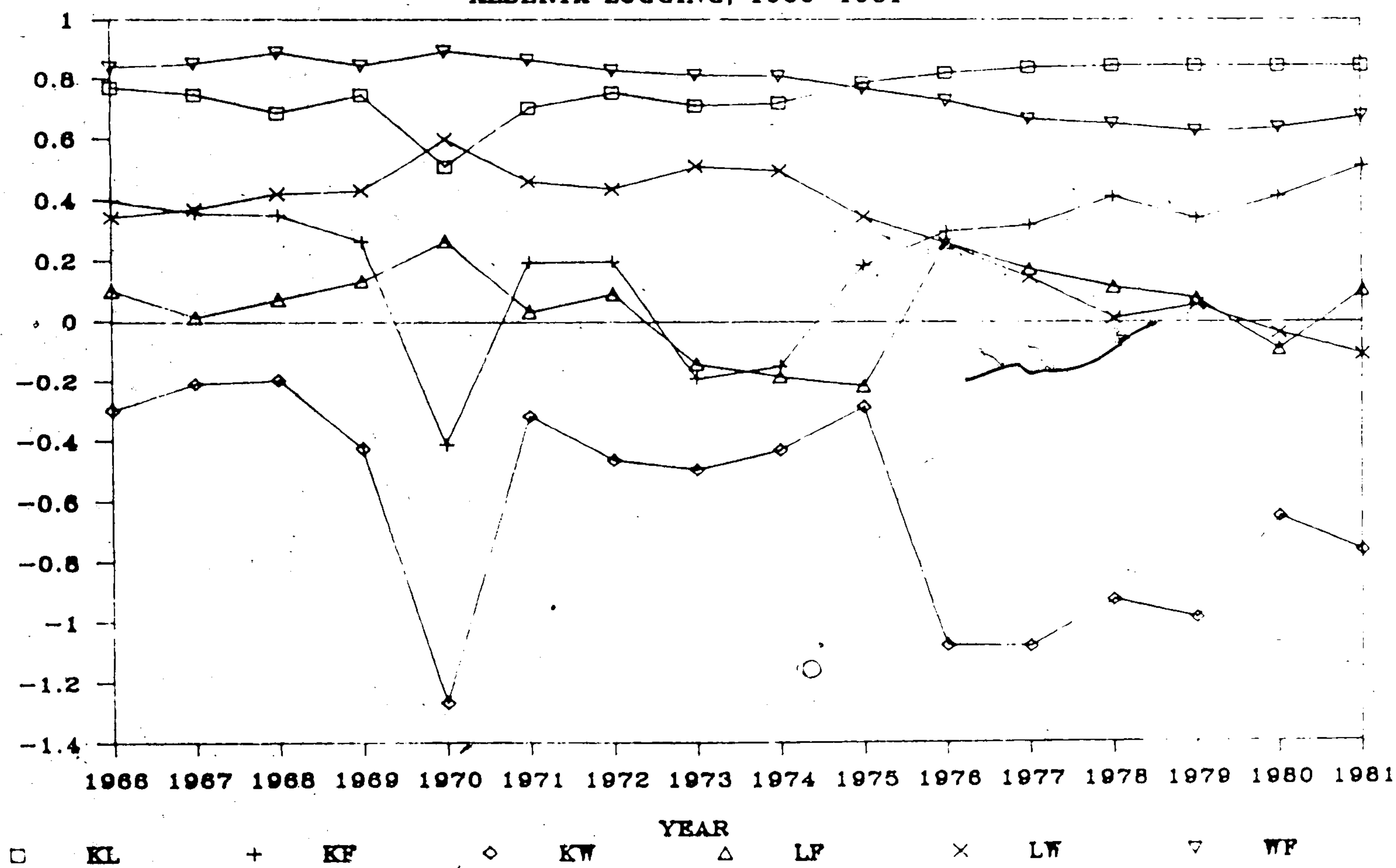
The movement in relative factor shares in logging (see Figure 5.2) was somewhat less dramatic than price movements over the same time period. Labour dominated as the largest cost component through most of the time period and showed an increasing trend. Capital also showed an increasing trend and replaced labour as the largest cost input at the end of the study period. The wood share of total cost varied widely through the 1960's until the mid 1970's when it declined sharply and leveled off. Fuel maintained a small and relatively stable cost share throughout the time period.

Capital Input

The price of capital, in addition to a general decreasing trend, showed wide variation over the time period. It also displayed significant fluctuations or deviations in price from the overall trend. The price of capital is derived from the changes in capital stock observed from year to year via expenditures on capital and repair. Since this represents changes in investment (rather than total capital investment) it is sensitive to the cyclical fluctuations that characterize the forest products market. Thus, abrupt short-run changes in the price of capital are not unexpected and may not influence the overall

FIGURE 5.3: ELASTICITIES OF SUBSTITUTION

ALBERTA LOGGING, 1966–1981



trend. The trend towards a declining price of capital arises from the technological component embodied in capital. Over time technology changes and new technology is only available through capital investment. Technological changes allow greater levels of output per unit of input. Therefore, a decreasing price of capital may occur in response to increased productivity of capital.

Capital's share of total cost (see Figure 5.2) declined from 1966 through the early 1970's after which it climbed steadily to become the dominant input in terms of its share of total cost by the end of the study period. The capital share is characterized by cyclical fluctuations which may be related to the cyclical variations observed in the forest products market. An increased capital share coupled with a declining price indicate increased capital usage in the logging industry over the period of study.

Labour Input

The price of labour showed a distinct increasing trend over the time period. This trend is characterized by cyclical fluctuations. The fluctuations range from one to four years in length and may be related to the cyclical movements of the forest industry. There is reason to believe that the price of labour responds to cyclical changes in the price of forest products (i.e. when the price of lumber falls the demand for labour in the logging industry falls, lowering the wage rate or price of labour). Labour, among the four inputs in the production function, shows the greatest increase in real price over time and, the price of labour has increased at a rate greater than the rate of inflation. This increasing price trend is reinforced by the relative cost share of labour (see Figure 5.2) which shows a slight increase over the time period. The small increase in the labour cost share of total cost (five percent) relative to the large increase in the real price of labour (approximately 60 percent) indicates reduced labour usage over the study period.

The labour share of total cost dominates over most of the study period. This input share shows fluctuations that are countercyclical to those exhibited by capital. These fluctuations, as in the case of capital, may be related to the forest product market. However, the nature of labour as an input may account for the labour cycle being dissimilar, if not opposite, to the capital cycle. When product prices fall, the effect on capital can be immediate. Investment is suspended. Labour, however, is a less mobile input and, while layoffs do eventually occur, they are not as immediate. Consequently, the capital share of declining output levels is reduced by the decline in capital investment. Labour costs, on the other hand, remain constant but make up a larger proportion of total costs. Hence, the labour cost share may rise as capital's share declines.

Wood Input

The real price of wood is based on the deflated dues collected by the province for timber harvested and the actual volume of the harvest. Stumpage dues are appraised in several different ways in the province. The structure of timber dues is dependant upon the timber disposition method employed. There are two major methods of timber disposition employed in Alberta. These are the forest management agreement (F.M.A.) and the timber quota. F.M.A. holders negotiate stumpage independently and must renegotiate occaisionally (every 5 to 10 years). F.M.A. stumpage is essentially fixed, varying only in a block fashion over time. Assessment of quota stumpage differs from F.M.A. dues in two ways. Firstly, the same formulation is used to assess all quota dues and secondly, the method of appraisal has changed during the period of this study.

Among the four input price indexes, wood shows the most dramatic fluctuations. There are sharp peaks in 1973 and 1974 followed by a steep decline and then a leveling off at an extremely low price through the remainder of the study period. These features correspond roughly with several historical events in both the marketplace and the administration of timber dues in Alberta. During the period from the late 1960's to the mid-1970's stumpage charges for quota holders were adjusted according to a three-month running average of forest product prices. As market prices for forest products increased and declined, stumpage charges were adjusted accordingly. During 1973 and 1974 lumber prices fell dramatically from month to month (see appendix A) but because the stumpage adjustment was based on a three month average there was a time lag in the adjustment of stumpage charges. As a result woods operators could experience increasing stumpage charges while market prices were actually falling. The dramatic price instability which occured during 1973-74 (possibly related to the energy crisis) caused some operators to become insolvent from the combination of excessive stumpage charges and falling prices. This result led to a re-evaluation of quota stumpage charges and establishment of the current stumpage appraisal system by the Alberta government. The current appraisal system sets a flat rate of $3.00 per MFBM that can be adjusted according to haul distance, percentage defects, and other factors that influence the revenues and costs associated with the harvest (Alberta Energy and Natural Resources, Forest Service, 1976, chapter 13). The base rate of $3.00 per MFBM (which can be reduced to a minimum of $.75 per MFBM) is not allowed to fluctuate with market conditions and thereby cannot reflect the true cost of the input to the producer. The reduced real price of wood input which is observed from 1976 through the remainder of the time period reflects the lower stumpage charges. The input cost shares of wood (see Figure 5.2) show a similar reduction from about 35 percent of input cost before 1976 to appoximately 20 percent after 1976. This change can almost certainly be attributed to the imposition of the current flat rate stumpage appraisal system used in Alberta.

Fuel Input

The real price of fuel is based upon the quantities (in BTU's) consumed and the expenditures upon gas and diesel type fuels for logging. During the study period, the real price of fuel shows an increasing price trend. There is a slight price trend decrease from 1966 to 1971 after which an increase takes place. Like the price of labour, the price of fuel increased at a rate exceeding that of inflation throughout the period. The performance of the real price of fuel during the period of the oil embargo and energy crisis (1973-1975) is noteworthy. It showed no dramatic changes of irregular movements during this period. This result may have occurred because of Canada's (and particularly Alberta's) reduced dependency on oil from the Persian Gulf compared with the U.S. due to a larger proportion of domestically produced petroleum. Consequently, only a steadily increasing price trend is observed during this period.

The relative share of fuel in total production costs is small and constant throughout the period of study. The consistency of the fuel share in light of an increasing real price indicates a reduction in the consumption but not expenditure on, fuel. Thus, the ratio of output per BTU of fuel consumed has increased over time and more efficient use of the fuel input has taken place.

B. PRODUCTION STRUCTURE PARAMETERS

Three variations of the translog production model were estimated as described in Chapter 4. The model estimated in its most restricted form is homothetic with Hick's neutral technical change. The homothetic Hick's neutral model involves a total of 11 restrictions. Under the homotheticity restrictions β_{yy} and all β_{yi} are set equal to zero while under the Hick's neutral technical change restrictions β_t, β_{tt} and all β_{ti} are set equal to zero. The two unrestricted models each have one restriction (either homotheticity or Hick's neutral technical change) relaxed. Estimation of unrestricted model which allows for non-neutral technical change determines values for the parameters β_t, β_{tt} and all β_{ti}'s. Estimates of the parameters β_{yy} and all β_{yi}'s are calculated for the unrestricted model which allows nonhomotheticity in production. In both unrestricted cases the above specified parameters are estimated in addition to the 16 parameters specified in the restricted model. The coefficient estimates for the restricted model and the two unrestricted models are listed in Table 5.1.

Estimation of the coefficients for the different models was performed as a system of regression equations consisting of a cost equation and the cost share equations with one cost share equation deleted[1]. The labour cost share was deleted in the parameter estimation. The behavior of the different labour coefficients was the most consistent among

[1] See chapter 2 for an explanation of the deletion of one cost share in estimation.

TABLE 5.1: PRODUCTION COEFFICIENTS FOR ALBERTA LOGGING COST FUNCTIONS, 1966-1981

COEFFICIENT	NON HOMOTHETIC MODEL (unrestricted)	NON NEUTRAL TECHNICAL CHANGE MODEL (unrestricted)	HOMOTHETIC, HICKS NEUTRAL TECHNICAL CHANGE MODEL (restricted)
α_0	(25.6290)	(-1822.0)	-5.4262
βy	(-3.8882)	.9249	1.1839
βk	(-.6393)	-17.5800	.3599
βl	-.3656*	6.5090	.0984
βf	(-.2337)	3.0833	-.5245
βw	(.5074)	7.9877	(.0662)
βkl	.0285*	-.0080	.0602
βkf	-.0097	-.0103	(-.0023)
βkw	-.1086	-.1183	-.1044
βkk	.0898	.1366	(.0465)
βlf	-.1097*	-.0170*	-.0460*
βlw	-.0871*	-.0700*	-.0990*
βll	.0696*	.0950*	.0848*
βfw	(-.0017)	(-.0039)	(-.0032)
βff	.0224	.0312	.0515
βww	.1973	.1922	.2066
βyk	(.0832)	-	-
βyl	.0271*	-	-
βyf	-.0239	-	-
βyw	(-.0322)	-	-
βyy	(.4135)	-	-
βt	-	(.0180)	-
βtk	-	.00009	-
βtl	-	-.00003*	-
βtf	-	-.00002	-
βtw	-	-.00004	-
βtt	-	(-.0000001)	-
Loglikelihood value	188.41	191.23	179.04
Durbin Watson Statistic	2.2232	2.1715	1.6507
R^2	.9111	.9419	.9006
F Statistic	15.938	7.303	

() indicates coefficients which are not significant at the 95% confidence level
* indicates coefficients determined algebraically using the restrictions on the equation system
all other coefficients are significant at the 95% confidence level

the inputs throughout the various estimations. Therefore, this input was believed to be the most suitable for deletion.

C. **MODEL SELECTION**

Estimation of coefficients for the different versions of the translog model enabled the statistical testing and comparison of the various sub-models nested within the translog model. Thus, the determination of a model best representing the production structure of Alberta logging was possible.

Estimation of coefficients for the models listed in Table 5.1 indicate that two of the five homothetic parameters, βyf and βyl, are significantly different from zero. Similarly four of the six technical change parameters, βtk, βtl, βtf, and βtw, are significant.

The log likelihood values listed in the lower portion of Table 5.1 indicate that the model is improved through the inclusion of homothetic and biased technical change parameters[10]. Likelihood ratio tests indicate that the non homothetic and biased technical change cost functions cannot be rejected as appropriately representing the production structure of logging.

The R^2 coefficients for the three models reinforce this result. The R^2 values for the unrestricted models are higher

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[10]See Judge, Hill, Griffeths, Lutkepohl and Lee, (1982) chapter 4 for a discussion of likelihood ratio tests and Banskota (1984), p. 80 for loglikelihood ratio testing applied to translog results.

than that of the restricted (homothetic, Hick's neutral) model. This can partially be explained by the addition of extra parameters to the unrestricted models which automatically increases their R^2 values. However, the quality of the overall regression may also be improved in the unrestricted cases.

The Durbin Watson statistics listed in Table 5.1 indicate that the possibility of autocorrelation exists for the restricted model but not for the two unrestricted models. The inclusion of nonhomothetic and biased technical change parameters improves the quality of the estimators through the elimination of autocorrelation.

Two restricted unrestricted F tests were conducted to compare models. One comparing the restricted homothetic, Hick's neutral model with the unrestricted nonhomothetic model and the other comparing the restricted homothetic, Hick's neutral model with unrestricted biased technical change model. The results of both conclude that nonhomotheticity and non neutral technical change cannot be rejected as representative of the production structure of the Alberta logging industry.

The implication from these tests is that the model which best represents the production structure of the Alberta logging industry is a non-homothetic, non-neutral technical change translog cost function. Limitations on the data set made impossible the estimation of this model as a system of equations that included a cost equation as well as cost share equations (as in the case of the other unrestricted forms). Hence, the complete unrestricted model (a 21 parameter non - homothetic, non-neutral translog cost function) is inferred from the models which estimated each feature (nonhomotheticity and non-neutral technical change) separately.

The acceptance of nonhomotheticity and non-neutrality of technical change in the specification of the production structure has several characteristics pertaining to the production process. Nonhomotheticity implies that changes in output will affect input demand functions and that there is no constraint of constant returns to scale in the logging industry. The non-neutral technical change characteristic suggests that the logging industry exhibits biased technical change in input usage. Further, the logging industry is constrained by factor prices in altering the production process and external price shocks will influence factor substitution due to the variation in the elasticity of substitution permitted by the flexible form production structure.

Estimation of the different elasticity measures utilized the parameters estimated from the fully unrestricted (nonhomothetic, non-neutral technical change) model. Since data was insufficient to estimate the complete unrestricted model (as a cost function and share equation system), only the share equation system was estimated. Although this estimation was incomplete the parameters necessary to determine all of the elasticities were estimated. These parameters are listed in appendix B.

D. TECHNICAL CHANGE AND SCALE PARAMETERS

Technical Change

Technical change parameters for all four of the production inputs were significant while those measuring technical change alone (using time as a proxy for technological change), βt and βtt, were not significant (see Table 5.1). All time coefficients were very small in magnitude. However interpretation of their signs provides useful economic information.

Technical change was capital using but labour, fuel and wood saving. This result is consistent with observed increasing input costs and technological progress. Over the study period, the occurence of the energy crisis has directed research and investment into fuel saving methods of operation. Similarily increased labour costs have led to increased automation and labour saving technology. Natural resource scarcity (i.e. timber supply) caused by increased production levels and a history of insufficient regeneration of harvested areas have inspired research into wood savings. Wood saving technologies commonly appear as increased recovery factors and an expanded range of merchantable timber (species, tree size, tree form).

Scale Effects

Scale effects measure output changes relative to input usage and price indexes. The results of the unrestricted, nonhomothetic model in Table 5.1 showed that the scale parameters for capital, wood and output were not significant at the 95 percent confidence level. The scale parameters that are significant indicate that scale is fuel saving and labour using. Both of these results are as expected for the logging industry. Logging due to its seasonal and cyclic nature, will likely respond to output changes with those inputs that are most rapidly available. Labour can readily be added to boost output levels. Fuel savings at higher output levels may be related to the technical change parameter for fuel. Technical change was found to be fuel saving. Thus, at higher output levels where investment and scale are greater, the possiblity of utilizing more fuel saving technology exists.

Although not statistically significant, the scale parameter for capital indicates that scale may be capital using. This result is expected since higher output levels have higher capital use intensities through investment in technologically advanced, high output equipment.

The scale parameter for wood, also not statistically significant, indicates that scale may be wood saving. This scale result is as expected because of the wood saving nature of technical change and the increased use of technologically advanced capital at higher levels of output.

E. FACTOR PRICE AND SUBSTITUTION ELASTICITIES

The coefficients estimated by the model permit the estimation of several different elasticities for each of the 16 years in the time period. The estimation of own-price factor demand elasticities, cross-price factor demand elasticities and elasticities of substitution is possible for all combinations of inputs.

Own Price Elasticities

Neoclassical economic theory indicates that input demand curves (or output demand curves) are well behaved when they are downward or negatively sloped. Therefore, own-price elasticity of input demand should also be of negative sign''. The own-price elasticities for the four inputs in the logging production process all have the expected negative sign except for the wood input elasticities after 1976. These results are displayed in Table 5.2.

The period of positive own-price elasticities for wood corresponds to the imposition of a flat rate stumpage appraisal system in Alberta. Although the own-price elasticities for wood are positive after 1976 the conclusion that wood becomes an inferior input after this time is invalid. Since the change in stumpage policy after 1976 institutionally fixed the stumpage price, the demand for the wood input is prohibited from behaving in a manner

''For a discussion of own-price elasticities, their determination and interpretation see Green, (1976) 53-56.

TABLE 5.2: OWN-PRICE ELASTICITIES FOR ALBERTA LOGGING INPUTS FOR SELECTED YEARS

YEAR	CAPITAL	LABOUR	FUEL	WOOD
1966	-.2028	-.3401	-.3996	-.0744
1971	-.1366	-.3406	-.3715	-.1259
1976	-.1927	-.2992	-.3444	0.1562
1981	-.2246	-.3343	-.3541	0.3240
MEAN	-.1495	-.3294	-.3180	-.0033

Source: see appendix B

consistent with economic theory. Therefore, the own-price elasticities for the wood input after 1976 do not have signs which reflect normal neoclassical input demand functions.

In addition to the sign, the magnitude of the own-price elasticity of input demand provides important economic information. All of the four inputs to logging production are inelastic over the study period (having own-price elasticities with absolute values less than one).

Prior to the imposition of flat rate stumpage the wood input was extremely inelastic, the most inelastic of the four inputs (see Table 5.2). Own-price elasticities are not considered after 1976 because of the institutional fixing of the input price[12].

Labour was the least inelastic of the four inputs with an average own-price elasticity of -.33 (one third of unitary elasticity). Labour was also the most stable of the inputs in its own-price elasticity, deviating little from its mean value over the time period.

Fuel was slightly more inelastic than labour and became more so over the study period. During the period corresponding to the energy crisis (1973-1975) the own-price elasticity of fuel declined in absolute value from -.33 in 1972 to -.19 in 1973, -.17 in 1974 and -.19 in 1975. As alternative sources of petroleum were found and the energy crisis eased, the own-price elasticity of fuel returned to its pre-energy crisis level of around -.34. The increased

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[12] The price elasticity of demand is not relevant when it is constrained in this manner

inelasticity of the fuel input during the oil embargo seems logical in light of the relative inelasticity of the fuel input and the manipulation of supply by the oil producing cartel. This would force the demand relation to become even more inelastic due to reduced quantities supplied and lack of substitutes.

Capital was more inelastic than fuel or labour over the study period. The own-price elasticity of the capital input showed an increased inelasticity during the energy crisis of the 1970's. The increased price inelasticity of capital in response to the oil embargo may be the result of the substitution of capital for fuel and the overall price instability caused by this event.

Cross-Price-Elasticities

The cross-price elasticities of demand are summarized over the study period in Table 5.3. Cross-price demand elasticities are useful in determining the substitutability or complementarity of inputs. They are proportionately related to substitution elasticities as described by the relation:

$$\eta_{ij} = S_i \sigma_{ij},$$

where η is the cross-price elasticity between inputs i and j, S_i is the share of input i and σ_{ij} is the partial elasticity of substitution between inputs i and j. Relationships between inputs are best described by the partial elasticities of substitution (Banskota, 1984) and

TABLE 5.3: CROSS PRICE ELASTICITIES FOR ALBERTA LOGGING INPUTS

INPUTS	1966	1971	1973	1976	1981	MEAN
CAPITAL-LABOUR	.268	.242	.276	.386	.321	.295
LABOUR-CAPITAL	.234	.170	.154	.237	.347	.227
CAPITAL-FUEL	.021	.010	-.007	.014	.025	.010
FUEL-CAPITAL	.120	.047	-.042	.086	.211	.078
CAPITAL-WOOD	-.088	-.116	-.177	-.208	-.123	-.157
WOOD-CAPITAL	-.090	-.076	-.108	-.311	-.315	-.181
LABOUR-FUEL	.005	.002	-.005	.012	.005	.003
FUEL-LABOUR	.035	.011	-.055	.122	.038	.021
LABOUR-WOOD	.101	.169	.183	.049	-.018	.100
WOOD-LABOUR	.112	.158	.199	.120	-.042	.111
WOOD-FUEL	.045	.044	.031	.035	.033	.037
FUEL-WOOD	.248	.317	.291	.141	.108	.222

consequently this study will place more emphasis on the interpretation of elasticities of substitution (covered in the following section).

Interpretation of cross-price demand elasticities involves considering the effect of a change in the demand for factor i, when the price of factor j changes and all other prices are held constant. When the cross-price elasticity, η_{ij}, is positive, input i is said to be a substitute for input j[13]. Similarily if η_{ij} is less than zero, input i is a complement for input j[14].

The cross-price demand elasticities in Table 5.3 are for five-year intervals over the study period. In addition, the year 1973 is reported since 1973 was the first year where the effects of the energy crisis were felt in the economy. The effect of this event is observable in some of the cross-price input demand elasticities for logging in Alberta.

Several general trends and relationships can be inferred from the cross-price elasticities. These general trends will be discussed in this section followed by a more detailed analysis in the following section on the elasticities of substitution.

All of the cross elasticities showed substitutability between pairs of inputs except for capital and wood (see Table 5.3). The complementary relationships for capital-wood

[13] However the reverse is not necessarily true, i.e. j may not be a substitute for i

[14] Again symmetry may not hold and j may not be a complement for i

(K-W) and wood-capital (W-K) increase in magnitude over the time period. Noteworthy among the substitute inputs are wood-labour (W-L) and labour-wood (L-W) which both show a shift from substitutability to complementarity of inputs at the end of the study period. There are two potential causes for this shift. First, there has been a shift away from labour through the time period due to increasing real prices of labour (discussed at the beginning of this chapter). At some point, substitution away from labour may have reached its saturation point and some inputs may have no longer been substitutable with labour. This may be a valid result for the wood input. Second, the institutional fixing of the price of wood after 1976 may have influenced the cross elasticity. This result is not unexpected, especially when one considers that the cross elasticity measures the change in input demand in response to a price change for another input. If the other input is wood and its price is fixed then the elasticity becomes invalid.

Among the other substitute inputs capital-labour (K-L) and labour-capital (L-K) show the strongest substitutability while labour-fuel (L-F) and fuel-labour (F-L) show the weakest substitutability.

The effect of the energy crisis is apparent in several of the cross elasticities involving the fuel input. The capital-fuel pairs, (K-F) and (F-K) and the labour-fuel pairs, (L-F) and (F-L), all reversed from substitution to complementarity among inputs during the energy crisis. This result may have occurred because the reduced supply and increased price of fuel caused substitution of other inputs to the extent of saturation forcing complementarity among these inputs.

Elasticity of Substitution

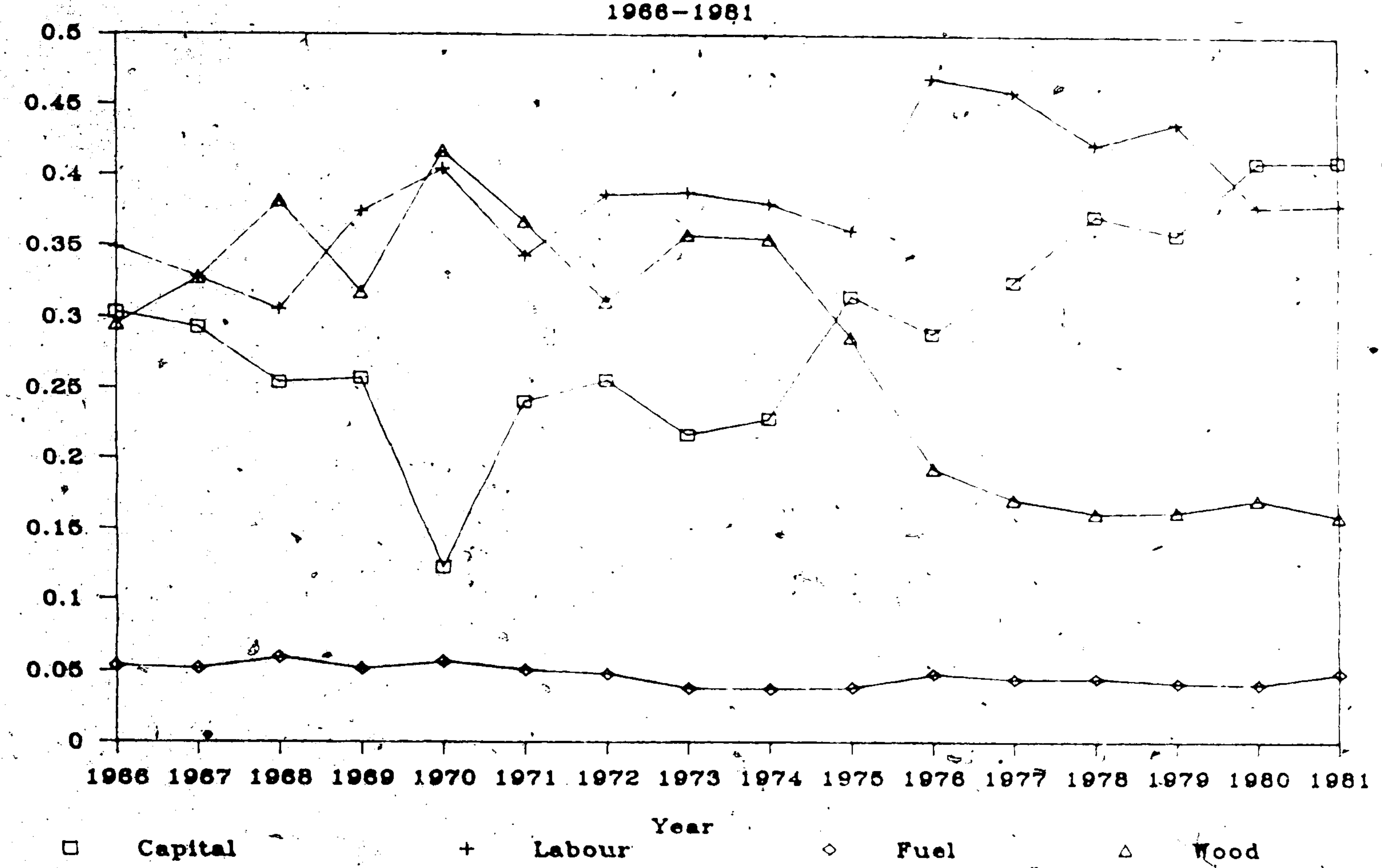
The elasticity of substitution measures the responsiveness of the ratio of two quantities to changes in the ratio of their prices (Green, 1976). Substitution elasticities differ from cross-price elasticities in that they have a forced symmetry imposed on output pairs (i.e. the elasticity of substitution of capital in response to a change in the price of labour is the reverse of the elasticity of substitution of labour when the price of capital is varied). Thus the elasticity of substitution, symbolically represented as σ_{ij}, measures the manner in which the quantities of inputs i and j change in such a way to keep a firm on the same isoquant or output level. The elasticities of substitution for logging in Alberta between 1966 and 1981 are displayed in Figure 5.3.

All of the substitution elasticities are significant at the sample means with the exception of the mean elasticity between capital and wood. The substitution elasticity for capital-wood (K-W) is not twice its standard error[15] and

[15] A common and convenient test of the significance of elasticities is to see if the value of the elasticity is twice or more than twice its standard error. If this is the case then the elasticity is significant. The use of two as a critical value is analagous to a conventional Z-test at the 95% confidence level (where the critical value is 1.96).

Figure 5.2 Alberta Logging Cost Shares

1966–1981



therefore is of dubious reliability and significance.

Significant substitute relationships exist for capital-labour (K-L) and wood-fuel (W-F). These relationships are consistent and are maintained over the duration of the study period. Substitutions between K-L and W-F are strongest among all input combinations. This result is consistent with that observed for the cross-price elasticities.

The elasticity between labour and wood shows consistent substitutability up to 1975 and then weakens until the two inputs become slightly complementary after 1980. The occurence of this change corresponds to the imposition of flat rate stumpage on the wood input. Thus the institutional fixing of the price of the wood input, which allowed its real price to decline as inflation progressed, may have reduced the substitutability between labour and wood to the point that the inputs ultimately become complements.

The elasticity of substitution between capital and fuel shows that substitutability between the inputs at the outset of the study period. At two points over the time period the sign of this elasticity reversed, indicating a shift from substitutability to complementarity. The first was in 1970 and the second was in 1973-1974. The second anomaly can likely be attributed to the energy crisis. This same

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[5] (cont'd) The standard error for the elasticity of substitution between inputs i and j is estimated as b_{ij}/S_iS_j where b_{ij} is the standard error of the β_{ij} coefficient and S_i and S_j are the shares i and j. This standard error may underestimate the true standard error since it assumes that the cost shares are fixed.

relation was observed for the cross-price elasticities involving the fuel input. The first anomaly in 1970 corresponds to a year of poor market conditions. However, poor market conditions alone do not explain the abrupt change. The raw data as well as the computed results reflect the irregularity occuring in capital in 1970. This observation cannot be readily explained and may be best regarded as an outlier. After the instability of the energy crisis, the substitutability of capital and labour strengthens increasing in magnitude for the remainder of the study period.

The elasticity between labour and fuel fluctuates between slight substitutability and slight complementarity over the study period. L-F, of all input combinations, has an elasticity which most closely approximates zero (the mean elasticity of substitution of L-F is .048, lowest of all the inputs). A zero elasticity of substitution indicates a Leontief type relation or fixed factor production (Green, 1976). The L-F elasticity shows slight substitutability over most of the time period. Slight complementarity between the inputs is observed during the period corresponding to the energy crisis and also in 1980. Overall the substitution elasticities indicate the two factors must be used in near fixed proportions with only minor substitution possible.

The elasticity of substitution for capital and wood was less than twice its standard error indicating insignificance of the elasticity. These were the only two inputs demonstrating complementarity over the entire study period (confirming the results observed for the cross elasticities of K-W and W-K). Complementarity between capital and wood was quite weak at the outset of the study period but became stronger during the energy crisis. After the imposition of a flat rate stumpage appraisal system in 1976, the complementarity between capital and wood increased dramatically and was sustained for the remainder of the study period.

F. SUMMARY

Price trends for fuel and labour show increases over the study period, 1966-1981. Capital and wood prices show decreasing price trends after 1975. Labour was the dominant cost in production accounting for 30 to 40 percent of total costs over the study period. Capital held the next largest share. Wood maintained a large cost share until 1976 after which the share dropped from about 30 percent to about 20 percent due to the imposition of flat rate stumpage. The fuel share is small and consistent over the study period.

Empirical analysis of the different production structures indicate that the model which best represents logging is a nonhomothetic non-neutral translog cost function. The results of this model were inferred rather than estimated directly.

The comparative static results from parameter estimates indicate that there is positive technical change in the logging sector. Technical change was found to be capital using and labour, fuel and wood saving. The output parameter estimates in the nonhomothetic model indicate that scale was fuel and wood saving as well as capital and labour using.

Determination of own-price elasticities revealed that all input elasticities are inelastic. Capital elasticities became more inelastic over the study period and fuel input elasticities became more inelastic during the energy crisis of the early 1970's.

Cross-price elasticities show that all input combination pairs except K-W are substitutes. The K-W and W-K pairs demonstrate increasing complementarity over the study period. The strongest input substitutability was observed for L-K combinations. The occurence of the energy crisis temporarily reversed several of the input relationships from substitutability to complementarity.

Elasticities of substitution reinforced the cross-price elasticity results. Significant substitution relationships exist between K-L and W-F . Substitutability between L-W is maintained until 1975 after which the relationship becomes slightly complementary. The elasticity of substitution of L-F is near zero indicating a fixed-factor-type of relationship. The K-W elasticity, while not significant, was the only complementary input combination over the entire study period.

The implications of these results for the logging sector of the Alberta forest industry and implications for resource management policy are discussed in the following final chapter.

VI. SUMMARY AND CONCLUSIONS

A. SUMMARY

Logging is the most primary sector of the forest industry. In Alberta there are many problems facing the forest industry which are economic in nature. Economic analysis of the forest industry is an identified area of research need. A high priority research need in Alberta is production structure. Past research has tended to neglect the logging sector and for these reasons a production analysis of Alberta logging was undertaken.

Analysis of production structure requires specification of an appropriate functional form. The translog cost model was selected for its flexibility characteristics and its favourable data requirements. The translog cost model specifies production cost as a function of the input prices of capital, labour, fuel and wood. Parameter estimates for the translog model were obtained from both the cost function and share equations. The estimated cost functions satisfied the required neoclassical conditions of positivity, monotonicity and convexity through the imposition of the appropriate theoretical restrictions.

Time-series data covering the period of 1966-1981 were used in the estimation. The four production inputs were represented as a Divisia index of quantity and expenditure for each input. All expenditure data were deflated to real dollars using a GNE index. The price of labour was a Divisia index of manhours paid and the total expenditure on wages. The price of capital was determined from the expenditure on capital and repair and a proportion of capital stock as the quantity measure. The wood index was defined in terms of the stumpage paid and volume of harvest. The price of fuel was obtained from the expenditure and quantity of gasoline and diesel fuels used in logging.

Estimation of the parameters of the model was performed in a sequential order, moving in a decreasing order of restrictiveness. The SHAZAM econometrics package, available through the University of Alberta Computing Services, was used for the estimation.

Estimation and testing of the various nested models revealed that the nonhomothetic, non-neutral technical change translog cost function best represented the production structure of the Alberta logging sector. Positive technical change, observed over the study period, was found to be capital using and labour, wood and fuel saving. Estimation of output parameters (the nonhomothetic case) indicated scale was capital and labour using and wood and fuel saving. Comparative static results indicated input demand was highly inelastic in all cases. Significant substitution relationships were observed between capital and labour. Input complementarity between capital-wood and labour-wood was also observed. The elasticity of substitution for capital-fuel indicated a substitute relationship at the outset of the study period becoming slightly complementary by the end of the period.

The implications of these results are discussed from a policy perspective in the following section of this chapter.

B. POLICY IMPLICATIONS

Price Stability

A significant finding of this analysis was the inelasticity of all the logging production inputs. Inelasticity in input demand is an expected result for logging because of its primary industry nature. The inelasticity of input demand tends to decline with the movement from primary to secondary to manufacturing industries. This result is confirmed by the findings of Banskota (1984) and Berndt and Wood (1975). Inelasticity implies an insensitivity of input demand to price changes. The own-price elasticities for logging inputs demonstrated a stable and strongly inelastic relationship over the study period. However, stability of elasticities does not necessarily infer stability in prices. Forest product prices are typically unstable. Therefore, price instability in logging may be intensified by the highly inelastic nature of the production inputs of this sector. The relative insensitivity of input demand to price changes may cause the logging sector to be significantly affected by price instability. The role of governments in dealing with this problem is quite limited. Inelasticity tends to be inherent in the structure of primary industries and particularly logging (as evidenced by the results of this study) and hence stabilization policies will have to recognize this situation. Similarly, price instability is an accepted reality in forest product markets and governments have few options other than letting the market operate freely (since market intervention, such as wage and price controls, tends to be difficult and politically unpopular). Thus, policymakers should be aware of the inelasticity in the logging sector and promote the use of inputs with somewhat more elastic supply schedules. In addition there is some expectation (although it was not observed in the results of this analysis) of declining inelasticity over time as the sector expands and input supply becomes more competitive.

Stumpage Policy

A contentious issue in Canadian forestry is currently the setting of Crown dues or stumpage. Stumpage policy in Alberta experienced a major change during the period of this study. Crown dues for F.M.A. holders have been fixed throughout the study period. Quota stumpage however, previously adjusted according to market prices, were institutionally fixed after 1976. The effect of this change is quite dramatic in both the data and subsequent results. Economic indicators, such as the own-price elasticity of wood were distorted by the institutional fixing of the wood input price. This distortion causes the market to operate in a manner inconsistent with theoretical expectations. Wood is a scarce renewable resource. The Ricardian response to resource scarcity is increased price, thereby expanding the economically accessible supply. The presence of fixed stumpage prices (i.e. declining real price) prevents the market from responding to scarcity. In a functioning market, stumpage values should follow output prices. The inflexibility of the wood price forces output price changes to be absorbed among the other inputs. This raises an issue which this study cannot conclusively address - does the institutional fixing of stumpage contribute to, or reduce price instability?

Stumpage as currently assessed in Alberta is ineffective in properly capturing the price of the timber resources used. In addition to the size of the stumpage charges (an issue not addressed in this study), the ability of stumpage to vary with output prices should be considered by policymakers attempting to reevaluate stumpage appraisal in Alberta.

Employment

Many of the results determined in the production analysis have direct implications for labour. Technical change was found to be labour saving, expansion of sector output (i.e. scale) was labour using and significant substitution between capital and labour was observed. These results indicate that there is a shift away from labour as an input to logging. This same result is widely reported in the literature (Banskota, 1984, Greber and White, 1982, and Robinson, 1975). The substitution of capital for labour in logging production is indicated by the large (0.8), slightly increasing, elasticity of substitution for K-L calculated over the study period. The strength of the substitution relationship suggests that, in the future, employment will continue to be displaced in the logging sector. This effect is reinforced by the labour saving technology constantly being brought into production. The industry tends to be driven by capital intensive technological change. Government may contribute to this trend through the promotion of capital investment in the forest industry. In Alberta, F.M.A.'s are allocated to firms willing to construct large scale, technologically advanced mill complexes. Low rents, tax concessions and other incentives are used to attract firms willing to make such large, capital intensive investments.

The effects of substitution away from labour are offset by scale effects. The scale parameters indicate that an increase in employment will occur when there is expansion in the industry. This effect, while opposite to the substitution and technical change results, may only be sufficient to prevent an exodus of labour from logging rather than generate employment in the sector. Measurement of the size of these impacts is beyond the scope of this analysis. The extent to which these effects offset each other is unknown, only their direction is certain.

Policymakers actively seek employment generating projects and policies. Further investigation of the magnitude of the above impacts is warranted for policymakers considering forest industry investment alternatives. Their impact is of particular concern in regions where communities are singularly dependant on the forest industry.

Other Policy Considerations

Many of the comparative static results determined in this analysis have implications for policy.

The elasticity of substitution for K-F showed input substitutability at the outset of the period, but slight complementarity by the end of the period. This end of period result agrees with Banskota's (1984) findings for Alberta sawmills and Berndt and Wood's (1975) results for manufacturing industries. Further information on this relationship is lacking. However, this observation may have implications for fuel tax policy in primary industries.

Complementarity was observed between wood and some of the other inputs. The partial elasticity of substitution for K-W indicated complementarity over the entire study period. The primary nature of the wood input may account for this result. Increased log utilization through capital investment in technological change is unlikely in this sector. Thus, at a primary level such as logging, capital cannot be substituted for wood. In secondary industries such as sawmilling, K-W substitution is more likely. The literature supports this finding (Banskota, 1984).

Another complementary relationship was observed for L-W. These inputs showed a fixed factor relationship over most of the study period but moved towards complementarity by the end of the study period. This result agrees with Banskota's (1984) sawmilling results. Complementarity between these inputs indicates increased wood utilization will enhance employment.

C. Synopsis

The objective of this thesis was to conduct a production analysis of the logging sector of the Alberta forest industry. The translog cost functional form was used in estimation and measures of input demand, factor substitution, technical change and scale were obtained. The overall statistical validity of the results was evaluated and the various economic measures were interpreted in policy terms. Many of the results of this study support past findings from this and other sectors of the forest industry. Other results not supported in the literature, particularly regarding stumpage in Alberta, are noteworthy. It is hoped that this thesis has contributed to the state of knowledge concerning the structure of the logging sector and may guide further research in this area.

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APPENDIX A

APPENDIX A: SELLING PRICE INDEX - ALBERTA SOFTWOOD, SPRUCE FOR EXPORT 1971-1981

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1971	79	93	98	94	94	104	111	113	104	100	104	106
1972	115	122	123	129	131	132	144	148	159	169	172	165
1973	175	182	190	202	191	191	181	184	190	176	163	155
1974	134	139	174	171	158	149	143	135	121	101	108	104
1975	101	109	110	134	154	144	145	146	143	131	136	148
1976	159	158	165	158	157	151	160	170	174	164	161	171
1977	170	169	175	174	173	177	209	232	242	218	213	226
1978	261	268	271	267	264	257	252	267	271	280	284	272
1979	279	292	299	289	292	295	309	333	354	339	299	273
1980	266	280	263	204	202	223	259	271	234	225	239	240
1981	235	236	226	240	247	256	257	250	266	213	217	218

Source: Statistics Canada cat. no. 62 - 011

APPENDIX B

APPENDIX B: SELECTED COEFFICIENTS FROM FULLY UNRESTRICTED SHARE EQUATION ESTIMATION (USED FOR ELASTICITY CALCULATIONS)

COEFFICIENT	NONHOMOTHETIC, NON-NEUTRAL TECHNICAL CHANGE MODEL (share equation system only)
βkl	-.02425
βkf	-.00376
βkw	-.11600
βkk	.14977
βlf	-.01674
βlw	-.06755
βll	.10853
βfw	-.00253
βff	.02920
βww	.18606

APPENDIX C

APPENDIX C: OWN PRICE ELASTICITIES FOR ALBERTA LOGGING INPUTS

YEAR	CAPITAL	LABOUR	FUEL	WOOD
1966	-.2028	-.3401	-.3996	-.0744
1967	-.1959	-.3411	-.3845	-.1042
1968	-.1564	-.3392	-.4471	-.1309
1969	-.1604	-.3357	-.3810	-.0959
1970	-.3426	-.3273	-.4253	-.1368
1971	-.1366	-.3406	-.3715	-.1259
1972	-.1585	-.3328	-.3394	-.0903
1973	-.0926	-.3323	-.1890	-.1220
1974	-.1164	-.3345	-.1765	-.1206
1975	-.2094	-.3384	-.1949	-.0641
1976	-.1927	-.2992	-.3444	0.1562
1977	-.2142	-.3043	-.2924	0.2566
1978	-.2254	-.3201	-.3008	0.3116
1979	-.2237	-.3143	-.2515	0.3045
1980	-.2247	-.3348	-.2368	0.2558
1981	-.2246	-.3343	-.3541	0.3240