AN ECONOMIC ANALYSIS OF LUMBER MANUFACTURING COSTS IN THE INTERIOR OF BRITISH COLUMBIA

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by

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EXECUTIVE SUMMARY

Purpose

The purpose of this study was to:

1. identify the factors which are important in determining lumber manufacturing costs;
2. estimate cost functions which can predict the effect changes in these factors would have on manufacturing costs;
3. determine how costs may vary in response to differences in timber stand characteristics resulting from silvicultural treatments; and
4. provide a potentially more accurate means of determining manufacturing costs for stumpage appraisal.

The study examines lumber manufacturing costs in the interior region of British Columbia. The lumber manufacturing costs examined includes only the cost of processing the logs into lumber and does not include delivered log costs.

Data Source

Confidential data collected by the Revenue Branch of the B.C. Forest Service in an annual survey of lumber manufacturing costs in the interior of British Columbia was obtained for use in the study. However, in order to preserve the confidential nature of the data all individual mill names, mill numbers and any other unique identifiers were deleted from the data file by the Revenue Branch before it was released. The Revenue Branch staff were committed to the preservation of respondent confidentiality and would not release any identifiable data. This report presents only summary data.

Data from the 1990, 1991, and 1992 surveys was obtained which provided a total of 175 usable observations with 58, 57 and 60 observations coming from the 1990, 1991, and 1992 surveys respectively.

In order to allow for meaningful comparisons of costs across survey years, all cost data was converted from nominal dollars to constant 1993 dollars using the GDP implicit prices deflator.

Model Development

Economic theory suggests that a cost function could be developed using a firm's output and its factor input prices as the explanatory variables. Theory further suggests that industries which had cyclical demands for their products might require some means to account for potential short-run variations from the cost minimizing factor input combination in the estimation of their cost functions. The lumber industry of the interior of British Columbia, with the derived demand for its output being largely based on the cycles of the U.S. construction industry, appears to fit this description. A measure of the firm's operating rate was included in the model to account for the effects of market fluctuations.

While mill output (Q) plus the price of capital (PK) and the price of labour (PL) can be included in the model, the price of energy, supplies, and log inputs could not due to data limitations. Thus, PL and PK were the only factor input prices included in the model. Variation in log quality is also an important determinant of mill costs and the mill's lumber recovery factor (LRF) was used as a measure of the quality of logs being fed into a mill. Thus, LRF was included as a variable in the total cost function. Finally the mill's capacity utilization (CAP) is included as the measure of the mill's operating rate. Thus, the basic model used for the firm's total cost function was:

(1) $$TC = f(Q, PL, PK, LRF, CAP)$$

The total cost function was estimated using the following multiplicative power functional form:

(2) $$TC = \alpha Q^{\beta_1} PL^{\beta_2} PK^{\beta_3} LRF^{\beta_4} CAP^{\beta_5} \varepsilon$$

Equation 2 can be transformed into a linear function by taking the natural logarithms of each side of the equation to yield:

(3) $$\ln(TC) = \ln\alpha + \beta_1 \ln(Q) + \beta_2 \ln(PL) + \beta_3 \ln(PK) + \beta_4 \ln(LRF) + \beta_5 \ln(CAP) + \ln\varepsilon$$

An average total cost function (ATC) was also estimated which used the following quadratic functional form:

(4) $$ATC = \alpha + \beta_1 Q + \beta_2 Q^2 + \beta_3 PL + \beta_4 PL^2 + \beta_5 PK + \beta_6 PK^2 + \beta_7 LRF + \beta_8 LRF^2 + \beta_9 CAP + \beta_{10} CAP^2 + \varepsilon$$

Regression Results

Equations 3 and 4 were estimated using ordinary least squares regression analysis which produced the following results:

(5) $$\ln(TC) = 15.3098 + 0.8164 \ln(Q) + 0.04457 \ln(PL) + 0.3068 \ln(PK) - 0.5199 \ln(LRF) - 0.1754 \ln(CAP) \qquad F = 788.7 \qquad R^2 = 0.96$$

(6) $$ATC = 456.17 - 0.59\,Q + 0.001341\,Q^2 + 0.1881\,PL + 2.4313\,PK - 2.0521\,LRF + 0.003418\,LRF^2 - 0.2613\,CAP \qquad F = 88.4 \qquad R^2 = 0.79$$

Both equations were highly significant and had reasonable predictive power. All estimated coefficients had the theoretically correct sign and were significant at the 95% confidence level or better.

Current Appraisal Methods

The interior stumpage appraisal system derives the value of standing timber by deducting all harvesting, transportation and manufacturing costs from the value of the lumber and chips which can be produced from the stand's timber. The value left after this net down process is used in the current appraisal system as an index of the value of the standing timber.

The estimate of lumber manufacturing costs, net of delivered wood costs, is calculated in the appraisal manual as:

(7) $$\$/m^3 = \text{Decay\%} \times 0.1321 + \text{Base Value}$$

Decay% is the percentage of merchantable volume in the stand which has been lost due to rot, as determined by the timber cruise. The base value varies by species group and appraisal zone and is derived from the annual survey of lumber manufacturing costs.

As equation 7 is expressed in dollars per volume of log input, rather than dollars per board foot of lumber output, the results must be converted to $/MBF in order to be compared to the results of this study. This can be accomplished using the average LRF for the stand as follows:

(8) $$\$/MBF = [\$/m^3] \times [1000/LRF]$$

Note however that equation 8 is not based on an empirical relationship between costs and LRF but results simply from holding cost per m^3 constant while allowing the average LRF to vary.

Potential Improvements to the Appraisal System

The cost functions presented in this report may offer a potential improvement to the way in which lumber manufacturing costs are currently estimated by providing an empirical relationship between a stand's average LRF and the resulting lumber manufacturing costs. For example, the average cost during 1992 can be estimated by substituting the industry averages for output, PL, PK and CAP reported for 1992 into the estimated cost functions . Making this substitution while holding all other variables except LRF constant at their 1992 mean values yields the following estimates of the average total cost function based on variation in LRF alone:

(9) $ATC = 2{,}234.31\ LRF^{-0.5199}$

(10) $ATC = 422.66 - 2.0521\ LRF + 0.003418\ LRF^2$

Note that these functions produce average cost estimates measured in 1993 dollars as the data on which they were based were measured in 1993 dollars.

The 1992 provincial average manufacturing cost for all species across all interior appraisal zones was $29.27/m³ which converted to 1993 dollars is $30.13/m³.

Figure 1 graphs the results of equations 9 and 10 and overlays the results of substituting the appraisal manual average cost of $30.13/m³ into equation 8. The results suggest that the average lumber manufacturing cost for stands with a high LRF may be underestimated by the current appraisal system while the average cost for stands with a low LRF may be overestimated.

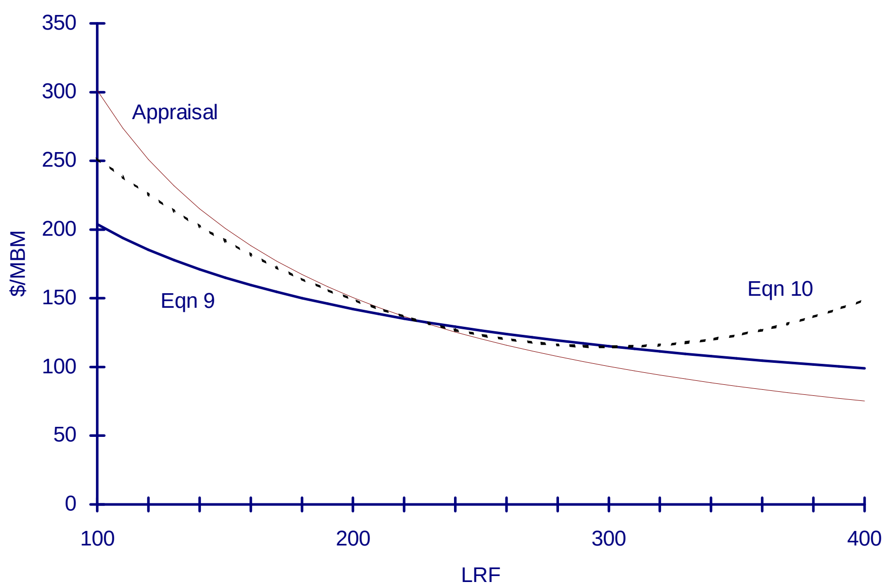

FIGURE 1
COMPARISON OF INTERIOR APPRAISAL MANUAL TREATMENT OF LUMBER MANUFACTURING COSTS WITH THE COST FUNCTION RESULTS

Effects of Silviculture Treatments on Lumber Manufacturing Costs

In order to correctly evaluate the economic efficiency of silvicultural treatments the potential effects of the treatment on lumber manufacturing costs should be incorporated into the analysis whenever the evaluation is being done based on the values of the manufactured products.

The assessment of silvicultural investments requires an estimate of the net value of the standing timber at some future harvest date. This estimate was calculated in the same manner as was done for the value index in the stumpage calculation process. The major difference being that the stumpage appraisal system deals with actual data from a timber cruise on an existing stand while silviculture investment analysis has to make projections on future stand conditions.

Projections of stand conditions are typically done using growth and yield models such as the Ministry of Forests' Tree and Stand Simulator (TASS). If an estimate of the lumber recovery for the stand can also be produced then the stand's average LRF can be calculated and used with equation 9 and 10 to provide an estimate of the lumber manufacturing cost. Fortunately some growth and yield systems now incorporate sub-systems which allow for estimates of end-product recovery. For example. the Ministry of Forests' SYLVER model takes the growth and yield information from the TASS model and simulates the bucking of the trees into logs and the sawing of lumber from the logs. Equations 9 and 10 could be incorporated directly into these models to provide estimates of manufacturing costs .

Recommendations for Further Research

Areas which may provide useful extensions to this work include:

- The incorporation of the mill's delivered log costs into the cost functions. This would show how delivered log costs would affect the cost of lumber production which together with market prices for lumber could be used to determine the economically operable forest land base.

- The potential effects of the mill's headrig type, the dimension mix produced by the mill, and the species used by the mill on lumber manufacturing cost should also be explored.

- The effect of decay on lumber manufacturing costs is deserving of special attention.

- Better data on individual mill input prices, such as wage rates and power prices, would also be likely to improve the results.

ACKNOWLEDGEMENTS

I would like to thank Alec McBeath and Neil Stuchbury for their able research assistance during the preparation of this report. I am particularly indebted to Emil Czillinger-Horvath for taking the time to explain many of the intricacies of the sawmilling process to a neophyte in the field. In addition Dave Coffey, Mike Falkiner, Gary Townsend, Steve Fletcher and Andrew Howard provided helpful comments on an earlier draft of the paper. All remaining errors are the responsibility of the author (although I'll try and blame it on someone else).

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The purpose of this study was to:

1. identify the factors which are important in determining lumber manufacturing costs;
2. estimate cost functions which can predict the effect changes in these factors would have on manufacturing costs;
3. determine how costs may vary in response to differences in timber stand characteristics resulting from silvicultural treatments; and
4. provide a potentially more accurate means of determining manufacturing costs for stumpage appraisal.

The study examines lumber manufacturing costs in the interior region of British Columbia.[1] The lumber manufacturing costs examined includes only the cost of processing the logs into lumber and does not include delivered log costs.

Information on mill processing costs is necessary for the interior stumpage appraisal system which derives the value of standing timber by deducting from the value of the lumber and chips which can be produced from the stand's timber all manufacturing, transportation and harvesting costs. The residual value left after this net down process is the value of the standing timber. Knowledge of how mill processing costs varies in response to log size would also be useful in the analysis of silvicultural treatments. As silvicultural treatments can affect average tree size and other stand characteristics, the treatments should in turn affect mill processing costs. Thus, a means of relating stand characteristics to mill processing costs would be useful.

In the remainder of this section the lumber manufacturing process is briefly described, the economic theory behind the development of cost functions is reviewed and previous research on lumber manufacturing cost functions is examined. Section 2 describes the source of the cost data and discusses its relative accuracy. It also includes definitions and summary statistics for the variables used in this study. Section 3 develops a theoretical manufacturing cost model and presents the empirical results for the estimated cost functions. The regression results are used to show how sensitive manufacturing costs are to changes in the independent variables and also to determine the firm's derived demand for labour. Section 4 discusses how the results may be used in the valuation of standing timber. An appendix examines in more detail the manufacturing cost data by manufacturing phase.

1.2 Lumber Manufacturing

Lumber manufacturing is the process by which round, tapered logs, are converted into rectangular lumber, of various dimensions and grades, and into other products such as pulp chips, sawdust, and planer shavings (Buell and McBride, [1981]). This process, shown in Figure 1-1, may involve five or more phases including log yard operations, sawmilling, kiln drying, planing, and lumber yard operations.[2] The number of phases a mill has will depend on the mill's desired product mix. Thus, a mill producing rough green lumber would not have a kiln or a planer mill. On the other hand, mills may have additional phases such as finger joining mills.[3]

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[1] The interior region is defined as the geographical area east of the Cascade Mountains (coastal mountain range) but also includes those portions of the Kalum Forest District and Cariboo Forest Region lying west of the Cascades.

[2] For greater detail on the lumber manufacturing process see Williston [1988].

[3] Finger joining mills produce larger lumber sizes by end joining smaller lumber pieces. A finger joint is an end joint made up of several intermeshing fingers bonded together with glues.

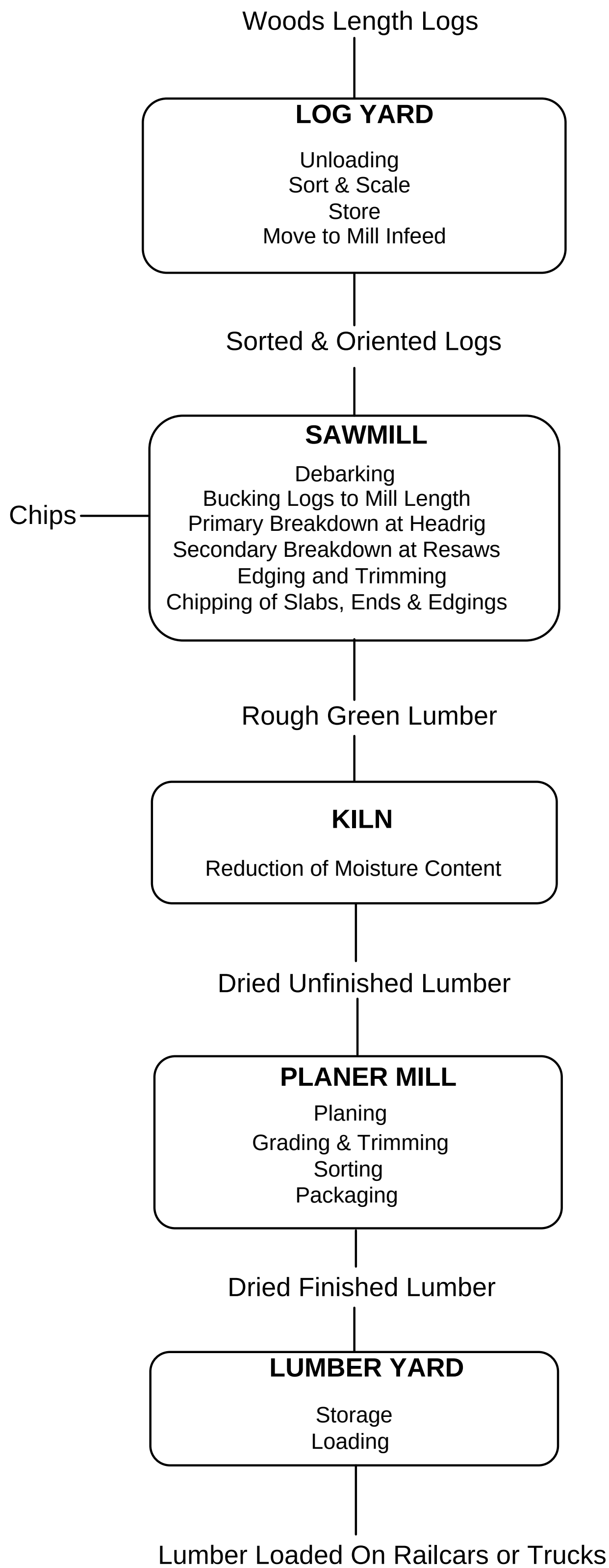

FIGURE 1-1
LUMBER PRODUCTION PROCESS

In the log yard, woods length logs arriving at the mill are unloaded, scaled for volume, sorted by species, size, and quality, stored and eventually fed into the mill's log infeed. Storage is required to ensure that the mill has an adequate supply of suitable logs in order to maintain production levels. This is particularly important in the interior of British Columbia where logs supplies may be interrupted during the spring thaw, before the fall freeze up, or during the summer fire season. Sorting allows mills to improve their downstream conversion process. Sorting by species allows for the separate processing of species or species groups. Sorting by size (diameter and length) and grade can also improve product recovery and increase mill productivity.

In the sawmill, the logs are first debarked in order to obtain bark-free pulp chips, to increase the service life of the saws, and to increase saw productivity. Next the logs are bucked (cut) from woods length (the length they arrive at the mill) into mill length (the length required to achieve the desired lumber products). At the headrig saw the primary breakdown of the log into slabs (the outer edge of the log with one flat inner face) and flitches (two parallel flat faces) occurs. The flitches proceed to resaws where secondary breakdown into desired lumber widths takes place. The flitches are edged to remove the rounded tapered edges and trimmed to length. The rough green lumber is sorted by width, thickness, length, and grade and stacked. The slabs, edgings and trim ends proceed to the chipper for conversion into pulp chips.

At the kiln the rough green lumber is dried to reduce the lumber's moisture content.[4] The moisture content of green wood, can vary from 30%, in the heartwood of some species, to 300% in the sapwood of some low-density species (Bramhall [1981]). Green lumber is considered to be any lumber with a moisture content greater than 19%, while dried lumber has a content of 19% or less (National Lumber Grades Authority [1987]). Lumber is dried to:

- provide protection against wood-staining moulds, decay-producing fungi and insect attack;
- minimize changes in lumber dimensions, such as shrink, warp, and check, after the wood is placed in service; and,
- reduce the weight of the lumber in order to minimize the cost of road and rail transportation of the lumber to markets.

The dried rough lumber proceeds to the planer mill were it is surfaced, graded, trimmed, sorted, and packaged. Planing produces a smooth finish on the lumber and ensures uniformity of width and thickness.

In the lumber yard the dried finished lumber is stored and eventually loaded onto rail-cars or trucks for shipment to markets.

1.3 Theory of the Firm and Cost Functions

<u>The Firm and Its Production Function</u>

The purpose of a firm is to organize factor inputs, such as labour, capital, and raw materials, in order to produce a product at a price desired by a market. All of the various combinations of ways in which factor inputs can be organized to produce various levels of outputs defines the firm's production possibilities set. However, not all of the production possibilities set is relevant. For example, if a level of output produced by a given combination of inputs could be produced with less of one or more of any of the inputs, then the first input combination would be an inefficient combination. The relevant or efficient portion of the set can be used to define a production function which shows the locus of minimum inputs required to produce any given level of output.[5] Equation 1-1 shows a hypothetical three input production function.

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[4] Moisture content is the weight of water in wood expressed as a percentage of the weight of oven dried wood.

[5] The discussion assumes that the production function is "well behaved" which requires that the production function be:
(a) a real valued function which is defined for all positive values of its inputs;
(b) a non-decreasing function of its inputs (i.e. any increase in inputs will not decrease output);
(c) be continuous from above for all non-negative input bundles, and

$$(1\text{-}1) \quad Q = f(L, K, M)$$

where Q = output of the firm in physical units;
L = labour input;
K = capital input; and
M = raw material inputs.

The cost of employing the factor inputs is of course the sum of all inputs multiplied by their price or:

$$(1\text{-}2) \quad C = wL + rK + pM$$

where C = total cost of production;
w = wage rate;
r = opportunity cost of capital; and
p = price of the raw material.

Economic theory suggests that a firm in a competitive market, facing competitively determined factor input prices, will act as a cost minimiser. That is, for any given level of output, they will select that combination of factor inputs that minimizes their total cost of production. In mathematical terms the firm minimizes equation 1-2 subject to the output constraint of equation 1-1 or:

$$(1\text{-}3) \quad \min_{L, K, M} \left[C = wL + rK + pM \mid Q \geq f(L, K, M) \right]$$

<u>Duality Theory and the Cost Function</u>

Deriving solutions to equation 1-3 would be cumbersome and require prior estimation of the firm's production function. Fortunately this is unnecessary, for if a firm behaves in a cost minimizing manner then, by the duality theory of Shephard [1953, 1970] and Samuelson [1947], we can specify a cost function for a firm simply in terms of its level of output and the price of its factor inputs or as:

$$(1\text{-}4) \quad C = C(Q, w, r, m) \equiv \min_{L, K, M} \left[C = wL + rK + pM \mid Q \geq f(L, K, M) \right]$$

Differentiation of the costs function of equation 1-4 with respect to output will of course yield the firm's marginal cost function while differentiation with respect to each of the factor input prices will yield, by Shephard's lemma, the firm's derived demand for each factor input.[6] For example, differentiation of the cost function with respect to the wage rate yields the firm's derived demand for labour input or:

$$(1\text{-}5) \quad \frac{\partial C}{\partial w} = L = L(Q, w, r, m)$$

(d) be strictly quasi-concave (i.e. the production function exhibits diminishing returns with respect to any single factor input).

[6] The usual assumptions of the cost function are:
(a) C is a positive real valued function defined and finite for all positive and finite values of output levels and input prices;
(b) C is a non-decreasing function of output (i.e. as output increase so does total cost) and tends to plus infinity as output tends to plus infinity;
(c) C is a non-decreasing function of input prices (i.e. an increase in the price of any input will not decrease total cost);
(d) C is linear homogeneous with respect to input prices (i.e. if all input prices doubled so would cost);
(e) C is a concave function of input prices for every positive output level.

Total Cost and Variable Cost Functions

An explicit assumption of the total cost minimization model of equation 1-4 is that firms can instantaneously adjust all factor inputs, including capital, to the cost minimizing input combination for any given output level. That is firms adjust their combination of factor inputs such that they always remain on their long-run marginal cost curve. However, this condition may not hold in the short-run which economists define as that period over which the use of at least one factor input cannot be varied and is considered to be fixed. Typically the fixed input is considered to be the firm's capital stock of land, buildings and machinery. In this case the total cost function can be broken down into variable costs (VC) and fixed costs (FC) or:

(1-6) $C = VC + FC$

Where one input is fixed, say capital, then it may not be possible to determine the firm's total cost function. However, a short-run variable cost function can be estimated which takes firm output, variable input prices and the firm's capital stock, in place of the price of capital, as the independent variables.[7] The assumption being that firms will still attempt to minimize their costs of the variable inputs subject to the fixed factor. Thus, the short-run variable cost function would be:

(1-7) $VC = VC(Q, w, m, K)$

The fixed cost will of course be equal to the capital stock times its user cost or as:

(1-8) $FC = r \times K$

Constantino and Townsend [1986] criticise this approach for arbitrarily assuming that only one input is quasi-fixed in the short-run. For example, they point out that there are costs associated with the hiring and releasing of labour which may induce the firm to maintain its pool of skilled workers in the short-run. As an alternative to the restricted variable cost function approach they modelled short-run producer behaviour based on the inclusion of an operating rate (OR). The operating rate is the ratio of actual output to capacity output which they hypothesised to be a function of unexpected sales, inventory levels and profitability. The inclusion of the operating rate thus allows for short-run departures from the long-run cost-minimizing factor input combination for all factor inputs. Thus our cost function becomes:

(1-9) $C = C(Q, w, m, r, OR)$

1.4 Factors Which Determine Manufacturing Costs

The review of economic theory points to a mill's level of production, factor input prices, and the firm's operating rate as major determinants of lumber manufacturing costs. However, the quality of the logs fed into the mill may also affect milling costs. In this case quality refers to log size, amount of log taper, and the presence or absence of defects. Figure 1-2 shows how the lumber recovery factor will increase up to a point with increasing log small-end diameter. Lumber recovery factor (LRF) is the ratio of lumber produced, measured in board feet, per m^3 of log input. The LRF curve shown is based on the LRFs listed in the interior appraisal manual (Ministry of Forests, [1994b]). As log diameter increases less wood is lost as a percentage of total log volume to slabs and edgings. Lumber recovery, for a given small end diameter, also increases with decreasing log taper as again less wood is lost in slabs. In addition, defects, such as seams, sweep, crook, rot, and fractures in the logs, can further reduce lumber recovery.[8]

[7] Factor fixed in the short-run are also known as quasi-fixed inputs and the short-run variable cost function is also known as a restricted cost function.

[8] The Ministry of Forest's scaling manual (Ministry of Forests, [1993b]) identifies the following defects which can reduce the quantity of the useful wood contained in a log:

Other factors besides log quality may also affect a mill's LRF. This can include the type of headrig used, the sawing patterns employed, the dimensions of the end-product desired, plus general mill efficiency. Nevertheless, the mill's average LRF may still serve as a useful indicator of the mill's average log quality.

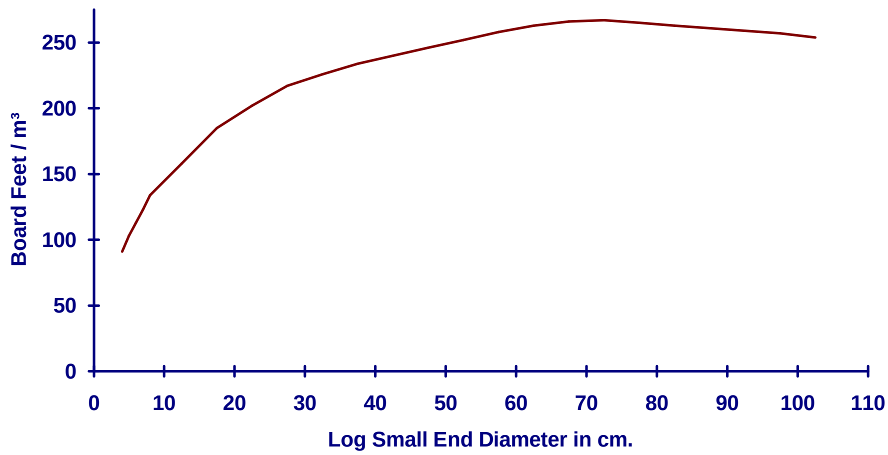

FIGURE 1-2
LUMBER RECOVERY FACTOR

1.5 Previous Research

Previous studies of lumber manufacturing costs can be roughly grouped into two categories: econometric studies and what will be referred to as engineering studies. The econometric approach attempts to develop cost functions based on observed economic variables such as prices and quantity of output. Typically these econometric studies have used data for the industry as a whole aggregated at the national or provincial level.

The engineering approach uses results from time and motion studies of different machine cost centres within a plant. The engineering approach is particularly well suited for optimising a plant's production processes and for determining the effects of design changes. A good example of this approach is given by Howard [1993]. However, the engineering approach has drawbacks which include the need for in-plant data collection and the fact that the results would only be applicable to specific mill configurations. For these reasons the remainder of this section will review only econometric studies although this does not imply that the engineering approach is without merit.

<u>Econometric Studies</u>

Previous studies of cost function for lumber industries in Canada and the U.S. includes (Stier [1980], Singh and Nautiyal [1985], Martinello [1985], Banskota *et al.* [1985], Nautiyal and Singh [1985], Merrifield and Singleton [1986], Abt [1987], and Meil *et al.* [1988]). Most of these studies

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- Seams - a seam in the bark of a tree is caused by the lack wood growth at one point on the circumference of a tree so that over time a seam of bark is left extending inward from the outer edge of a tree.
- Sweep or Crook - a sweep is a bow like bend in the trunk of the tree while a crook is a kink at one point in the stem caused by the tree losing its leader (the topmost or terminal shoot of the stem).
- Rot - the decomposition of wood caused by a variety of fungi which feed on the lignin or cellulose of the wood and which enter a tree through a root, broken branch, damaged leader or a scar on the stem.
- Fractures - wood may separate at right angles to the annual rings (check) or along the annual rings (shake) or may be damaged during logging (shatter). Lumber cannot be cut out across these separations.

have used time series data on national or regional industry costs and inputs, with the use of cross-sectional data on individual mills being rare (Banskota *et al*. is a notable exception). These studies have estimated cost functions not so much to examine costs but rather, by the principles of duality theory, to use the cost function to examine the underlying production function. Specifically the studies have been interested in examining economies of scale in the production function and elasticities of substitution amongst inputs.

Most studies assumed instantaneous adjustments in factor inputs and thus, the results represented estimates of the industry long-run cost curve. Three studies however used a restricted short-run variable cost function approach (Abt [1987], Meil *et al.* [1988], and Merrifield and Singleton [1986]).

Functional Forms

All of the studies reviewed have used the translog functional form of Christensen *et al.* [1973, 1975] to estimate the cost functions. This functional form has been popular because it meets the requirements of a well behaved cost function and provides a local second order approximation of an arbitrary functional form (Varian, [1978]). A drawback to this functional form is the requirement for the inclusion of numerous transformations of independent variables in the regressions. This means that the estimated coefficients do not easily lend themselves to economic interpretation. As the major purpose of this study was to examine how changes in the independent variables affect lumber manufacturing costs the translog functional form was not considered to be an appropriate choice.

Timber Inputs

All of the econometric studies reviewed have treated the timber input as homogenous, that is uniform in quality and physical characteristics. As discussed earlier, the quality of the timber inputs may substantially affect manufacturing costs unless the price of the logs accurately reflects these quality differences. Inclusion of some measure of log quality, such as a mill's average LRF, may be an improvement particularly when examining manufacturing costs which are net of log costs.

Outputs

Lumber output, measured in board feet, has also, by necessity, been treated as a homogenous product. In addition, the industry is treated as producing only one output - lumber, with pulp chips usually considered strictly as a by-product. Meil *et al.* [1988] deducted the value of the chips from variable costs in order to derive a net variable cost function.

SECTION 2
DATA SOURCE AND DESCRIPTION

2.1 Data Source

Confidential data collected by the Revenue Branch of the B.C. Forest Service in an annual survey of lumber manufacturing costs in the interior of British Columbia was obtained for use in the study. However, in order to preserve the confidential nature of the data all individual mill names, mill numbers and any other unique identifiers were deleted from the data file by the Revenue Branch before it was released. The Revenue Branch staff were committed to the preservation of respondent confidentiality and would not release any identifiable data. This report presents only summary data.

2.2 The Interior Lumber Manufacturing Cost Survey

The annual interior lumber manufacturing cost survey collects an extensive amount of information from each responding mill. Survey details include:

- Annual total costs by six cost centres and by six cost categories.
- Cost centres defined in the survey were:
    1. Log Yard - includes unloading, dryland sort or log pond operation, sorting in the log yard, storage and movement to the mill's log in-feed.
    2. Sawmill - includes bucking, debarking, chipping and processing into rough green stacked lumber.
    3. Kiln - kiln operating costs.
    4. Planer Mill - includes planing, grading, wrapping and stacking of dressed/dry lumber.
    5. Lumber Yard - includes moving and loading lumber from the yard to rail cars or trucks.
    6. Other - all other phases not listed under the above centres, for example finger joining.
- Cost categories defined in the survey were:
    1. Supplies - refers to all day to day supply cost, parts, small tool repair and maintenance costs but it does not include the delivered log costs.
    2. Wages - includes direct wages plus benefits paid to or on behalf of the employees. This is assumed to include only production related workers.
    3. Power - includes hydro, natural gas, diesel, propane, and konus systems[9] used for power and heat generation. The cost of company generated power was to include all variable and fixed costs.
    4. Depreciation - recorded in accordance with the company's depreciation schedule from their financial statements.
    5. Plant Overhead & Administration.
    6. Head Office Administration.
- Whole log chipping costs which were also broken down by the six cost categories.
- The number of shifts per year and the average number of employees per shift for the sawmill, planer mill, and whole log chipper.
- Total annual mill output in MBF (thousands of board feet of lumber) and annual output by each cost centre (log yard output was measured in m^3).
- The mill's annual net log consumption in m^3.
- A percentage breakdown of the logs consumed by tree species and the percent of total volume classed as reject.

Data from the 1990, 1991, and 1992 surveys was obtained which provided a total of 229 observations. Of this total 175 observations had sufficient information for use in the manufacturing cost model with 58 observations coming from the 1990 survey, 57 observations from the 1991 survey and the final 60 from the 1992 survey.

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[9] A konus system is wood waste incineration system from which energy is recovered.

In order to allow for meaningful comparisons of costs across survey years, all cost data was converted from nominal dollars to constant 1993 dollars using the GDP implicit prices deflator at market prices for British Columbia (BC STATS [1994]).

Unfortunately the survey did not collect data on delivered log costs nor did it collect data on the quantity of power used. Therefore, neither log input prices nor energy input prices could be derived for each mill. In addition this meant that the cost data was net of delivered log costs

2.3 Variable Definitions

The following variables are used in the remainder of the report:

- TC - total annual mill costs in $/year.
- TVC - total annual variable costs in $/year, which is defined as the sum of the mill's cost of supplies, wages and power.
- TFC - total annual fixed costs in $/year, which is defined as the sum of the mill's depreciation, plant overhead and head office administration costs.
- ATC - average total mill costs, in $/MBF, which equals total annual mill cost divided by total annual mill output.
- AVC - average variable costs, in $/MBF, which equals total variable cost divided by total annual mill output.
- AFC - average fixed costs, in $/MBF, which equals total fixed cost divided by total annual mill output.
- Q - total annual mill lumber production in millions of board feet (MMBF).
- LRF - annual average lumber recovery factor in board feet/m^3. Defined as total annual mill output divided by the mill's net annual log consumption.
- PL - the price of labour in $/hour, defined as total annual mill wages divided by the product of the number of shifts per year times the average number of employees per shift times an assumed average shift length of eight hours.
- PK - the unit price of capital defined as total fixed costs divided by average production per shift. The unit is $/MBF/shift.
- CAP - capacity utilization in %, defined as the number of shifts per year times 100 divided by 480. This definition is based on the assumption of an average of two shifts operating 240 days per year.
- FIXPCT - fixed cost percentage. The mill's annual fixed costs expressed as a percentage of the mill's total annual costs.
- PRODPS - average production per shift which is defined as total annual mill output divided by the number of shifts per year.
- SHIFTS - number of shifts per year.

2.4 Discussion

In assessing the quality of the data collected by the annual survey it would be reasonable to assume that mill's accurately record their costs, production levels, and log input quantities. However, there is some concern about the accuracy with which firm's recorded the number of shifts per year and particularly the average number of employees per shift. Both of these are necessary for the calculation of the mill's average wage rate. Initial data runs showed the estimated wage rates for some mill's to be outside of the $10-$60/hour range. Where a mill's average wage rate was outside of this range it was set at the upper or lower limit of the range. While the calculated average wage rate was retained for use in this study there remains some concerns about its accuracy.

Another potential area of concern is the manner in which firm's break down their cost between variable and fixed cost categories. Variation in mill accounting practices may effect the distribution of costs but should not affect total mill costs.

2.5 Summary of Survey Results

Figures 2-1 and 2-2 show the percentage distribution of total mill costs by cost centre and cost category. The sawmilling phase accounted for over half of total lumber manufacturing costs by phase and wages accounted for over half of total costs by cost category.

Table 2-1 provides a comparison of average costs by cost category over the three years for which data was obtained. Average total cost varied little, by only ± 3%, over the study period. Comparison by cost category also shows little variation.

Table 2-2 provides a breakdown of average cost per MBF of lumber produced by all respondents by phase and cost category. Table 2-3 presents the percentage breakdown of total costs for each cost centre by cost category. Variable costs accounted for roughly three-quarters of total costs across all phases except kiln operations where the significantly higher power costs brought variable costs to over 80% of total kiln costs.

Table 2-4 presents industry averages for the variables defined earlier in the section. Table 2-5 on the other hand presents mill averages for these same variables. These later averages are averages of individual mill averages which should give values representative of a "typical mill" rather than the industry average. For example, in Table 2-4, ATC is calculated as the sum of each mill's total cost divided by the sum of each mill's total output whereas in Table 2-5, ATC is the sum of each mill's average total cost divided by the number of mills.

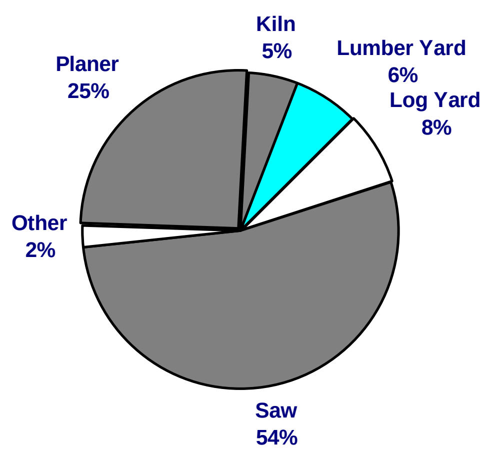

FIGURE 2-1
LUMBER MANUFACTURING COST BREAKDOWN BY COST CENTRE

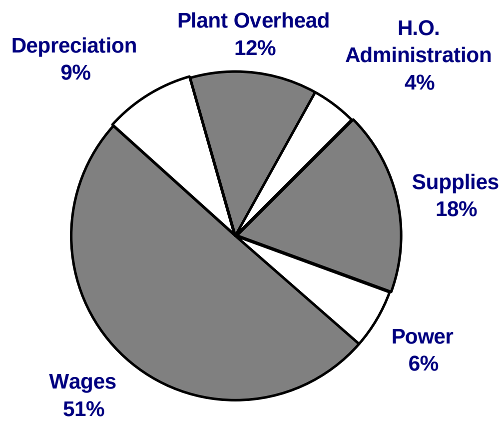

FIGURE 2-2
LUMBER MANUFACTURING COST BREAKDOWN BY COST CATEGORY

TABLE 2-1
AVERAGE COSTS BY COST CATEGORY BY YEAR
(constant 1993 $/MBF)

Cost Category	1990	1991	1992	Average 1990-92
Supplies	24.28	23.92	24.10	24.07
Wages	67.53	67.28	63.30	65.88
Power	7.83	8.52	7.87	8.05
Total Variable	99.64	99.72	95.27	98.01
Depreciation	11.46	13.12	10.79	11.93
Plant Overhead	17.08	16.94	16.05	16.64
Head Office Admin.	5.25	5.92	5.91	5.68
Total Fixed	33.79	35.98	32.75	34.25
Total Cost	133.43	135.70	128.02	132.26

TABLE 2-2
AVERAGE COSTS BY COST CENTRE AND COST CATEGORY
(1993 dollars/MBF)

Cost	Cost Centres						
Category	Log Yard	Saw	Kiln	Planer	Lumber Yard	Other	TOTAL
Supplies	3.28	10.70	1.49	5.50	2.52	0.59	24.07
Wages	4.22	37.02	1.87	17.39	3.97	1.41	65.88
Power	0.12	4.13	2.43	1.16	0.09	0.12	8.05
Total Variable	7.62	51.85	5.79	24.05	6.58	2.12	98.01
Depreciation	0.82	7.02	0.56	2.52	0.56	0.45	11.93
Plant Overhead	1.19	9.25	0.47	4.42	1.07	0.24	16.64
Head Office	0.40	3.24	0.16	1.51	0.35	0.03	5.68
Total Fixed	2.41	19.51	1.18	8.44	1.98	0.72	34.25
TOTAL	10.03	71.37	6.97	32.49	8.56	2.84	132.26

TABLE 2-3
PERCENTAGE DISTRIBUTION OF TOTAL COSTS BY COST CENTRE AND COST CATEGORY
(percent)

Cost	Cost Centres						
Category	Log Yard	Saw	Kiln	Planer	Lumber Yard	Other	TOTAL
Supplies	32.73	15.00	21.32	16.92	29.40	20.68	18.20
Wages	42.05	51.88	26.83	53.53	46.35	49.73	49.81
Power	1.16	5.79	34.88	3.57	1.10	4.21	6.09
Total Variable	75.94	72.67	83.03	74.02	76.86	74.62	74.11
Depreciation	8.20	9.84	7.96	7.76	6.53	15.82	9.02
Plant Overhead	11.91	12.95	6.70	13.59	12.51	8.63	12.58
Head Office	3.95	4.54	2.31	4.63	4.10	0.94	4.30
Total Fixed	24.06	27.33	16.97	25.98	23.14	25.38	25.89
Cost Centre Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
% of Grand Total	7.58	53.96	5.27	24.57	6.47	2.15	100.00

TABLE 2-4
PRODUCTION VARIABLE INDUSTRY AVERAGES BY YEAR

Variable	Units	1990	1991	1992	1990-92
Q	MMBF/year	120.32	110.24	116.58	115.73
ATC	$/MBF	133.43	135.70	128.02	132.26
AVC	$/MBF	99.64	99.72	95.27	98.01
AFC	$/MBF	33.79	35.98	32.75	34.25
LRF	BF/m³	191.11	211.61	240.45	212.97
PL	$/hour	24.60	26.07	23.15	24.53
PK	$000/MBF/shift	17.68	18.34	16.30	17.40
CAP	%	108.00	100.96	103.07	103.99
FIXPCT	%	25.24	27.38	25.57	26.04
PRODPS	MBF/shift	232.09	227.49	235.64	231.84
SHIFTS	number/year	518.40	484.61	494.73	499.17

TABLE 2-5
MILL AVERAGES BY YEAR

Variable	Units	1990	1991	1992	1990-92
Q	MMBF/year	120.32	110.24	116.58	115.73
ATC	$/MBF	147.27	147.75	137.58	144.08
AVC	$/MBF	109.91	108.83	103.41	107.32
AFC	$/MBF	37.35	39.21	34.17	36.86
LRF	BF/m³	233.16	232.46	238.33	234.71
PL	$/hour	29.90	30.62	29.42	29.97
PK	$000/MBF/shift	20.12	19.69	16.76	18.82
CAP	%	108.00	100.96	103.07	103.99
FIXPCT	%	25.29	26.66	24.74	25.55
PRODPS	MBF/shift	229.21	223.35	234.26	229.01
SHIFTS	number/year	518.40	484.61	494.73	499.17

SECTION 3
MANUFACTURING COST MODEL

3.1 Introduction

In Section 1, the economic theory of cost functions was reviewed which suggested that a cost function could be developed using a firm's output and its factor input prices as the explanatory variables. Section 1 further suggested that in the estimation of cost functions for industries which had cyclical demands for their products, and thus frequent excess capacity, might require some means to account for potential short-run variations from the cost minimizing factor input combination. The lumber industry of the interior of British Columbia, with the derived demand for its output being largely based on the cycles of the U.S. construction industry, would certainly appear to fit this description as confirmed by the results of Meil *et al.* [1988]. The inclusion of a measure of the firm's operating rate, as suggested by Constantino and Townsend [1986] may satisfy this requirement.

3.2 Model Description

While mill output (Q) plus the price of capital (PK) and the price of labour (PL) can, with some concerns about the latter's accuracy, be included in the model, the price of energy, supplies, and log inputs could not due to data limitations. Thus, PL and PK were the only factor input prices included in the model. Variation in log quality was described in Section 1 as an important determinant of mill costs and the mill's lumber recovery factor (LRF) was suggested as a useful measure of the quality of logs being fed into a mill. Thus, LRF was included as a variable in the total cost function. Finally the mill's capacity utilization (CAP) is included as the measure of the mill's operating rate. Thus, the basic model used for the firm's total cost function was:

(3-1) $TC = f(Q, PL, PK, LRF, CAP)$

The usual requirements of a well behaved cost function, i.e. increasing in output and non-decreasing in input prices, requires that the first partial derivatives of equation 3-1 with respect to Q, PL and PK all be positive. An increase in LRF implies increasing quality of the log inputs which should imply lower milling costs. This implies that the first partial derivative of the cost function with respect to LRF should be negative. As capacity utilization increases the firm's average fixed costs should fall which implies that the sign of the partial derivative with respect to CAP should be negative. Thus, the expected signs of the first partial derivatives of the total costs functions were:

$$\frac{\partial TC}{\partial Q} > 0, \quad \frac{\partial TC}{\partial PL} > 0, \quad \frac{\partial TC}{\partial PK} > 0, \quad \frac{\partial TC}{\partial LRF} < 0, \text{ and } \quad \frac{\partial TC}{\partial CAP} < 0.$$

The firm's variable cost function (TVC) was modelled using the same variables as the total cost function.

(3-2) $TVC = f(Q, PL, PK, LRF, CAP)$

The expected signs of the variable cost function's first partial derivatives are the same as for the total cost function with the sole exception of the derivative with respect to CAP, which may be positive. This may result from the exclusion of fixed costs, which are expected to fall as capacity increases, plus the potential for rising labour costs as a mill moves past an average of two shifts per day or has to rely on increases in over time.

Initial regressions of total fixed costs using the same independent variables as were used in the total cost model showed that there was a strong positive correlation between the regression residuals and the mill's reported fixed costs. This suggested that there may be a problem resulting from a missing variable. There may in fact be two problems at work. First there may be errors in measurement of fixed costs as there is a certain arbitrariness to the assignment of costs to fixed or variable categories. Variation in mill accounting practices may cause some of the variation. The second problem may lay in the mill's actual production rates being in disequilibrium with respect to the mill's expectations of their output levels.

To account for both of these problems a new variable FIXPCT, which is the percentage of a mill's total cost assigned to fixed costs, was constructed. If an individual mill's accounting practices assign a greater share of total cost to fixed costs then FIXPCT may pick up this variation. Similarly, if a mill's current output is in disequilibrium with respect to the expected output level then FIXPCT should vary from the average for all mills. Thus, the model selected to predict a mill's fixed costs was:

(3-3) TFC = f(Q, PL, PK, LRF, FIXPCT)

The expected signs of the fixed cost function partial derivatives were:

$$\frac{\partial TFC}{\partial Q} > 0, \quad \frac{\partial TFC}{\partial PL} > 0, \quad \frac{\partial TFC}{\partial PK} > 0, \quad \frac{\partial TFC}{\partial LRF} < 0, \text{ and } \frac{\partial TFC}{\partial FIXPCT} > 0.$$

The total cost, variable and fixed cost models of equations 3-1 to 3-3 were estimated using two functional forms. One form was used for estimating total cost (TC) total variable cost (TVC) and total fixed cost (TFC) and another for estimating average total cost (ATC) average variable cost (AVC) and average fixed costs (AFC).

Total, Variable and Fixed Cost Functions

The total cost, variable cost and fixed cost functions were estimated using a Cobb-Douglas or multiplicative functional form as shown in equations 3-4 to 3-6:

(3-4) $TC = \alpha Q^{\beta 1} PL^{\beta 2} PK^{\beta 3} LRF^{\beta 4} CAP^{\beta 5} \varepsilon$

(3-5) $TVC = \alpha Q^{\beta 1} PL^{\beta 2} PK^{\beta 3} LRF^{\beta 4} CAP^{\beta 5} \varepsilon$

(3-6) $TFC = \alpha Q^{\beta 1} PL^{\beta 2} PL^{\beta 3} LRF^{\beta 4} FIXPCT^{\beta 5} \varepsilon$

where α and β_1 to β_5 are the coefficients to be estimated and ε is a stochastic error term.

Equations 3-4 to 3-6 can be transformed into a linear model by taking the natural logarithms of each side of the equations to yield:

(3-7) $\ln(TC) = \ln\alpha + \beta_1 \ln(Q) + \beta_2 \ln(PL) + \beta_3 \ln(PK) + \beta_4 \ln(LRF) + \beta_5 \ln(CAP) + \ln\varepsilon$

(3-8) $\ln(TVC) = \ln\alpha + \beta_1 \ln(Q) + \beta_2 \ln(PL) + \beta_3 \ln(PK) + \beta_4 \ln(LRF) + \beta_5 \ln(CAP) + \ln\varepsilon$

(3-9) $\ln(TFC) = \ln\alpha + \beta_1 \ln(Q) + \beta_2 \ln(PL) + \beta_3 \ln(PK) + \beta_4 \ln(LRF) + \beta_5 \ln(FIXPCT) + \ln\varepsilon$

The expected signs of all coefficients to be estimated were positive except for the coefficient for LRF in all equations and the coefficient for CAP in the total cost function.

Average Total, Average Variable and Average Fixed Cost Functions

The average total, average variable and average fixed cost functions were estimated using a quadratic functional form as shown in equations 3-10 to 3-12. This functional form while linear in coefficients still allows for non-linear variation in the dependent variable in response to changes in the independent variables.

(3-10) $$ATC = \alpha + \beta_1 Q + \beta_2 Q^2 + \beta_3 PL + \beta_4 PL^2 + \beta_5 PK + \beta_6 PK^2 + \beta_7 LRF + \beta_8 LRF^2 + \beta_9 CAP + \beta_{10} CAP^2 + \varepsilon$$

(3-11) $$AVC = \alpha + \beta_1 Q + \beta_2 Q^2 + \beta_3 PL + \beta_4 PL^2 + \beta_5 PK + \beta_6 PK^2 + \beta_7 LRF + \beta_8 LRF^2 + \beta_9 CAP + \beta_{10} CAP^2 + \varepsilon$$

(3-12) $$AFC = \alpha + \beta_1 Q + \beta_2 Q^2 + \beta_3 PL + \beta_4 PL^2 + \beta_5 PK + \beta_6 PK^2 + \beta_7 LRF + \beta_8 LRF^2 + \beta_9 FIXPCT + \varepsilon$$

3.3 Regression Results

The linear in logarithms transformation of the total, variable and fixed cost functions and the quadratic average total, variable and fixed cost functions were estimated using ordinary least squares regression analysis. After initial regression runs, influence diagnostics of the regression observations suggested that one observation was an outlier.[10] This observation was deleted from the data set leaving a total of 174 observations. Table 3-1 presents summary statistics for the regression observations.

TABLE 3-1
SUMMARY STATISTICS FOR THE REGRESSION OBSERVATIONS

Variable Name		Mean	Standard Deviation	Minimum Value	Maximum Value
TC	($/yr)	15,305,823.00	6,510,462.00	2,677,141.00	32,973,641.00
TVC	($/yr)	11,344,885.00	4,867,911.00	2,266,143.00	23,006,934.00
TFC	($/yr)	3,985,091.00	2,087,319.00	410,999.00	11,197,968.00
ATC	($/MBF)	144.09	34.45	87.65	268.60
AVC	($/MBF)	107.32	27.64	65.06	206.48
AFC	($/MBF)	36.86	13.58	11.83	95.64
Q	(MMBF/yr)	115.73	61.20	14.33	308.32
LRF	(BF/m³)	234.71	26.44	160.00	320.00
PL	($/hour)	29.97	14.20	10.00	60.00
PK	($000/MBF/shift)	18.82	6.52	3.99	40.28
CAP	(%)	103.99	25.52	38.54	170.83
FIXPCT	(%)	25.55	6.97	9.93	55.46

[10] Influence diagnostics measures the influence that each observation has on the estimated coefficients. One tests is the DFFITS statistic which is a scaled measure of the change in the predicted value for the i^{th} observation. A large value for DFFITS indicates that the observation is very influential in its neighbourhood. A cut-off value of 2, as recommended by Belsley *et al*. (1980), was used to indicate outliers.

Total, Variable and Fixed Cost Functions

The regression results for the total, variable and fixed cost functions are presented in Table 3-2. The results for all estimated equations are highly significant, as indicated by the F statistic, which allows for rejection of the null hypothesis that all coefficients are not significantly different from zero. The coefficient of determination (R^2) and the adjusted R^2, suggest that the equations also have a high degree of "explanatory" power.[11] All coefficients have the theoretically correct sign and all are significant at the 95% confidence level or better.

Figure 3-1 presents a scattergram of the predicted value of ln(TC) against actual values of ln(TC), while Figure 3-2 shows a scattergram of the residuals (predicted value - actual value) against actual values of ln(TC). Neither diagram suggests any problems with missing variables, wrong functional form or any other violation of the assumptions of classical linear regression. Figures 3-3, 3-4, 3-5 and 3-6 present the same scattergrams for the both the total variable and fixed cost functions which suggest that the same conclusions can be reached for these functions.

TABLE 3-2
TOTAL COST, VARIABLE COST AND FIXED COST FUNCTION REGRESSION RESULTS

Independent Variables	Dependent Variables ln(TC)	ln(TVC)	ln(TFC)
Intercept	15.3098 (31.242)a	15.9073 (24.494)a	9.5553 (19.785)a
ln(Q)	0.8164 (43.521)a	0.7675 (30.871)a	0.762 (47.210)a
ln(PL)	0.04457 (2.699)a	0.06316 (2.886)a	0.05296 (3.101)a
ln(PK)	0.3068 (13.113)a	0.08822 (2.845)a	0.327 (10.381)a
ln(LRF)	-0.5199 (6.015)a	-0.7843 (6.847)a	-0.3661 (3.840)a
ln(CAP)	-0.1754 (4.602)a	0.1145 (2.267)b	-
ln(FIXPCT)	-	-	0.8959 (21.730)a
F	788.711	418.940	1181.326
R^2	0.959	0.926	0.972
Adj. R^2	0.958	0.924	0.972

Values in brackets are the absolute value of the "t" statistic for the estimated coefficients.
a - significant at the 99% confidence level.
b - significant at the 95% confidence level.

[11] The adjusted R^2 is the R^2 after adjustment for the degrees of freedom, i.e. the number of independent variables contained in the regression.

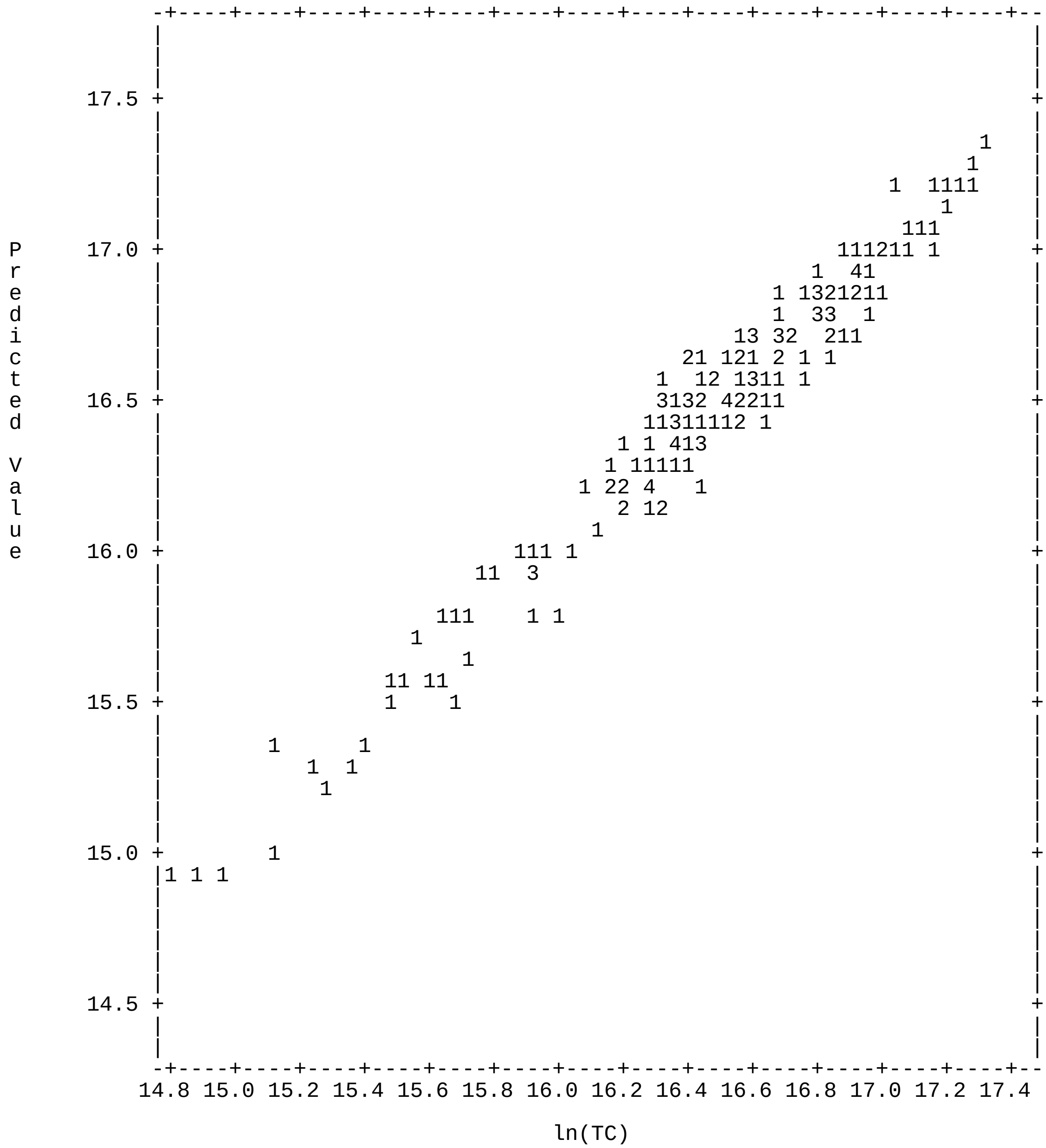

FIGURE 3-1
PLOT OF PREDICTED ln(TC) AGAINST ACTUAL ln(TC)

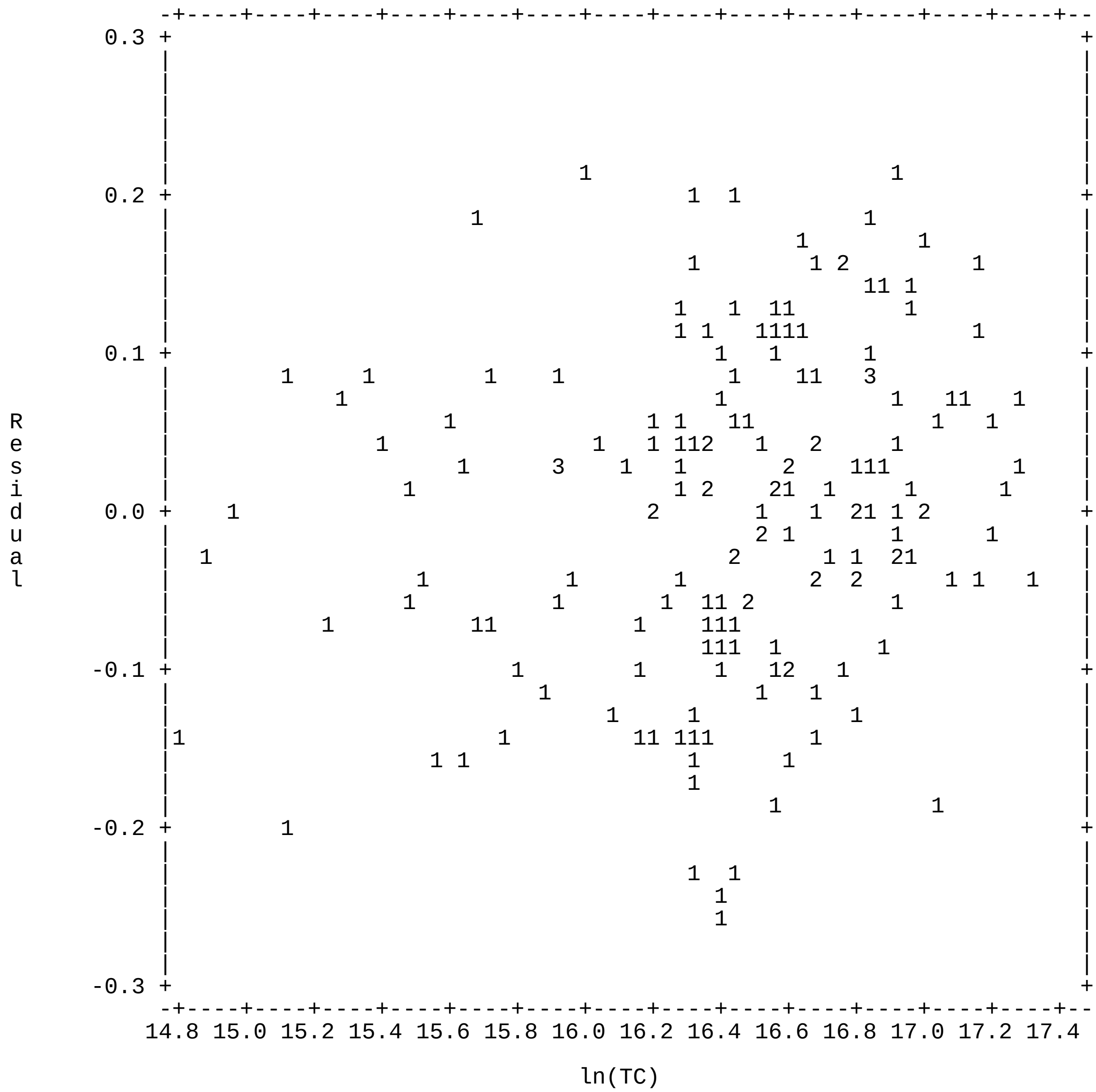

FIGURE 3-2
PLOT OF RESIDUALS AGAINST ACTUAL ln(TC)

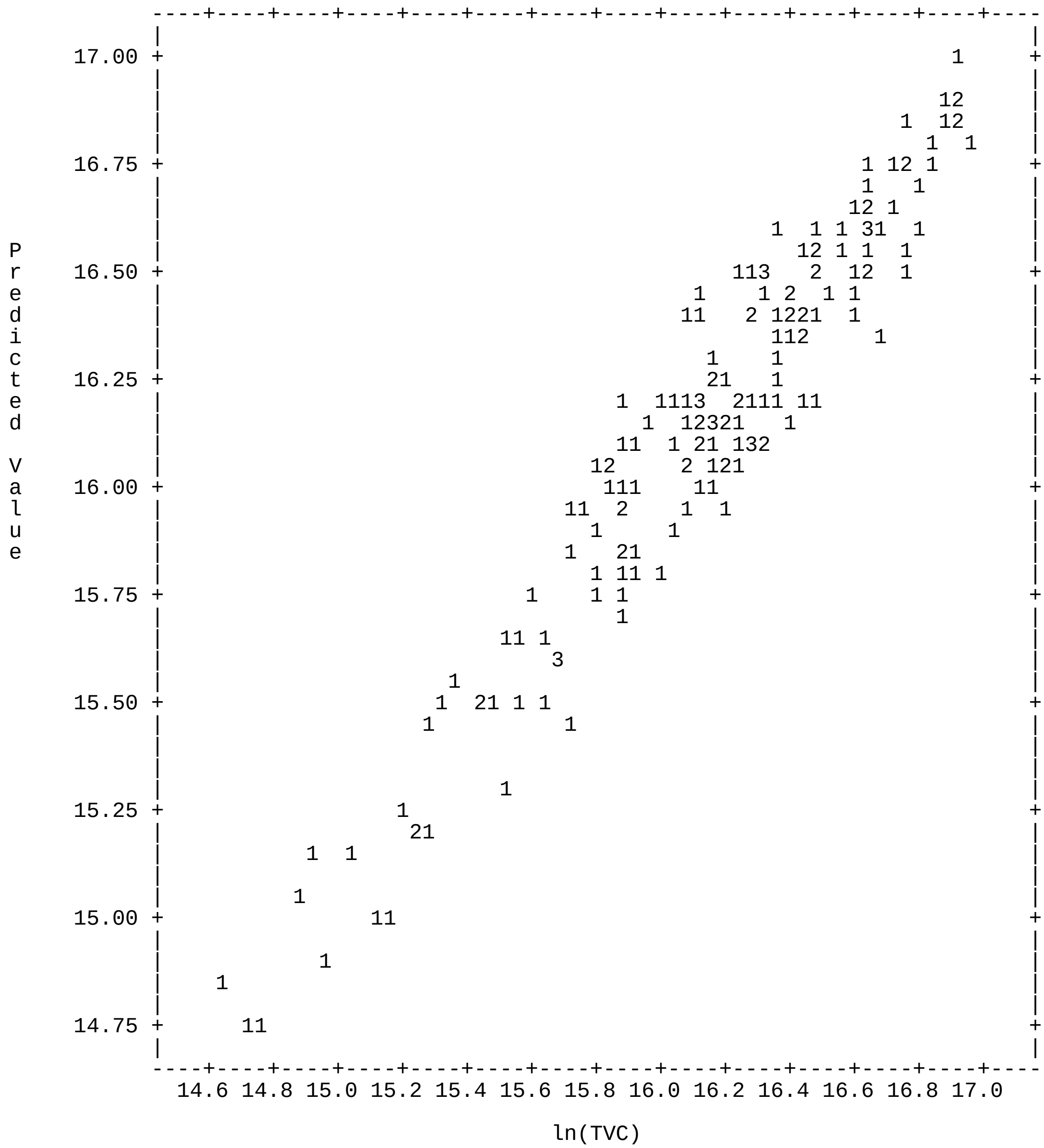

FIGURE 3-3
PLOT OF PREDICTED ln(TVC) AGAINST ACTUAL ln(TVC)

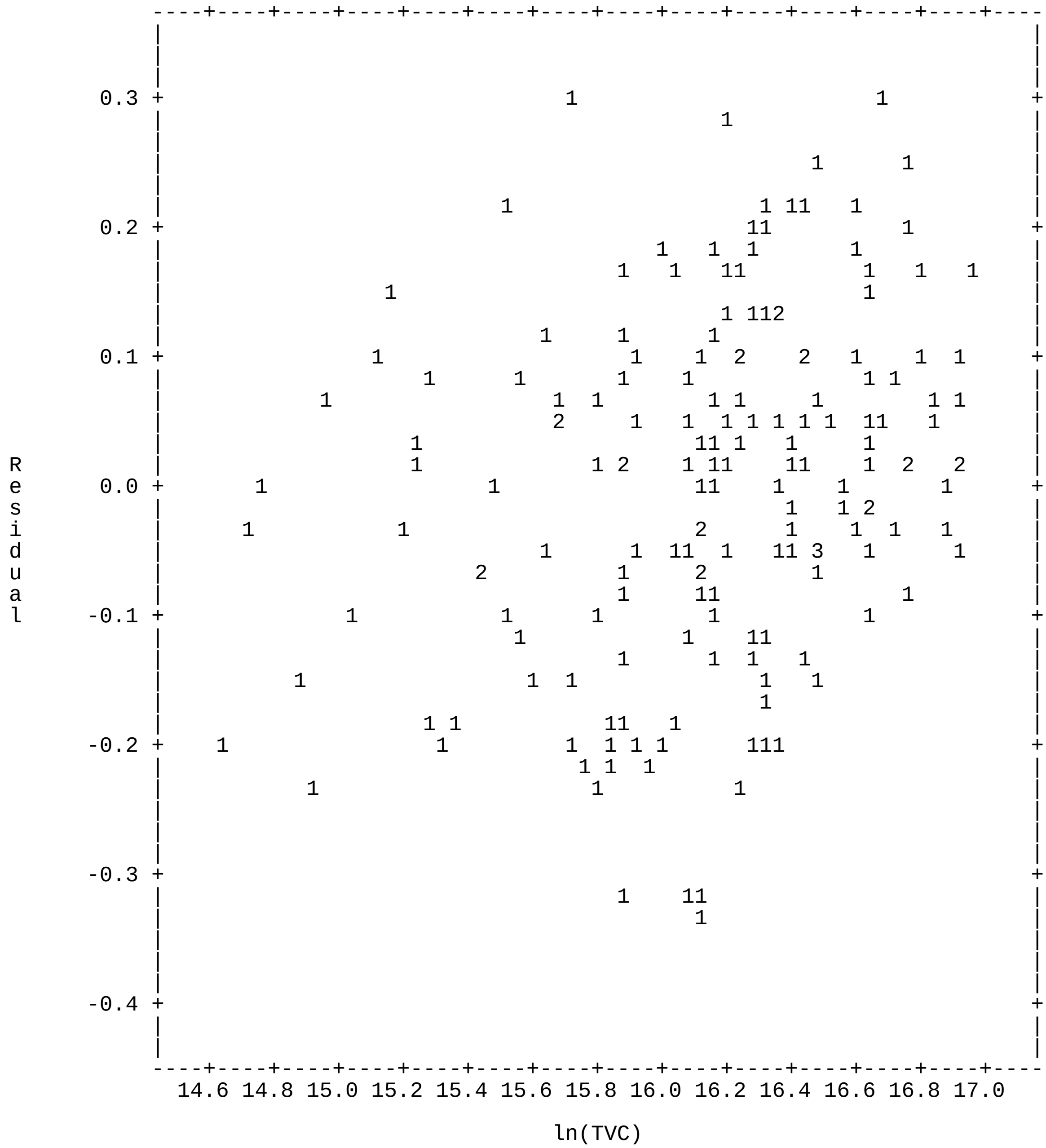

FIGURE 3-4
PLOT OF RESIDUALS AGAINST ACTUAL ln(TVC)

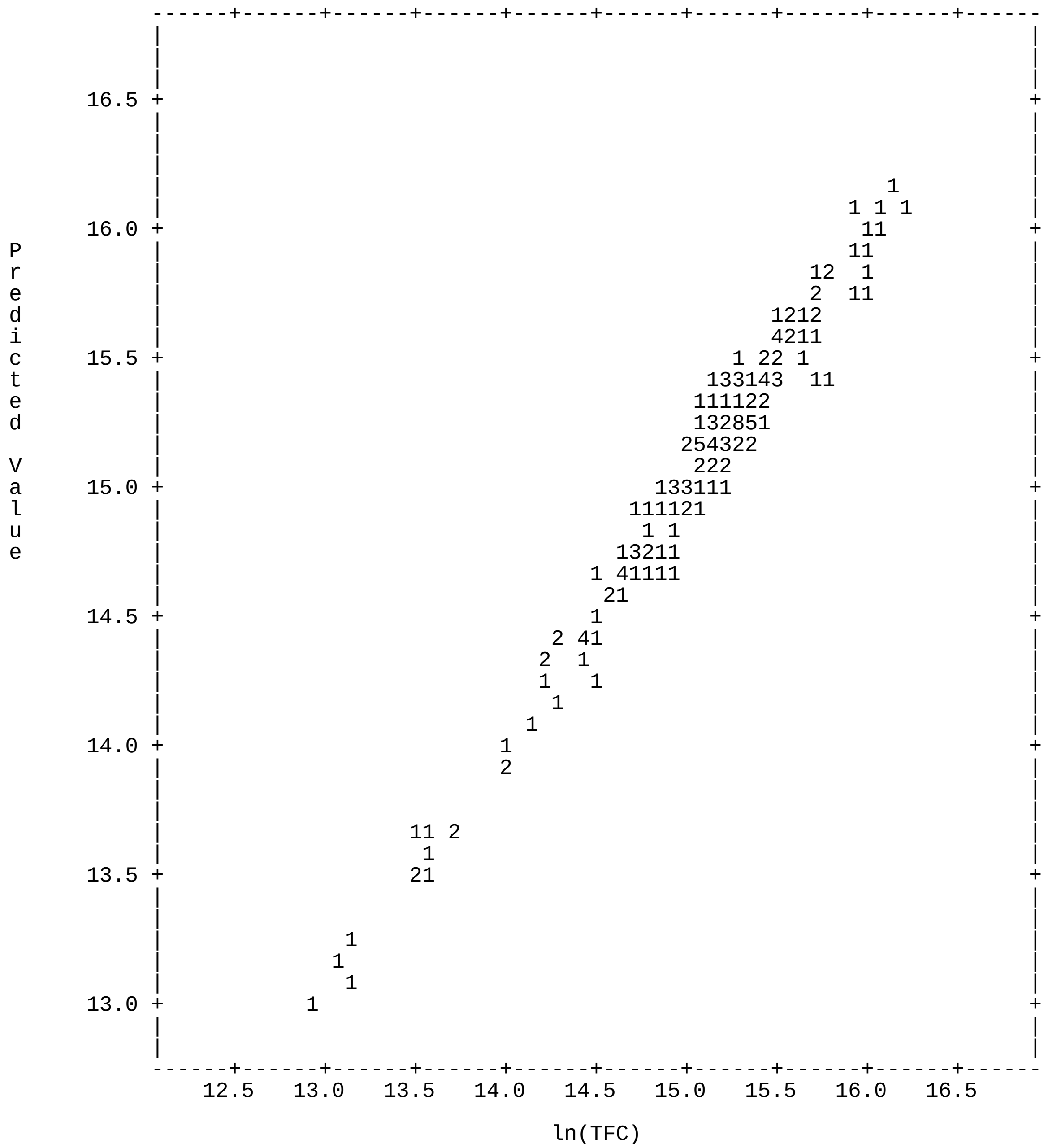

FIGURE 3-5
PLOT OF PREDICTED ln(TFC) AGAINST ACTUAL ln(TFC)

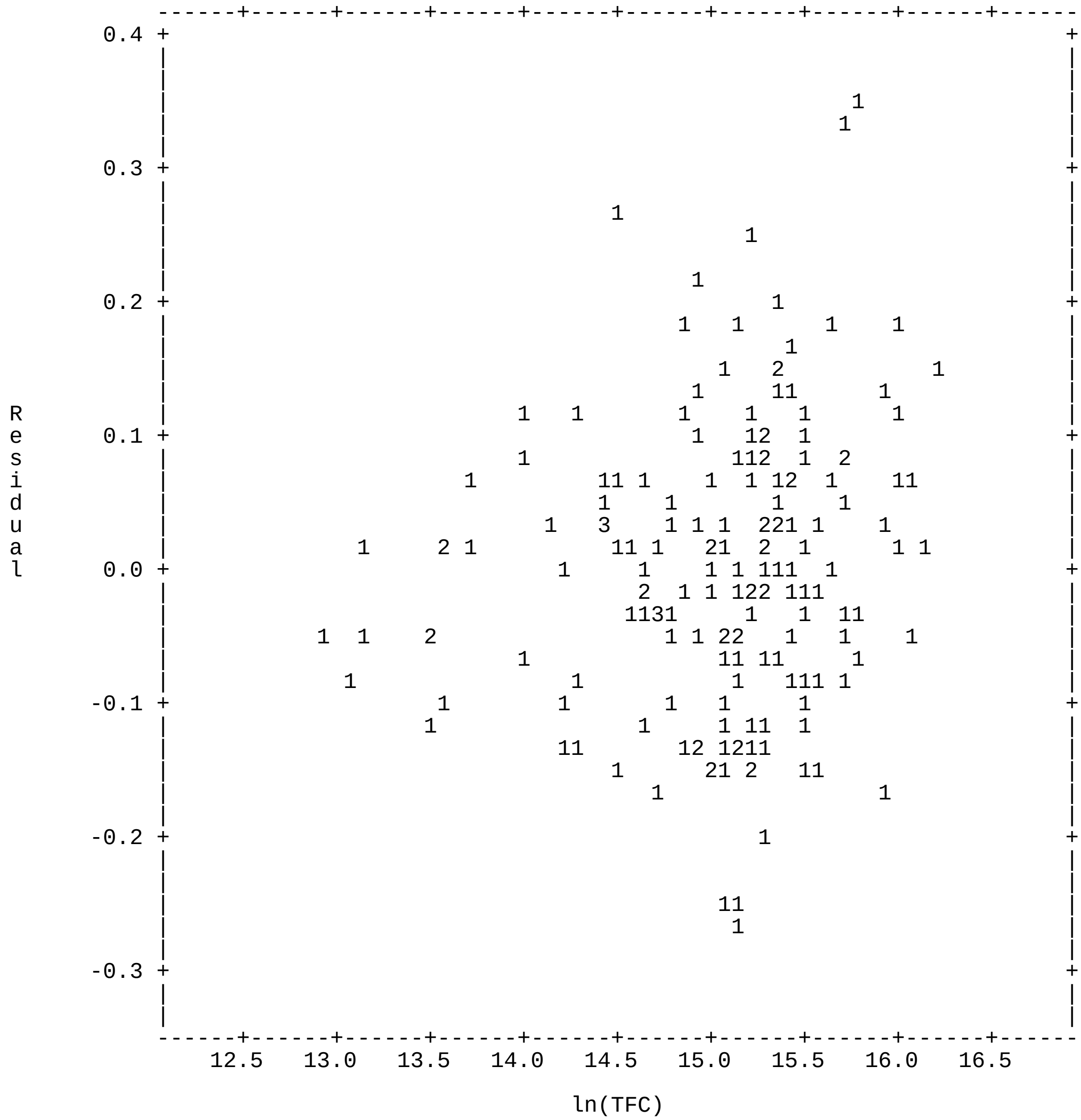

FIGURE 3-6
PLOT OF RESIDUALS AGAINST ACTUAL ln(TFC)

Average Total, Average Variable and Average Fixed Cost Functions

Initial regression runs of the average total and average variable cost functions showed the coefficients for PL^2, PK^2 and CAP^2 to be statistically insignificant as were the coefficients for PL^2, PK^2 and LRF^2 in the average fixed cost function. These variable were thus dropped from the final regression runs, the results of which are listed in Table 3-3. The results for all estimated equations are highly significant as indicated by the F statistic while the adjusted R^2 suggest that the equations have a fairly high degree of "explanatory" power. In addition, all estimated coefficients have the theoretically correct sign and are significant at the 95% confidence level or better.

TABLE 3-3
AVERAGE TOTAL, VARIABLE AND FIXED COST FUNCTION REGRESSION RESULTS

Independent Variables	Dependent Variables: Average Total Cost	Average Variable Cost	Average Fixed Cost
Intercept	456.1682	422.5838	22.2672
	(6.526)a	(6.449)a	(5.438)a
Q	-0.59	-0.6313	-0.1935
	(6.104)a	(6.968)a	(7.785)a
Q^2	0.001341	0.001456	0.000428
	(4.535)a	(5.250)a	(5.152)a
PL	0.1881	0.1773	0.081
	(2.080)b	(2.091)b	(2.834)a
PK	2.4313	0.4891	0.5794
	(11.140)a	(2.391)b	(7.266)a
LRF	-2.0521	-2.1192	-0.08054
	(3.537)a	(3.896)a	(4.230)a
LRF^2	0.003418	0.003558	-
	(2.902)a	(3.223)a	
CAP	-0.2613	0.1661	-
	(3.830)a	(2.596)b	
FIXPCT	-	-	1.3792
			(18.631)a
F	88.429	58.448	173.522
R^2	0.789	0.711	0.862
Adj. R^2	0.780	0.699	0.857

Values in brackets are the absolute value of the "t" statistic for the estimated coefficients.
a - significant at the 99% confidence level.
b - significant at the 95% confidence level.

Figure 3-7 to 3-12 present scattergrams of the predicted values against actual values and of the residual values (predicted value - actual value) against actual values for the average total, average variable and average fixed cost functions. As with the total cost functions, these diagrams do not suggests any problems with missing variables, wrong functional form or any other violation of the assumptions of classical linear regression.

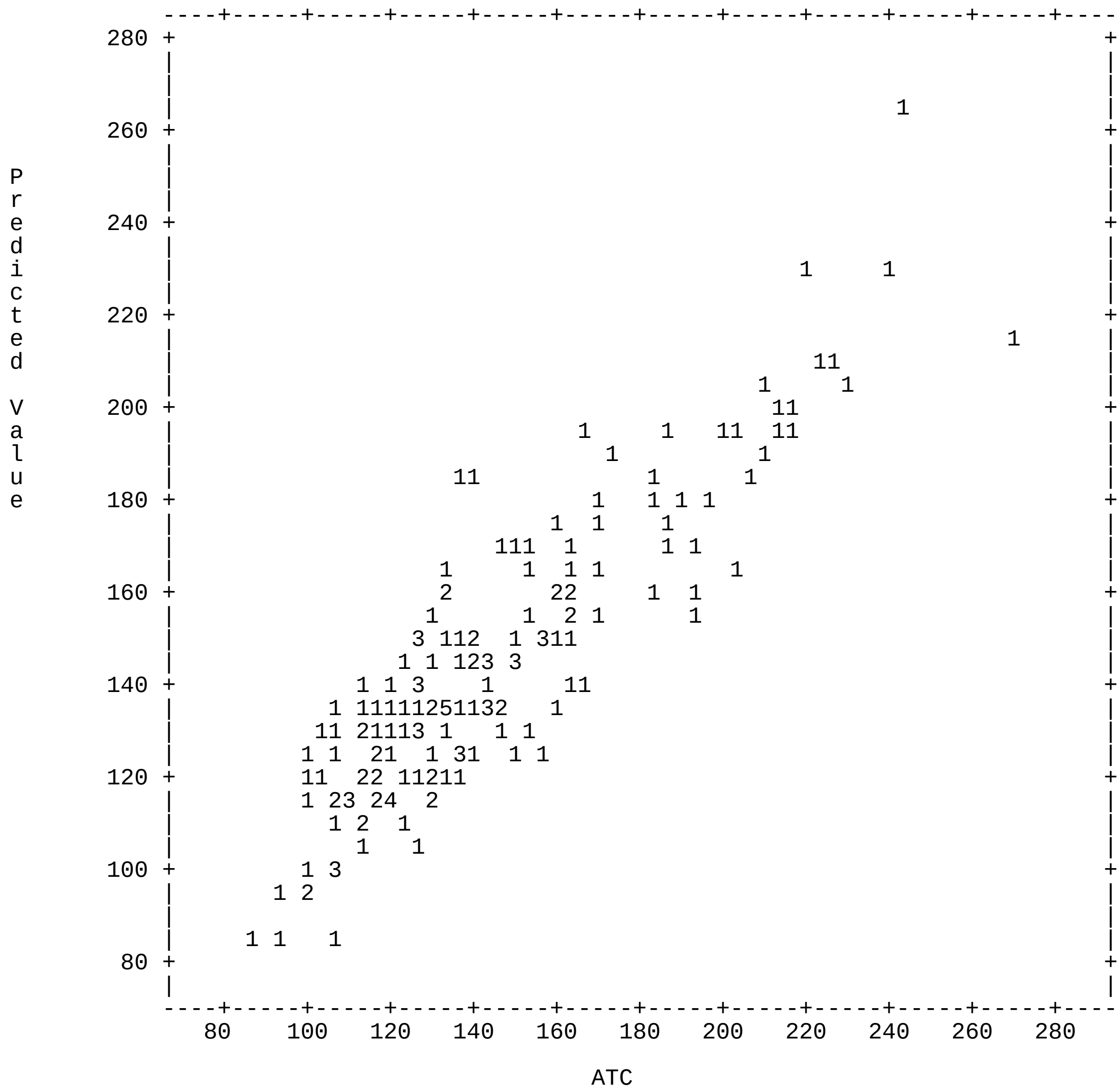

FIGURE 3-7
PLOT OF PREDICTED ATC AGAINST ACTUAL ATC

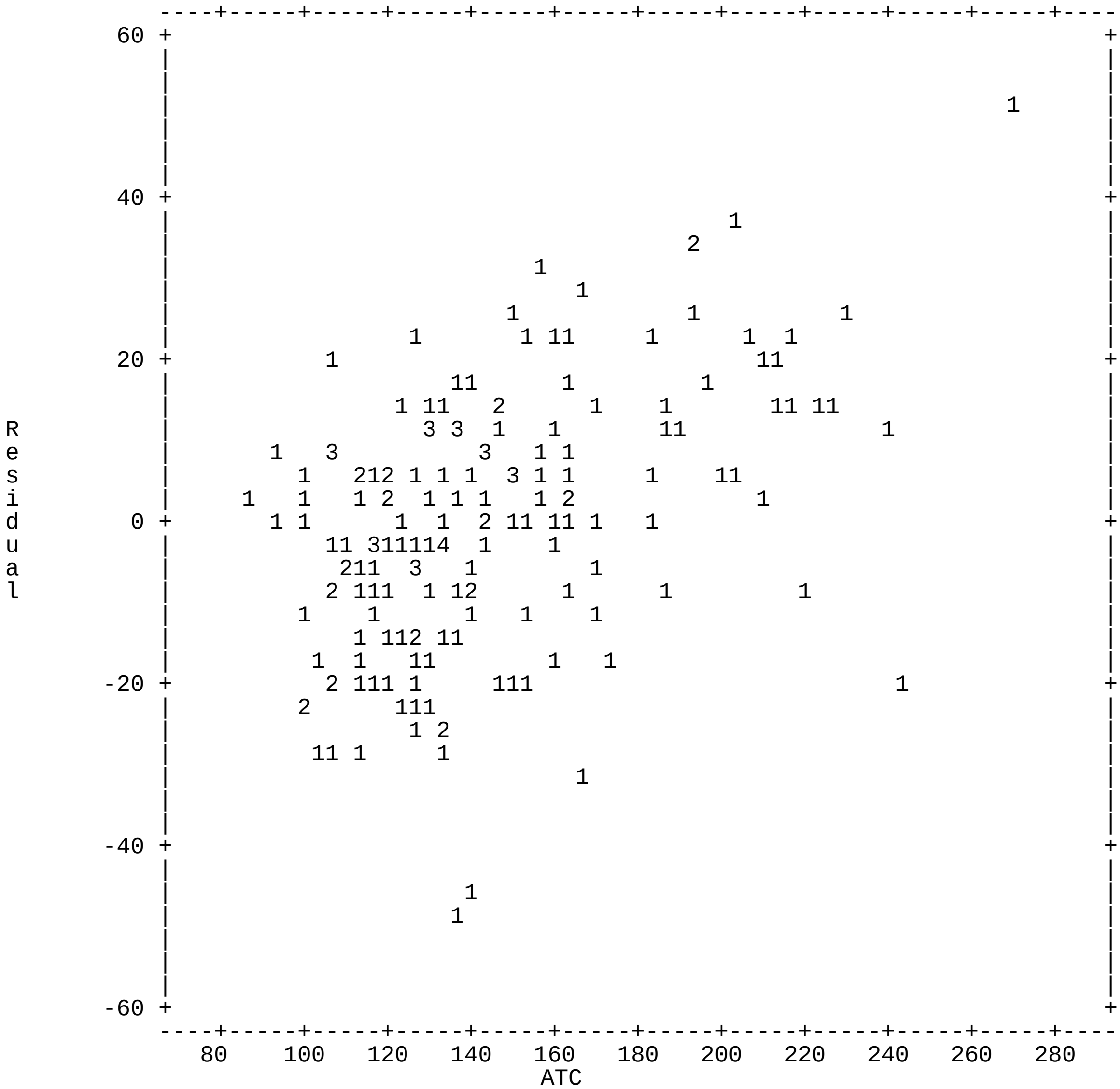

FIGURE 3-8
PLOT OF RESIDUALS AGAINST ACTUAL ATC

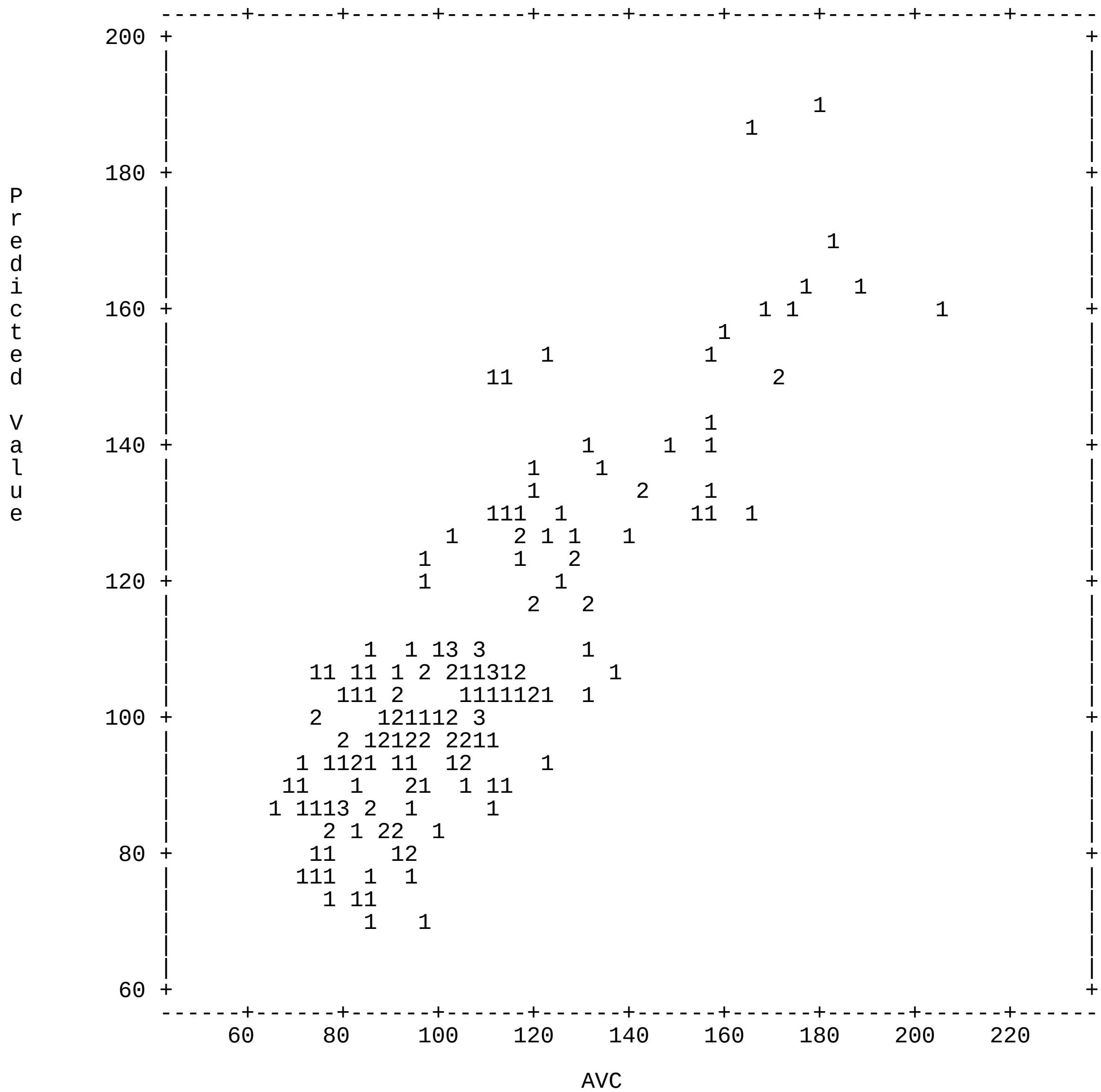

FIGURE 3-9
PLOT OF PREDICTED AVC AGAINST ACTUAL AVC

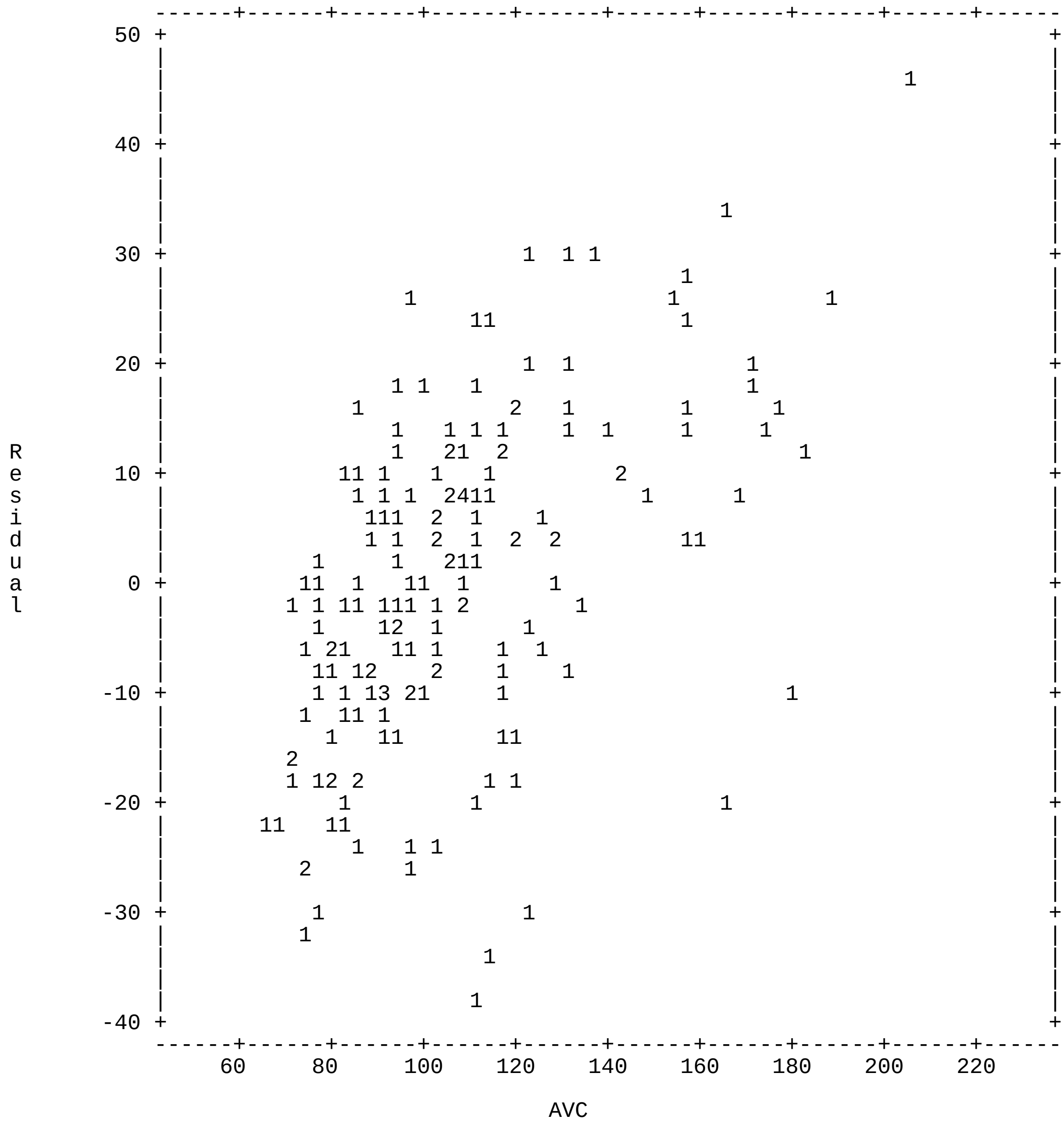

FIGURE 3-10
PLOT OF RESIDUALS AGAINST ACTUAL AVC

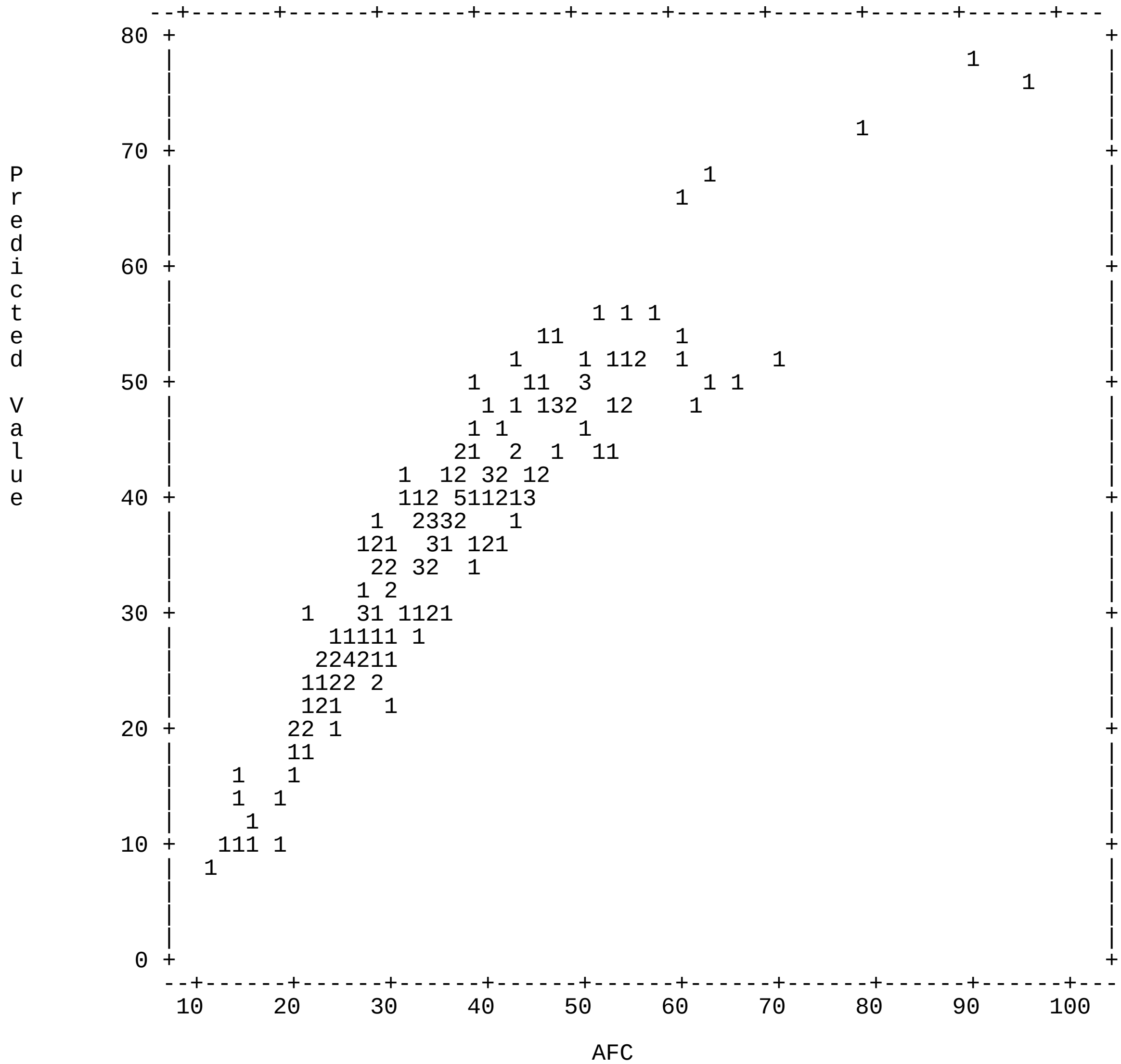

FIGURE 3-11
PLOT OF PREDICTED AFC AGAINST ACTUAL AFC

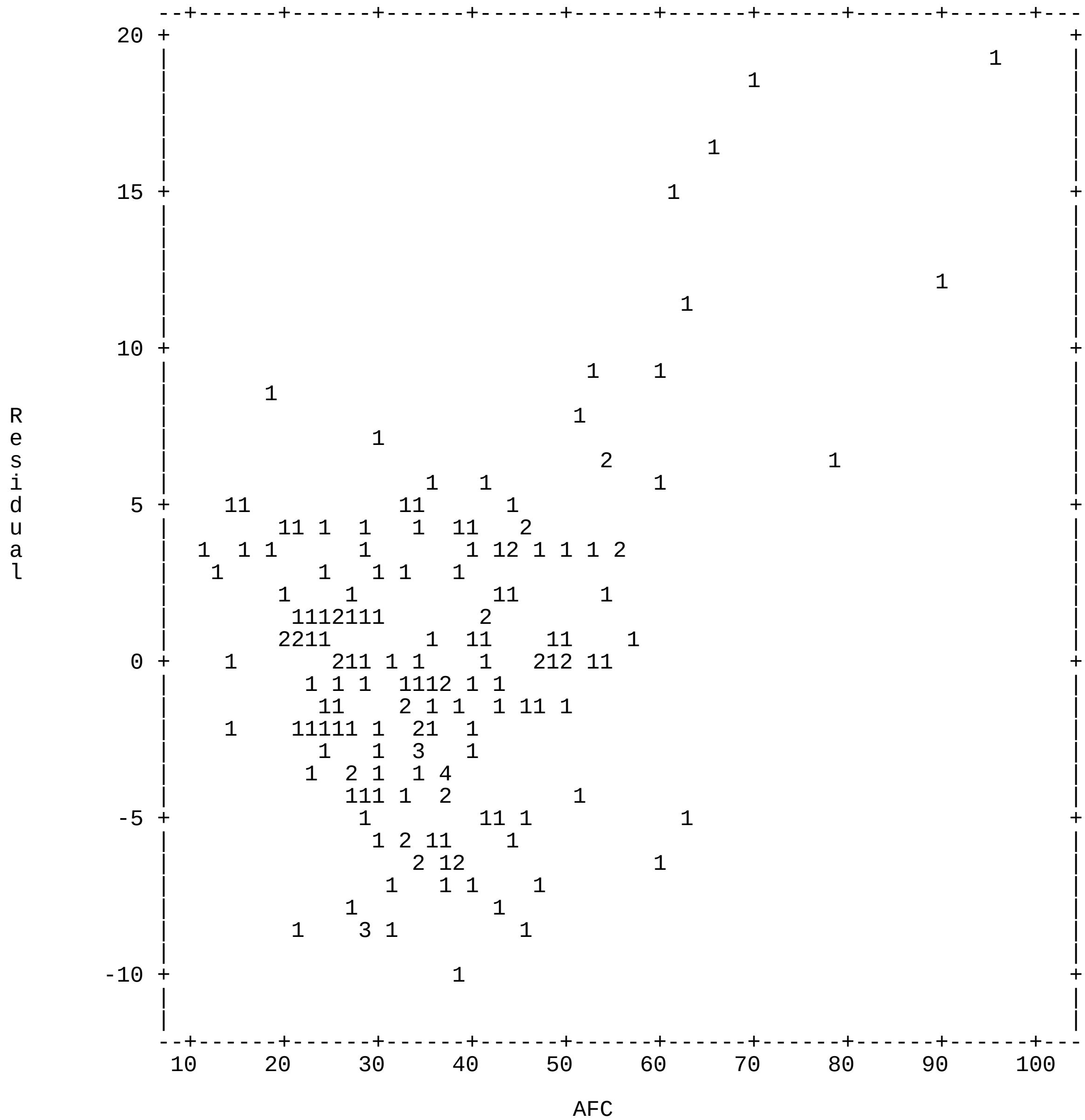

FIGURE 3-12
PLOT OF RESIDUALS AGAINST ACTUAL AFC

3.4 Discussion of the Results

Economies of Scale

Economies of scale exist if in the underlying production function an increase in all factor inputs results in a proportionally greater increase in output. Naturally if output per unit of input rises, all other factors held constant, then cost per unit of output will fall. For functions estimated using the Cobb-Douglas functional form, economies of scale will exist if the coefficient for Q is less than one, as was indeed the case for all three functions presented in Table 3-2. For the quadratic average cost functions, economies of scale will exist if the coefficient for Q is negative as was the case for functions listed in Table 3-3. However, the positive sign of the coefficient for Q^2 in the average cost functions indicates that average cost declines at a decreasing rate as output increases and that at some output level average costs may start to increase with increasing output levels.

These results are shown in Figure 3-13, which is based on holding all variables except output constant at the mean values reported in Table 3-1. The solid lines in the figure show the effect of output on average costs based on the results of the total, variable and fixed cost functions. To do this the total, variable and fixed cost functions were converted to average cost functions by subtracting one from the coefficients for output.[12] The dashed lines shows the effect of increasing output on average costs based on the average cost function results. Over the range of 30 - 260 MMBF the results of both functional forms are very similar.

Capacity Utilization

Capacity utilization was included as a variable to allow for short-run variations from the minimum cost input combination for any given output level due to quasi-fixed inputs. Figure 3-14 graphs the changes in average total and average variable costs resulting from variation in capacity utilization while holding all other variables constant at their mean values. Again the solid lines represent the results from the total cost functions while the dashed lines represent the average cost function results. The results of both functional forms are quite similar over the entire range shown.

Long-Run and Short-Run Marginal Cost

As discussed in Section 1, differentiation of the total cost function with respect to output yields the firm's marginal cost function (MC). Marginal cost is defined as the increase in total cost due to an increase in output. From the total cost function we can derive the following marginal cost function:

$$(3\text{-}13) \quad \frac{\partial TC}{\partial Q} = MC = 3{,}638{,}016\ Q^{-0.1836}\ PL^{0.04457}\ PK^{0.3068}\ LRF^{-0.5199}\ CAP^{-0.1754}$$

As output is measured in millions of board feet of lumber per year the marginal cost function of equation 3-13 is in \$/MMBF. Substituting the mean values for all variables except Q into the equation and dividing by 1,000, in order to convert from \$/MMBF to \$/MBF, yields the following marginal cost function expressed in \$/MBF:

$$(3\text{-}14) \quad MC = 270.094\ Q^{-0.1836}$$

The quadratic average cost function can also be used to derive a marginal cost function using the following relationship between marginal and average costs:

[12] The total cost functions were converted to average cost function simply by dividing by total output. However for the Cobb-Douglas functional form this is the same as subtracting one from the exponent of output.

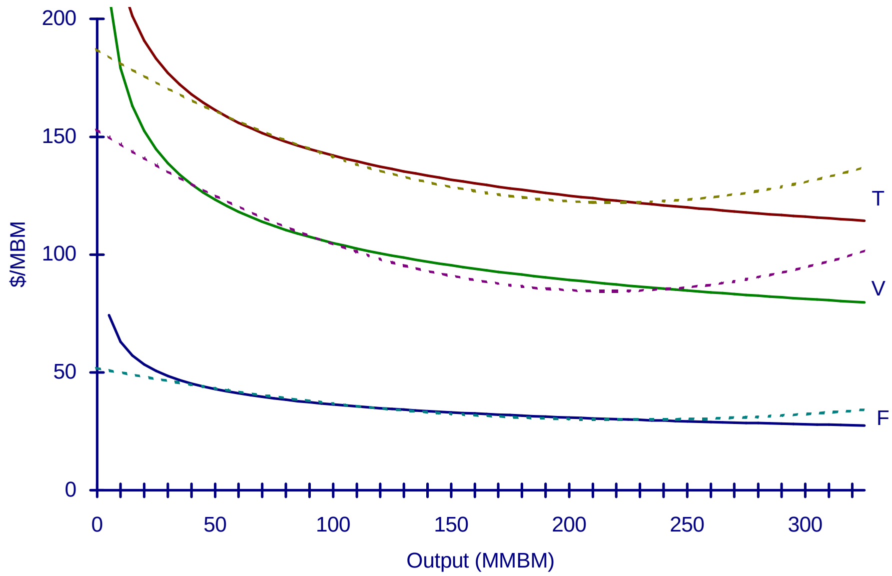

FIGURE 3-13
AVERAGE COSTS BY OUTPUT LEVEL

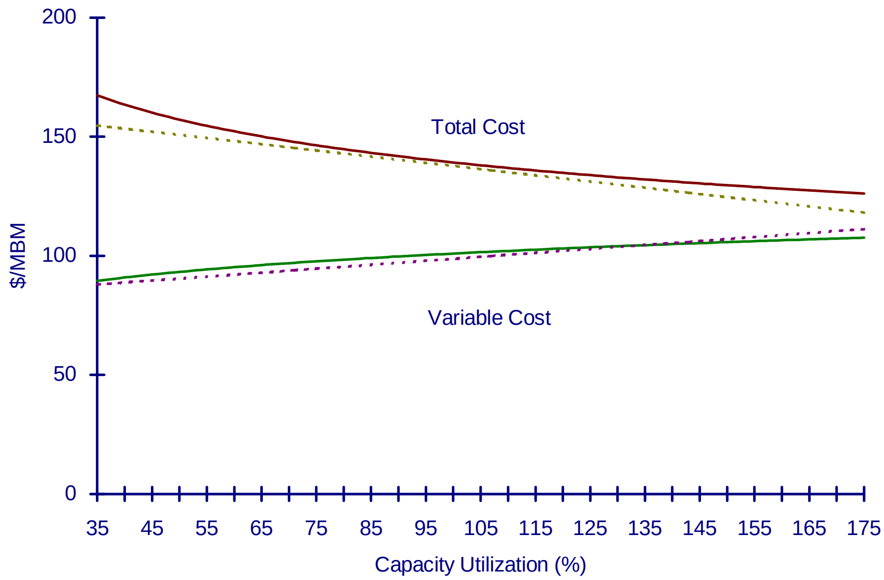

FIGURE 3-14
AVERAGE COSTS BY CAPACITY UTILIZATION

(3-15) $$MC = \frac{\partial ATC}{\partial Q} \times Q + ATC$$

Substitution of the average total cost function derivative, the average total cost function, and the mean values of the other independent variables except output into equation 3-15 yields:

(3-16) $$MC = 187.04 - 1.18\,Q + 0.004023\,Q^2$$

Figure 3-15 graphs the marginal cost functions derived from the total and average total cost functions. The solid line is the marginal cost curve based on the total cost function and shows marginal cost continuously declining as output increases. The dashed line is based on the average total cost function and shows marginal cost declining until an output of 150 MMBF per year is reached, after which marginal costs begins to rise. The curves are quite close over the range of 15-200 MMBF per year but starts to diverge quickly outside of this range.

Because capacity utilization is being held constant at the industry average in the diagram, the curves should represent estimates of the firm's long-run marginal cost curve. This assumes that the industry's average capacity utilization over the three years is representative of the firm's expectation of its average capacity utilization. Not an unreasonable assumption. However in the short-run, when a firm is facing quasi-fixed inputs, the firm cannot adjust plant capacity but can increase its capacity utilization. If we hold production per shift (PRODPS) constant then the firm can vary output only by varying the number of shifts. Increasing the number of shifts, by definition, also increases capacity utilization. The short-run marginal cost function (SRMC) can, using these assumptions, be derived by differentiation of the total cost function by the number of shifts or as:

(3-17) $$SRMC = \frac{\partial TC}{\partial SHIFTS} = \frac{\partial TC}{\partial Q} \cdot \frac{dQ}{dSHIFTS} + \frac{\partial TC}{\partial CAP} \cdot \frac{dCAP}{dSHIFTS}$$

Taking the derivative and substituting the mean values of the other variables into the result yields:

(3-18) $$SRMC = [609.95\,Q^{-0.1836}\,CAP^{-0.1754}\,PRODPS] - [27301\,Q^{-0.1836}\,CAP^{-0.1754}]$$

The short-run marginal cost function can also be derived from the average total cost function by substituting the derivative of ATC with respect to SHIFTS into equation 3-15 which yields:

(3-19) $$SRMC = [-0.0544 - 0.59\,PRODPS + 0.002681\,Q\,PRODPS]\,Q + ATC$$

Figure 3-16 graphs the short-run marginal cost functions based on equation 3-19 plus the long-run marginal cost curve based on the average total cost equation. SRMC1, SRMC2 and SRMC3 are the short-run marginal cost curves holding production per shift constant at 100, 250 and 400 MBF respectively. The short-run marginal cost curves are graphed over the production ranges which result from running between 240 and 720 shifts per year which represents an average of 1-3 shifts per operating day based on 240 operating days per year.

The reader should keep in mind that these curves represent lumber manufacturing costs net of delivered log costs. As a mill's capacity increases, all other factors held constant, the area from which the mill draws timber (its working circle) also increases. This should require timber to be hauled in over a greater distance resulting in higher haul costs and thus higher delivered wood costs. This suggests that even with declining marginal processing costs the addition of delivered log costs would at some point result in an increasing marginal cost if delivered woods costs were included.

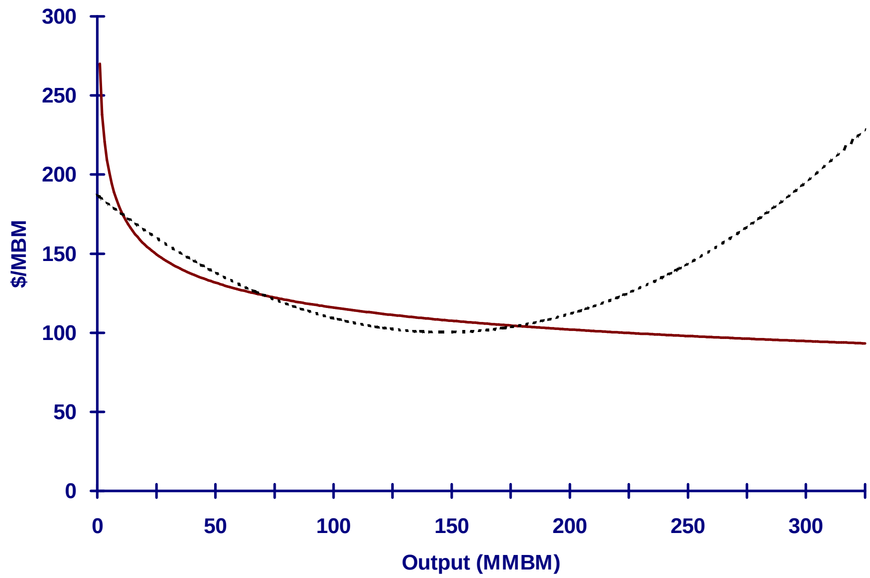

FIGURE 3-15
MARGINAL COST CURVES

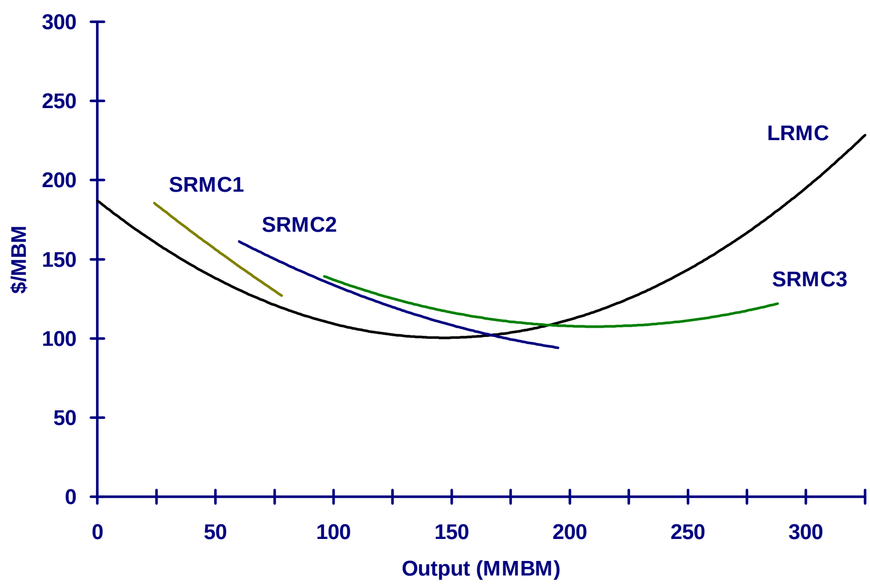

FIGURE 3-16
SHORT-RUN MARGINAL COST CURVES

Effect of Changes in LRF on Average Costs

The negative sign of the coefficient for LRF in all estimated functions confirms that costs decline with an increase in LRF which results from an increase in average log size, a decrease in average log taper or from a lessening of defect. However, the positive sign for LRF^2 in the average cost functions indicates that cost declines at a decreasing rate with increases in LRF.

Figure 3-17 A and B graphs the effects of changes in LRF on average total, average variable and average fixed costs. In the diagrams all variables, except LRF, are held constant at their mean values. Panel A shows the results based on the total cost functions, while panel B shows the results from the average cost functions. The vertical dashed lines indicate the observed range of LRFs from the data set. Extrapolation of the results outside of this range would be tenuous. Figure 3-17 C provides a comparison of functional forms by overlaying the curves. The quadratic average cost functions are more responsive to changes in LRF than the Cobb-Douglas total cost functions. However, over the range of 190-320 BF/m^3 both functional forms produce similar results.

Effect of Changes in the Price of Labour on Average Costs

Figure 3-18 illustrates the estimated effect changes in the price of labour would have on average cost. The solid lines are derived from the total cost functions while the dashed lines are from the average cost functions. Over the range shown their is little difference between the results of the two functional forms. In addition both show costs to be relatively unresponsive to changes in the price of labour. However, these results must be interpreted with extreme caution due to concerns about the accuracy of the labour wage data as discussed in Section 2.

The Firm's Derived Demand for Labour

As discussed in Section 1.3, differentiation of the firm's cost function with respect to the price of labour yields the firm's derived demand for labour inputs. Equation 3-17 is the derived labour demand function based on the Cobb-Douglas total cost function.

(3-17) $L = 1{,}588{,}892\ Q^{0.8164}\ PK^{0.3068}\ LRF^{-0.5199}\ CAP^{-0.1754}\ PL^{-0.95543}$

Substitution of the mean values for all variables except PL reduces the labour demand function to:

(3-18) $L = 4{,}903{,}714\ PL^{-0.95543}$

To provide a comparison equation 3-17 was estimated directly by regression analysis using the 174 observations of the data set. The results were:

(3-19) $L = 4{,}482{,}054\ Q^{0.6776}\ PK^{-0.01163}\ LRF^{-0.8456}\ CAP^{0.383} PL^{-0.9464}$

$F = 491.6 \qquad R^2 = 0.94$

All estimated coefficients were significant at the 99% confidence level except the coefficient for PK which was statistically insignificant. Substitution of the mean values reduces the equation to:

(3-20) $L = 6{,}350{,}830\ PL^{-0.9464}$

Figure 3-19 graphs the results of the equations 3-18 and 3-20 which hold all variables, except PL, at the mean values reported in Table 3-1. Both have essentially the same shape with the derived demand curve lying below the estimated labour demand curve.

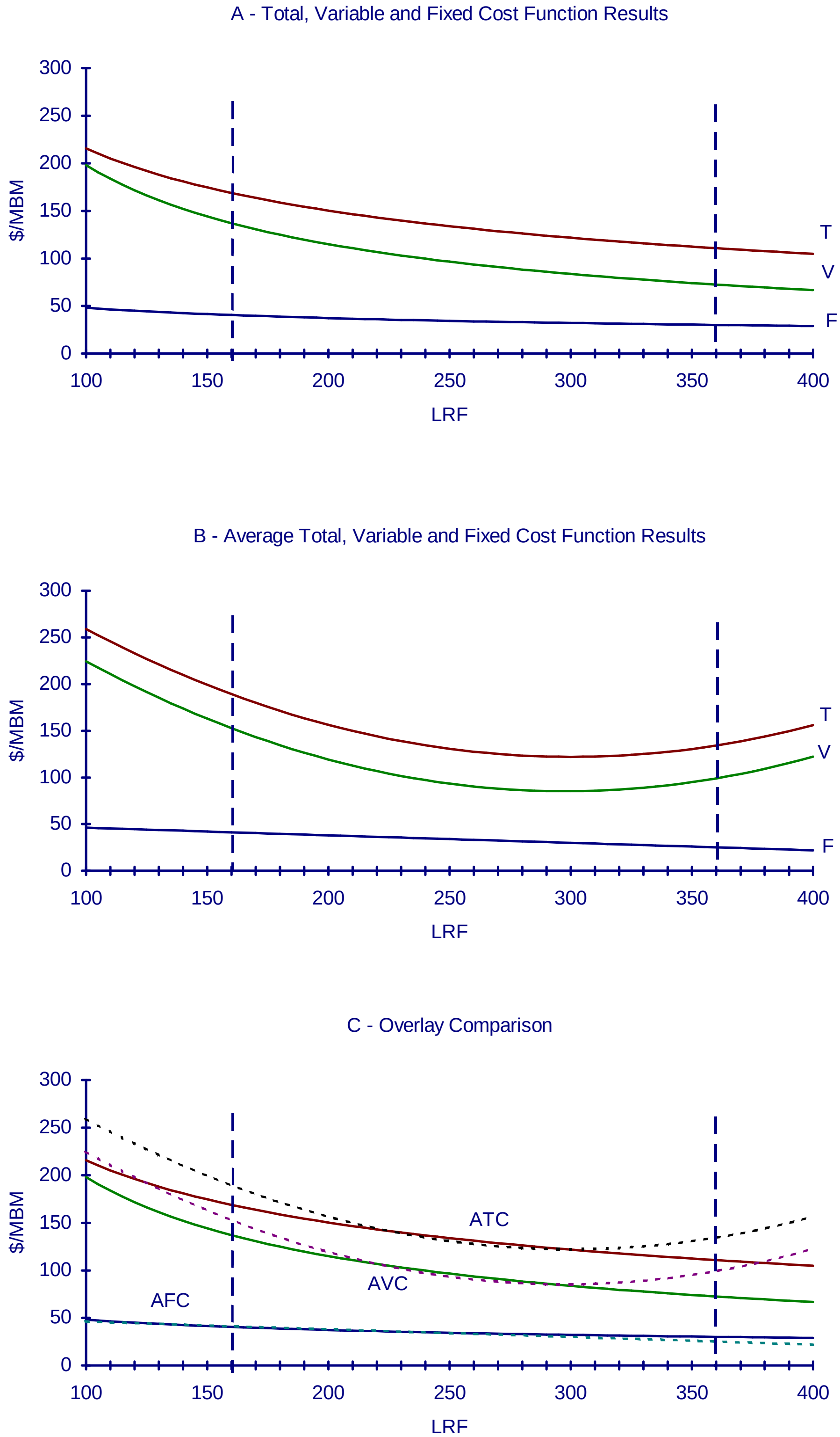

FIGURE 3-17
EFFECTS OF LRF ON AVERAGE TOTAL, VARIABLE AND FIXED COSTS

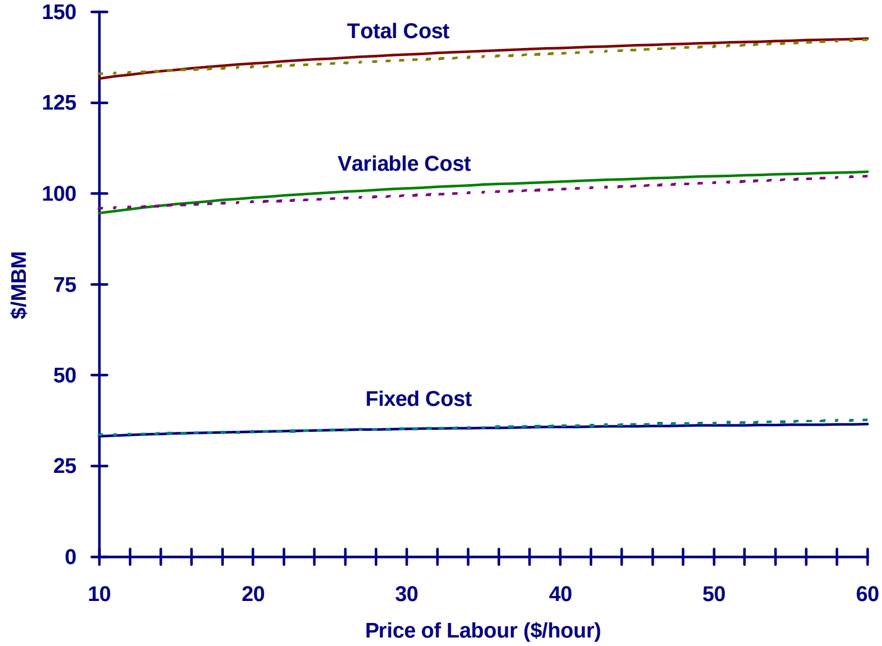

FIGURE 3-18
AVERAGE VARIABLE COSTS BY PRICE OF LABOUR

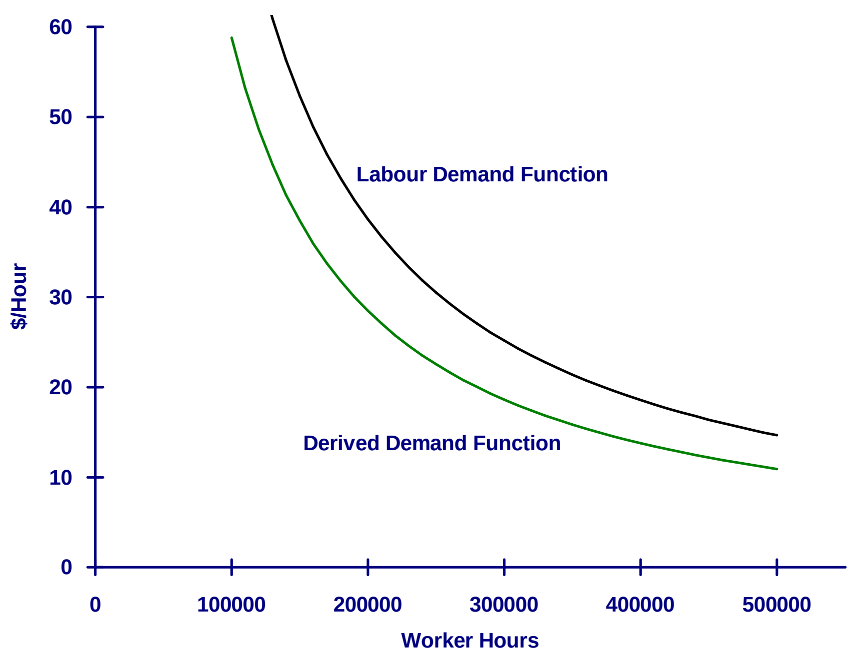

FIGURE 3-19
DERIVED DEMAND FOR LABOUR

Effect of Changes in the Price of Capital

Figure 3-20 shows the estimated effects of changes in the price of capital on average cost. Once again the solid lines are based on the total cost functions while the dashed lines are from the average cost functions. The results based on the quadratic average total cost function are more responsive than the Cobb-Douglas form.

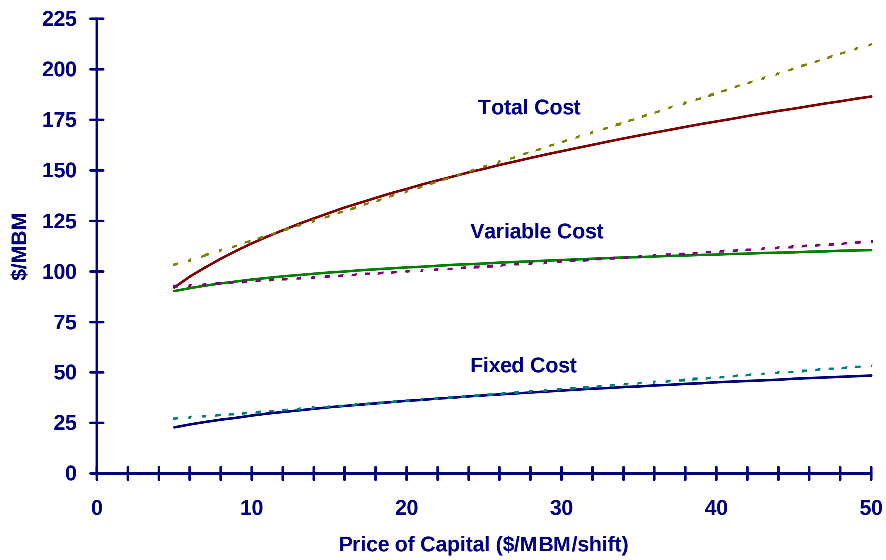

FIGURE 3-20
AVERAGE COSTS BY PRICE OF CAPITAL

Effect of Changes in FIXPCT

Finally the effect of changes in FIXPCT on average cost is graphed in Figure 3-21. Both functional forms produce similar results over the entire range shown.

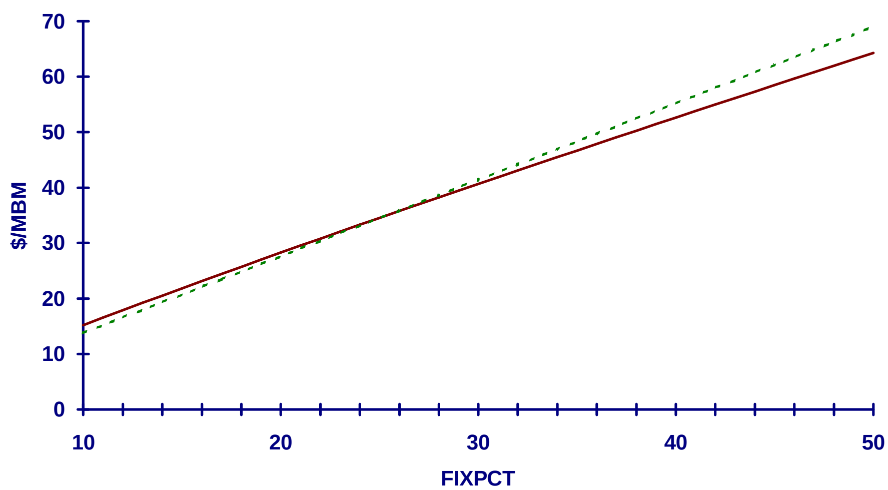

FIGURE 3-21
AVERAGE FIXED COSTS BY FIXPCT

3.5 Cost Elasticities

An elasticity is a unitless measure of how responsive a dependent variable is to changes in an independent variable. An elasticity is calculated as the percentage change in the dependent variable divided by the corresponding percentage change in the independent variable. For example the cost elasticity with respect to the price of labour would be:

$$(3\text{-}13) \quad \eta = \frac{\Delta Cost}{Cost} \div \frac{\Delta PL}{PL}$$

This can be rearranged to yield:

$$(3\text{-}14) \quad \eta = \frac{\Delta Cost}{\Delta PL} \cdot \frac{PL}{Cost}.$$

A point elasticity, the instantaneous responsiveness, can be derived as:

$$(3\text{-}15) \quad \eta = \frac{\partial Cost}{\partial PL} \cdot \frac{PL}{Cost}.$$

If the absolute value of the elasticity is greater than one it is known, in the parlance of economists, as "elastic" or relatively responsive to changes in the independent variable while an absolute value of less than one is called "inelastic" or relatively unresponsive to changes in the independent variable. An elasticity with an absolute value of one is called unitary elastic.

Table 3-4 presents the estimated average cost elasticities with respect to the independent variables used in the estimated cost functions. The elasticities for the average cost functions were calculated at the mean values of the regression observations given in Table 3-1. For the total cost functions the estimated elasticities are identical to the estimated coefficients for each independent variable. This is a characteristic of the Cobb-Douglas functional form which was used to estimate the total cost functions.

TABLE 3-4
AVERAGE COST ELASTICITIES

Independent	Average Total Costs		Average Variable Costs		Average Fixed Costs	
Variable	TC	ATC	TVC	AVC	TFC	AFC
Q	-0.18*	-0.22	-0.23*	-0.32	-0.24*	-0.30
LRF	-0.52	-0.73	-0.78	-0.98	-0.37	-0.51
PL	0.04	0.04	0.06	0.05	0.05	0.07
PK	0.31	0.32	0.09	0.09	0.33	0.30
CAP	-0.18	-0.19	0.11	0.16	-	-
FIXPCT	-	-	-	-	0.90	0.96

* In order to compare the total cost elasticities with respect to output to the average cost elasticities, the TC, TVC and TFC functions were converted to average cost functions by subtracting one from the estimated coefficient for output.

The cost elasticities reported in Table 3-4 are remarkably similar when compared across functional forms. All independent variables would be considered inelastic although the fixed cost elasticities with respect to FIXPCT and the variable cost elasticity with respect to LRF approach unitary elasticity.

SECTION 4
USE OF THE RESULTS FOR THE VALUATION OF TIMBER

4.1 Introduction

This final section describes some potential applications for the cost functions developed in this study. In particular, their application to timber appraisal and the evaluation of silviculture investments is examined. The section closes with some recommendations for further research on lumber manufacturing costs.

4.2 Current Appraisal Methods

The interior stumpage appraisal system derives the value of standing timber by deducting all harvesting, transportation and manufacturing costs from the value of the lumber and chips which can be produced from the stand's timber. The value left after this net down process is used in the current appraisal system as an index of the value of the standing timber.

The process starts with the determination of the value of the lumber and chips which can be produced from a stand using average market values for lumber, measured in $/MBF, and for chips, measured in $/BDU (bone dry unit). The value obtained is converted to an average value per m^3 of merchantable timber contained in the stand and all subsequent costs are also measured by the manual in $\$/m^3$. The estimate of lumber manufacturing costs, net of delivered wood costs, is calculated in the appraisal manual as:

(4-1) $\$/m^3 \quad = \quad \text{Decay\%} \times 0.1321 + \text{Base Value}$

Decay% is the percentage of merchantable volume in the stand which has been lost due to rot, as determined by the timber cruise. The interior appraisal manual states that if Decay% is greater than 50% then Decay% is set equal to 50% for use in equation 4-1. The base value varies by species group and appraisal zone as shown in Table 4-1. The base values are derived from the annual survey of lumber manufacturing costs described in Section 2.

As equation 4-1 is expressed in dollars per volume of log input, rather than dollars per board foot of lumber output, the results must be converted to $/MBF in order to be compared to the results of this study. This can be accomplished using the average LRF for the stand as follows:

(4-2) $\$/MBF \quad = \quad [\$/m^3] \times [1000/LRF]$

Figure 4-1 graphs out the average cost per MBF of lumber produced by species for the Northern Interior Zone holding Decay% at zero. The top line is the fir, larch, white pine and yellow pine species grouping, which had the highest average cost per m^3, while the bottom line is spruce which had the lowest average cost per m^3. The shape of the average cost per MBF curves are similar that derived in Figure 3-17 based on the Cobb-Douglas functional form in that average cost declines continuously at a decreasing rate as LRF increases.

Note however that the graphs in Figure 4-1 are not based on any empirical relationship between costs and LRF but result simply from holding cost per m^3 constant while allowing the average LRF to vary.

TABLE 4-1
INTERIOR APPRAISAL MANUAL UNTRENDED
LUMBER MANUFACTURING COST ESTIMATES
($/m³ - 1992 Cost Survey Base)

Species	Appraisal Zone N. Interior	 S. Interior	 S. Cariboo	 Ft. Nelson/Peace
Spruce	24.50	27.66	23.23	24.23
Lodgepole Pine	27.21	31.04	25.90	27.10
Balsam	27.70	31.53	26.29	26.94
Fir, Larch, White Pine & Yellow Pine	33.57	38.12	31.38	-
Cedar	31.58	36.71	28.12	-
Hemlock	29.59	35.65	27.09	-

Source: Ministry of Forests [1994b]

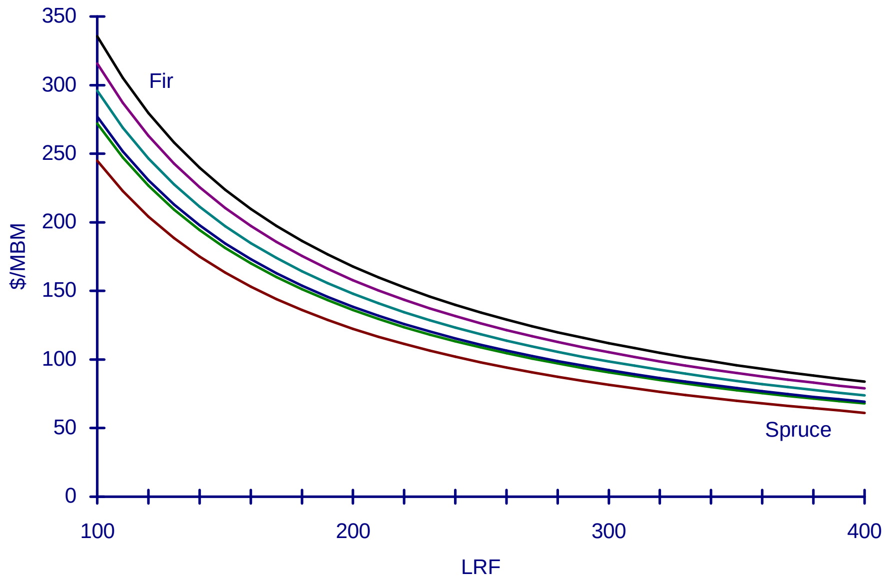

FIGURE 4-1
INTERIOR APPRAISAL MANUAL TREATMENT OF
LUMBER MANUFACTURING COSTS

4.3 Potential Improvements to the Appraisal System

The cost functions presented in this report may offer a potential improvement to the way in which lumber manufacturing costs are currently estimated by providing an empirical relationship between a stand's average LRF and the resulting lumber manufacturing costs. For example, the average cost during 1992 can be estimated by substituting the industry averages for output, PL, PK and CAP reported in Table 2-4 for 1992 into the cost functions developed in Section 3. Making this substitution and holding all other variables except LRF constant at their 1992 mean values yields the following estimates of the average total cost function based on variation in LRF alone:

(4-3) $ATC = 2{,}234.31\ LRF^{-0.5199}$

(4-4) $ATC = 422.66 - 2.0521\ LRF + 0.003418\ LRF^2$

Note that these functions produce average cost estimates measured in 1993 dollars as the data on which they were based were measured in 1993 dollars (see Section 2 for details).

The 1992 provincial average for all species across all interior appraisal zones was $29.27/m³ (Revenue Branch, pers. comm. [1995]). Converted to 1993 dollars this value is $30.13/m³ which can now be used to compare the current appraisal results to the cost function results.

Figure 4-2 graphs the results of equations 4-3 and 4-4 and overlays the results of substituting the appraisal manual average cost of $30.13/m³ into equation 4-2. The results suggest that the average lumber manufacturing cost for stands with a high LRF may be underestimated by the current appraisal system while the average cost for stands with a low LRF may be overestimated.

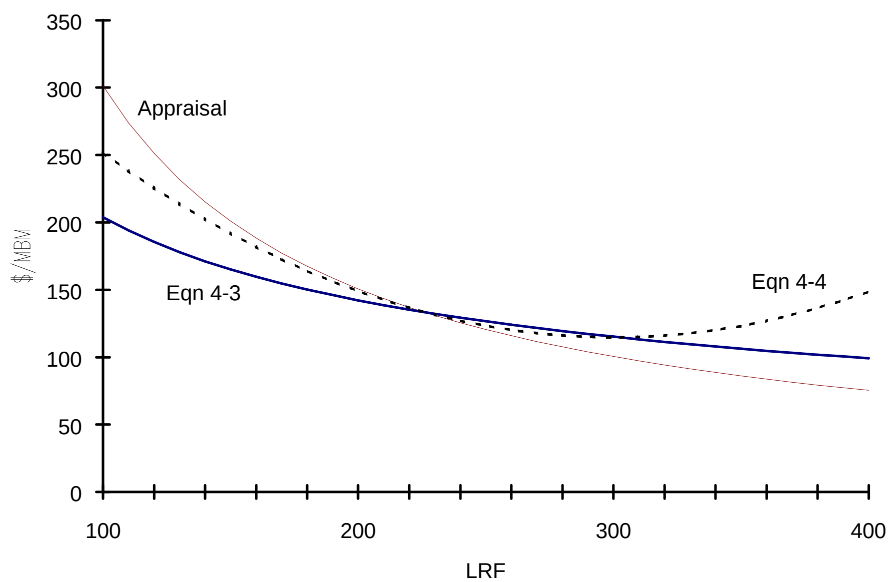

FIGURE 4-2
COMPARISON OF INTERIOR APPRAISAL MANUAL TREATMENT OF LUMBER MANUFACTURING COSTS WITH THE COST FUNCTION RESULTS

The adjustment used to account for the volume of log decay in equation 4-1 could also be incorporated by adding to the average total cost equations the following decay adjustment (DA):

(4-5) DA = $[\text{Decay\%} \times 0.1321] \times [1000/\text{LRF}]$

However, this adjustment factor has the same inherent weakness as Equation 4-2. That being the conversion from $\$/m^3$ to \$/MBF is based on a physical relationship and not an empirical economic relationship. Thus, further work on the effects of decay on lumber manufacturing costs is warranted.

<u>When to Incorporate the Manufacturing Costs</u>

It is recommended that the calculation of the lumber manufacturing costs be done at the same time as the stand's gross value is calculated and that the lumber manufacturing costs be subtracted from the gross value prior to the gross value being converted from \$/MBF to $\$/m^3$. This would produce the value per m^3 for wood delivered to the log yard rather than dealing with the gross value of lumber and chips per m^3 of log inputs and later dealing with manufacturing cost measured in $\$/m^3$.

<u>Adjustments for Capacity Utilization</u>

It was noted earlier in the report that the demand for lumber in the interior of British Columbia was largely based on the cycles of the U.S. construction industry. The cyclical demand can cause large swings in the industry's capacity utilization. If it was desired to incorporate the effect of fluctuations in average capacity utilization on average costs into the appraisal system, then the cost functions estimated in this study could provide an estimate of the effects. Note that any adjustment should only be based on industry averages and not on individual mill operations as this would reward inefficient operators and penalise efficient operators.

4.4 Effects of Silviculture Treatments on Lumber Manufacturing Costs

Stand tending treatments following site regeneration can affect individual tree growth. Spacing and thinning can concentrate the site's growth potential on fewer stems producing a larger average tree. Fertilization temporarily increases the site's growth potential which can again increase average tree size. In order to correctly evaluate the economic efficiency of silvicultural treatments the potential effects of the treatment on lumber manufacturing costs should be incorporated into the analysis whenever the evaluation is being done based on the values of the manufactured products.[13]

The assessment of silvicultural investments requires an estimate of the net value of the standing timber at some future harvest date. This estimate is calculated in the same manner as is done for the value index in the stumpage calculation process. The major difference being that the stumpage appraisal system deals with actual data from a timber cruise on an existing stand while silviculture investment analysis has to make projections on future stand conditions.

Projections of stand conditions are typically done using growth and yield models such as the Ministry of Forests' Tree and Stand Simulator (TASS) (see Mitchell [1975] for details of the TASS model). If an estimate of the lumber recovery for the stand can also be produced then the stand's average LRF can be calculated and used with equation 4-3 and 4-4 to provide an estimate of the lumber manufacturing cost. Fortunately some growth and yield systems now incorporate sub-systems which allow for estimates of end-product recovery. For example. the Ministry of Forests' SYLVER model takes the growth and yield information from the TASS model and simulates the bucking of the trees into logs and the sawing of lumber from the logs (see Mitchell *et al.* [1989] for

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[13] When the evaluation is based on log prices determined in a competitive market then the log prices should have the effects of larger piece sizes incorporated into the price and no further adjustments would be required.

details of the SYLVER model). Equations 4-3 and 4-4 could be incorporated directly into these models to provide estimates of manufacturing costs .

4.5 Recommendations for Further Research

A researcher would be amiss, and denying self interest, if he did not provide recommendations for further research. Areas which may provide useful extensions to this work include:

- The incorporation of the mill's delivered log costs into a separate set of cost functions. This would show how delivered log costs would affect the total cost of lumber production which together with market prices for lumber could be used to determine the economically operable forest land base.

- The potential effects of the mill's headrig type, the dimension mix produced by the mill, and the species used by the mill on lumber manufacturing cost should also be explored.

- The effect of decay on lumber manufacturing costs is deserving of special attention.

- Better data on individual mill input prices, such as wage rates and power prices, would also be likely to improve the results.

REFERENCES

Abt, R.C., 1987. "An analysis of regional factor demand in the U.S. lumber industry", Forest Science, 33(1):164-173.

Banskota, K., W. Phillips, and T. Williamson, 1985. "Factor substitution and economies of scale in the Alberta sawmill industry", Canadian Journal of Forest Research, 15:1025-1030.

BC STATS, 1994. British Columbia Economic Accounts 1984-1992 and 1993 Interim Estimates. Province of British Columbia, Ministry of Government Services.

Belsley, D.A., E. Kuh, and R.E. Welsch, 1980. Regression Diagnostics. John Wiley & Sons, Inc., New York.

Bramhall, G., 1981. "The drying of wood", in Mullins, E.J., and T.S. McKnight eds., Canadian Woods Their Properties and Uses, third edition, University of Toronto Press, Toronto.

Buell, A., and C.F. McBride, 1981. "Lumber production", in Mullins, E.J., and T.S. McKnight eds., Canadian Woods Their Properties and Uses, third edition, University of Toronto Press, Toronto.

Caves, D.W., L.R. Christensen, and J.A. Swanson, 1981. "Productivity growth, scale economies, and capacity utilization in U.S. Railroads, 1955-74", American Economic Review, 71(5):994-1002.

Christensen, L.R., D.W. Jorgenson, and L.J. Lau, 1973. "Transcendental logarithmic production frontiers", Review of Economics and Statistics, 55(1):28-45.

Christensen, L.R., D.W. Jorgenson, and L.J. Lau, 1975. "Transcendental logarithmic utility functions", American Economic Review, 65(3):367-383.

Constantino, L.F., and G.M. Townsend, 1986. Modelling short-run producer behaviour as an operating rate decision: The Canadian sawmilling and pulp and paper industries. Forest Economics and Policy Analysis Project, University of British Columbia, Report 86-10.

Ferguson, C.E., and J.P. Gould, 1975. Microeconomic Theory, fourth edition. Richard D Irwin Inc., Homewood, Illinois.

Howard, A.F., 1993. "A method for determining the cost of manufacturing individual logs into lumber." Forest Products Journal 43(1):1-5.

Martinello, F., 1985. "Factor substitution, technical change, and returns to scale in Canadian forest industries", Canadian Journal of Forest Research, 15:1116-1124.

Meil, J.K., B.K. Singh, and J.C. Nautiyal, 1988. "Short-run actual and least-cost productivities of variable inputs for the British Columbia interior softwood lumber industry", Forest Science 34(1):88-101.

Merrifield, D.E., and R.W. Haynes, 1983. "Production function analysis and market adjustments: an application to the Pacific Northwest forest products industry", Forest Science, 29(4):813-822.

Merrifield, D.E., and W.R. Singleton, 1986. "A dynamic cost factor demand analysis for the Pacific Northwest Lumber and Plywood Industries", Forest Science, 32(1):220-233.

Ministry of Forests, 1994a. Coast Appraisal Manual, Valuation Branch, Victoria, B.C.

Ministry of Forests, 1994b. Interior Appraisal Manual, Valuation Branch, Victoria, B.C.

Ministry of Forests, 1993a. Forest Service Cruising Procedures and Cruise Compilation. Valuation Branch, Victoria, B.C.

Ministry of Forests, 1993b. Forest Service Scaling Manual. Valuation Branch, Victoria, B.C.

Ministry of Forests, 1993c. Cruise Compilation and Documentation Manual. Valuation Branch, Victoria, B.C.

Ministry of Forests, 1993d. Major Primary Timber Processing Facilities in British Columbia. Economics and Trade Branch, Victoria, B.C.

Ministry of Forests, 1990. Comparative Value Timber Pricing. Stumpage Appraisal Information Paper No. 1. Valuation Branch, Victoria, B.C.

Mitchell, K.J., 1975. Dynamics and Simulated Yield of Douglas-fir. Forest Science Monogram No. 17.

Mitchell, K.J., R.M. Kellogg, and K.R. Polsson, 1989. Silvicultural Treatments and End-Product Value. In R.M. Kellogg (ed.), Second Growth Douglas-Fir: Its Management and Conversion for Value, Chap. 13, pp. 130-167. Forintek Canada Corp., Special Publication SP-32.

National Lumber Grades Authority, 1987. Standard Grading Rules for Canadian Lumber. National Lumber Grades Authority, Vancouver.

Nautiyal, J.C., and B.K. Singh, 1985. "Production structure and derived demand for factor inputs in the Canadian lumber industry", Forest Science 31(4):871-881.

Pindyck, R.S., and D.L. Rubinfeld, 1981. Econometric Models and Economic Forecasts. McGraw-Hill, Inc., New York.

Samuelson, P.A., 1947. Foundations of Economic Analysis. Harvard University Press, Cambridge, Massachusetts.

Shephard, R.W., 1953. Cost and Production Functions. Princeton University Press, Princeton, New Jersey.

Shephard, R.W., 1970. Theory of Cost and Production Functions. Princeton University Press, Princeton, New Jersey.

Singh, B.K., and J.C. Nautiyal, 1986. "A comparison of observed and long-run productivity of, and demand for, inputs in the Canadian lumber industry", Canadian Journal of Forest Research, 16(3):433-455.

Stier, J.C., 1980. "Estimating the production technology in the U.S. forest products industries", Forest Science, 26(3):471-482.

Varian, H.R., 1978. Microeconomic Analysis. W.W. Norton & Company, New York.

Williston, E.M., 1988. Lumber Manufacturing: The Design and Operation of Sawmills and Planer Mills, revised edition. Miller Freeman Publications, Inc., San Francisco.

APPENDIX
COSTS BY MANUFACTURING PHASE

A.1 Introduction

This section provides a more detailed examination of lumber manufacturing costs by manufacturing phase. Note that the average costs by cost centre reported in this section differ slightly from those reported in Table 2-2. The averages in Table 2-2 were derived by dividing total cost by phase by total mill output. In this section average costs are calculated by dividing total phase costs by total phase output which may differ from total mill output.

A.2 Log Yard Operations

Log yard operations make up 8% of total manufacturing costs, costing on average $2.34/m^3$ of log throughput. Figure A-1 provides a percentage breakdown of log phase costs by cost category. Variable costs accounted for 76% of total costs with fixed costs accounting for the remaining 24%. Table A-1 presents average log yard costs by year. Note that the average costs are given in $\$/m^3$, as m^3 is the unit of measurement for log volumes. The table does not reveal any significant changes in average cost or the distribution of total costs to the various cost categories with 1990 costs 6.8% higher and 1991 costs 5.7% lower than the three year average.

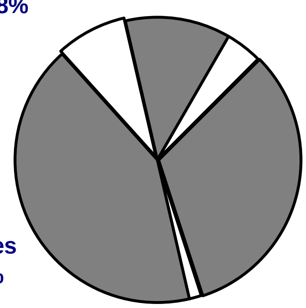

FIGURE A-1
LOG YARD COST BREAKDOWN BY COST CATEGORY

TABLE A-1
AVERAGE LOG YARD COSTS BY COST CATEGORY BY YEAR
(constant 1993 $/m³)

Cost Category	1990	1991	1992	Average 1990-92
Supplies	0.87	0.68	0.74	0.77
Wages	1.03	0.95	0.97	0.98
Power	0.02	0.04	0.03	0.03
Total Variable	1.92	1.67	1.73	1.78
Depreciation	0.21	0.19	0.17	0.19
Plant Overhead	0.28	0.29	0.27	0.28
Head Office Admin.	0.08	0.09	0.10	0.09
Total Fixed	0.57	0.57	0.54	0.56
Total Cost	2.50	2.24	2.27	2.34

<u>Log Yard Cost Functions</u>

The explanatory variable for log yard total and variable costs (LOGTC and LOGTVC) was limited to the volume of logs processed per year (LOGVOL). The fixed cost function had LOGVOL and LOGFPCT (log yard fixed costs as a percentage of total log yard costs) as explanatory variables. Both functions were estimated using the Cobb-Douglas and quadratic average cost functional forms but only the Cobb-Douglas form produced useful results. The estimated functions based on 162 observations were:

(A-1) $LOGTC = 5{,}313\ LOGVOL^{0.8631}$ $F = 225$ $R^2 = 0.58$

(A-2) $LOGTVC = 3{,}781\ LOGVOL^{0.8734}$ $F = 245$ $R^2 = 0.61$

(A-3) $LOGTFC = 21.66\ LOGVOL^{0.8755}\ LOGFPCT^{1.2675}$ $F = 311$ $R^2 = 0.80$

All estimated coefficients have the expected signs and were significant at the 99% confidence level. The coefficients for LOGVOL in both equations suggest that economies of scale exist for log yard operations.

A.3 Sawmilling

The sawmilling phase accounts for 54% of total lumber manufacturing costs, costing on average $72.47/MBF of rough green lumber produced. Figure A-2 provides a percentage breakdown of sawmilling phase costs by cost category. Variable cost made up 72% of total phase costs with fixed costs making up the remaining 28%. This phase had the highest depreciation costs. Table A-2 presents the average phase cost by cost category over the study period. Total average phase cost by year varied by only ± 3% over the 3 year average.

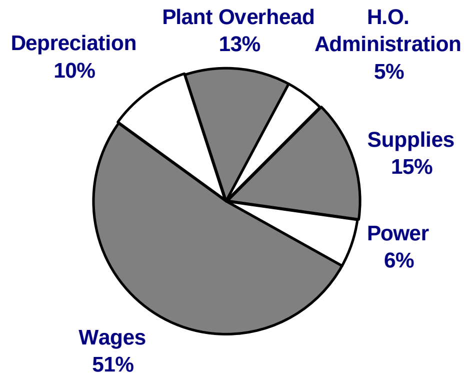

FIGURE A-2
SAWMILLING COST BREAKDOWN BY COST CATEGORY

TABLE A-2
AVERAGE SAWMILLING COSTS BY COST CATEGORY BY YEAR
(constant 1993 $/MBF)

Cost Category	1990	1991	1992	Average 1990-92
Supplies	10.51	11.10	10.97	10.87
Wages	38.35	38.21	36.10	37.60
Power	4.09	4.38	4.12	4.20
Total Variable	52.95	53.69	51.19	52.66
Depreciation	7.04	7.87	6.50	7.13
Plant Overhead	9.51	9.52	9.09	9.39
Head Office Admin.	2.96	3.40	3.51	3.29
Total Fixed	19.51	20.80	19.10	19.81
Total Cost	72.46	74.49	70.29	72.47

Sawmilling Cost Functions

The same model used in Section 3 to estimate lumber manufacturing cost functions was used to estimate sawmilling phase cost functions. The results for the total cost, variable, cost and fixed cost functions, estimated using the Cobb-Douglas power functional form, are listed in Table A-3. The results for the average cost quadratic functional form are presented in Table A-4. Initial regression runs showed the coefficient for PL to be statistically insignificant in all equations as were the coefficients for PK and CAP in the in the variable and average variable cost equations. These variables were dropped from the final regressions presented. The regressions are based on 170 observations.

TABLE A-3
TOTAL, VARIABLE AND FIXED COST FUNCTION REGRESSION RESULTS FOR THE SAWMILLING PHASE

Independent Variables	Dependent Variables ln(TC)	ln(TVC)	ln(TFC)
Intercept	16.6613 (23.255)a	17.6883 (24.355)a	11.0546 (15.298)a
ln(Q)	0.8011 (29.411)a	0.7646 (29.929)a	0.7366 (30.192)a
ln(PK)	0.2449 (7.010)a	-	0.16 (3.526)a
ln(LRF)	-0.7339 (5.702)a	-1.0396 (7.263)a	-0.7085 (4.975)a
ln(CAP)	-0.2588 (4.598)a	-	-
ln(SAWFPCT)	-	-	1.0645 (19.770)a
F	358.606	496.323	582.835
R^2	0.897	0.856	0.934
Adj. R^2	0.894	0.854	0.932

Values in brackets are the absolute value of the "t" statistic for the estimated coefficients.
a - significant at the 99% confidence level.
b - significant at the 95% confidence level.

All equations are highly significant, as shown by the F statistic, and have reasonable predictive power as indicated by their R^2. All coefficients have the theoretically correct sign and are significant at the 95% confidence level or better.

Comparison of the sawmilling phase results to the lumber manufacturing results reveals that the sawmilling phase is, not surprisingly, more sensitive to changes in LRF. For sawmilling the elasticity of average total cost with respect to LRF was estimated at -0.73 based on the total cost function results and at -1.27 from the average total cost quadratic functional form as compared to elasticities of -0.53 and -0.73 for the entire lumber manufacturing process.

The elasticity of average total cost with respect to output for the sawmilling phase was estimated at -0.20 based on the total cost function results and at -0.26 from the average total cost quadratic functional form as compared to elasticities of -0.18 and -0.22 for lumber manufacturing.

TABLE A-4
AVERAGE TOTAL, VARIABLE AND FIXED COST FUNCTION REGRESSION RESULTS FOR THE SAWMILLING PHASE

Independent Variables	Average Total Cost	Average Variable Cost	Average Fixed Cost
		Dependent Variables	
Intercept	431.5038	387.8944	72.3382
	(7.155)a	(8.394)a	(4.108)a
Q	-0.3825	-0.3656	-0.1199
	(4.619)a	(6.474)a	(5.686)a
Q^2	0.00095	0.000904	0.000276
	(3.760)a	(4.901)a	(4.052)a
PK	0.8991	-	0.1395
	(4.836)a		(2.180)b
LRF	-2.3412	-2.2304	-0.4875
	(4.690)a	(5.704)a	(3.316)a
LRF^2	0.004153	0.003973	0.000851
	(4.102)a	(4.979)a	(2.874)a
CAP	-0.2099	-	-
	(3.649)a		
SAWFPCT	-	-	0.849
			(16.427)a
F	62.249	86.697	109.407
R^2	0.696	0.678	0.801
Adj. R^2	0.685	0.670	0.794

Values in brackets are the absolute value of the "t" statistic for the estimated coefficients.
a - significant at the 99% confidence level.
b - significant at the 95% confidence level.

A.4 Kiln Drying

Kiln drying costs made up only 5% of total lumber manufacturing costs, costing on average $7.85/MBF of lumber dried. Figure A-3 provides a percentage breakdown of kiln drying phase costs by cost category. Not surprisingly energy inputs were the highest cost category, accounting for just over a third of total phase costs. This pushed variable costs up to 83% of total phase cost with fixed costs making up the remaining 17%. Table A-3 presents average phase costs by year. This was the only phase examined were there was a substantial year to year fluctuation in costs. Cost in 1991 were 10.2% below the three year averages and were 12.7% higher in 1992. Variation in average wage and supply costs appears to have been the reason.

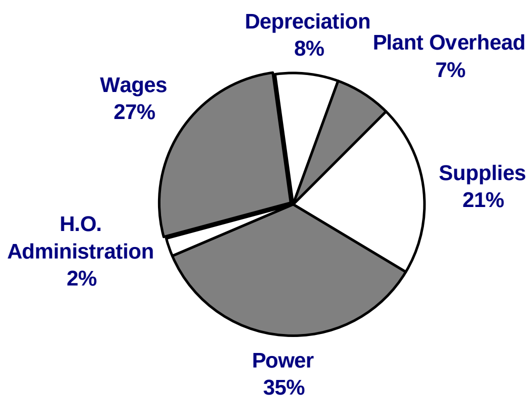

FIGURE A-3
KILN COST BREAKDOWN BY COST CATEGORY

TABLE A-5
AVERAGE KILN COSTS BY COST CATEGORY BY YEAR
(constant 1993 $/MBF)

Cost Category	1990	1991	1992	Average 1990-92
Supplies	1.52	1.46	2.03	1.67
Wages	2.10	1.69	2.50	2.11
Power	2.64	2.74	2.82	2.74
Total Variable	6.26	5.89	7.36	6.52
Depreciation	0.59	0.53	0.76	0.63
Plant Overhead	0.56	0.45	0.56	0.53
Head Office Admin.	0.18	0.18	0.18	0.18
Total Fixed	1.33	1.16	1.49	1.33
Total Cost	7.60	7.05	8.85	7.85

<u>Kiln Cost Functions</u>

As was the case with the log yard cost model developed above the explanatory variables used for kiln operation total and variable costs (KILTC and KILTVC) was limited to the volume of lumber dried per year (KILVOL). The fixed cost function had KILVOL and KILFPCT (kiln fixed costs as a percentage of total kiln costs) as explanatory variables. The functions were estimated using both the Cobb-Douglas and quadratic average cost functional forms. The estimated functions based on 158 observations were:

(A-4)	KILTC	=	$43{,}551\ KILVOL^{0.6158}$	F = 182.0	$R^2 = 0.53$
(A-5)	KILTVC	=	$31{,}264\ KILVOL^{0.6476}$	F = 200.5	$R^2 = 0.56$
(A-6)	KILTFC	=	$428.5\ KILVOL^{0.5759}\ KILFPCT^{1.081}$	F = 215.2	$R^2 = 0.74$
(A-7)	KATC	=	$32.1125 - 0.3339\ KILVOL + 0.000959\ KILVOL^2$	F = 14.2	$R^2 = 0.15$
(A-8)	KAVC	=	$19.583 - 0.1742\ KILVOL + 0.000485\ KILVOL^2$	F = 22.7	$R^2 = 0.23$
(A-9)	KAFC	=	$5.411 - 0.1446\ KILVOL + 0.000434\ KILVOL^2 + 0.3715\ KILFPCT$	F = 15.9	$R^2 = 0.24$

All estimated coefficients have the expected signs and were significant at the 99% confidence level except for the intercept term in the KAVC equation. The coefficients for KILVOL in all equations suggest that economies of scale exist for kiln operations.

A.5 Planer Mill

The planer mill was the second most expensive phase making up 24.6% of total lumber manufacturing costs. Figure A-4 provides a percentage breakdown of phase costs by cost category. Wages accounted for over half of total phase costs with variable costs making up 74% of total phase costs and fixed costs accounting for the remaining 26%. Table A-6 shows average phase costs by cost category over the three years. Planing costs averaged $33.10/MBF of finished lumber produced. Average cost by year varied by only ± 5% from the three year average.

<u>Planer Mill Cost Functions</u>

The same model used in Section 3 to estimate lumber manufacturing cost functions was used to estimate planer mill phase cost functions. The results for the total cost, variable, cost and fixed cost functions, estimated using the Cobb-Douglas power functional form, are listed in Table A-7. The results for the average cost quadratic functional form are presented in Table A-8. Initial regression runs showed the coefficient for CAP to be statistically insignificant in all equations. The coefficient for LRF was insignificant in the total cost functions but significant in the average cost functions. The coefficients for PL and PK were significant in all equations except the average variable cost functions. The insignificant variables were dropped from the final regressions presented. The regressions are based on 167 observations.

All equations are highly significant, as shown by the F statistics. The total cost functions had reasonable predictive power as indicated by their R^2. However, the average cost functions did not perform as well. All coefficients have the theoretically correct sign and are significant at the 95% confidence level or better.

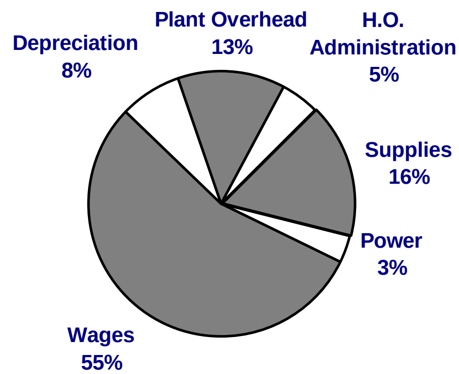

FIGURE A-4
PLANER COST BREAKDOWN BY COST CATEGORY

TABLE A-6
AVERAGE PLANER COSTS BY COST CATEGORY BY YEAR
(constant 1993 $/MBF)

Cost Category	1990	1991	1992	Average 1990-92
Supplies	5.51	5.78	5.51	5.60
Wages	17.74	18.51	16.88	17.72
Power	1.14	1.30	1.11	1.18
Total Variable	24.39	25.59	23.50	24.50
Depreciation	2.30	3.09	2.34	2.57
Plant Overhead	4.62	4.50	4.35	4.50
Head Office Admin.	1.40	1.60	1.61	1.53
Total Fixed	8.32	9.19	8.30	8.60
Total Cost	32.71	34.78	31.79	33.10

TABLE A-7
TOTAL, VARIABLE AND FIXED COST FUNCTION REGRESSION RESULTS FOR THE PLANER MILL PHASE

Independent Variables	Dependent Variables ln(TC)	ln(TVC)	ln(TFC)
Intercept	10.5309	10.7375	6.0657
	(38.140)a	(35.458)a	(21.076)a
ln(Q)	0.6593	0.6563	0.6647
	(19.665)a	(17.849)a	(19.830)a
ln(PL)	0.1346	0.1427	0.134
	(3.074)a	(2.971)a	(3.074)a
ln(PK)	0.3610	0.18	0.4321
	(5.912)a	(2.688)a	(5.779)a
ln(PLAFPCT)	-	-	0.8844
			(12.481)a
F	158.290	120.589	243.504
R^2	0.745	0.689	0.857
Adj. R^2	0.740	0.684	0.854

Values in brackets are the absolute value of the "t" statistic for the estimated coefficients.
a - significant at the 99% confidence level.
b - significant at the 95% confidence level.

The coefficients for output in the total cost functions suggested that there were greater economies of scale in the planer mill than was found in the sawmill or for the lumber manufacturing process as a whole. The elasticity of average total costs with respect to output was estimated to be -0.34 using the total cost function and -0.46 using the average total cost function. This compares to -0.20 and -0.26 for the sawmill phase and -0.18 and -0.22 for the entire lumber manufacturing process.

The insignificance of LRF in the total cost functions and its significance in the average cost functions is puzzling. LRF should not directly influence planer mill costs as its input is the rough lumber produced in the sawmill. However, LRF may indirectly affect planer mill operations by affecting the volume per shift produced in the sawmill and by affecting the dimensions of the lumber which can be cut out. Together these indirect effects may affect the flow of lumber through the planer mill. The elasticity of average total cost to changes in LRF, based on the average cost function was -0.44. This is well below the -1.27 and the -0.73 derived from the average total cost function for the sawmilling phase and for the entire lumber manufacturing process respectively.

TABLE A-8
AVERAGE TOTAL, VARIABLE AND FIXED COST FUNCTION REGRESSION RESULTS FOR THE PLANER MILL PHASE

Independent Variables	Dependent Variables: Average Total Cost	Average Variable Cost	Average Fixed Cost
Intercept	167.3724	187.3049	32.1227
	(3.707)a	(5.602)a	(2.122)b
Q	-0.29	-0.1791	-0.07133
	(5.486)a	(4.461)a	(4.102)a
Q^2	0.000676	0.000446	0.000156
	(3.950)a	(3.407)a	(2.790)a
PL	0.153	-	0.06508
	(2.648)a		(3.451)a
PK	0.7102	-	0.2008
	(5.273)a		(3.627)a
LRF	-1.0281	-1.136	-0.2704
	(2.752)a	(4.026)a	(2.161)b
LRF^2	0.002057	0.002148	0.000569
	(2.718)a	(3.735)a	(2.262)b
PLAFPCT	-	-	0.3496
			(9.184)a
F	25.179	30.677	40.920
R^2	0.486	0.431	0.643
Adj. R^2	0.466	0.417	0.627

Values in brackets are the absolute value of the "t" statistic for the estimated coefficients.
a - significant at the 99% confidence level.
b - significant at the 95% confidence level.

A.6 Lumber Yard

Lumber yard operations accounted for 6.5% of total lumber manufacturing phase costs, costing on average $8.60/MBF of lumber shipped. Figure A-5 shows the percentage breakdown of total phase costs to each cost category. Variable costs made up 76% of total phase costs with fixed costs making up the remaining 24%. Table A-9 presents average phase costs by cost category over the three year study period. Average cost by year varied by only ± 5% of the three year average.

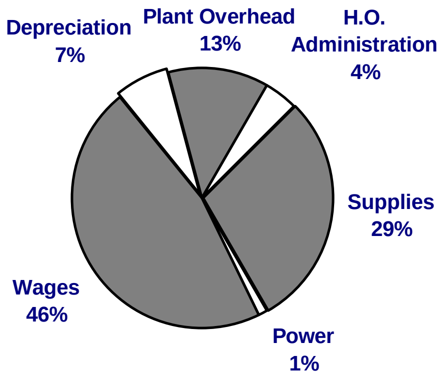

FIGURE A-5
LUMBER YARD COST BREAKDOWN BY COST CATEGORY

TABLE A-9
AVERAGE LUMBER YARD COSTS BY COST CATEGORY BY YEAR
(constant 1993 $/MBF)

Cost Category	1990	1991	1992	Average 1990-92
Supplies	2.88	2.34	2.33	2.53
Wages	4.19	3.79	3.95	3.99
Power	0.07	0.09	0.12	0.09
Total Variable	7.15	6.22	6.40	6.61
Depreciation	0.46	0.60	0.63	0.56
Plant Overhead	1.10	1.04	1.09	1.08
Head Office Admin.	0.36	0.34	0.35	0.35
Total Fixed	1.92	1.98	2.07	1.99
Total Cost	9.07	8.20	8.47	8.60

Lumber Yard Cost Functions

As was the case with the log yard and kiln cost functions, the lumber yard cost functions has phase volume, in this case lumber yard throughput per year (LUMVOL), as the only explanatory variable in the total and variable cost functions (LUMTC and LUMTVC). LUMVOL and LUMFPCT (lumber yard fixed costs as a percentage of total lumber yard costs) were the explanatory variables used in the fixed cost function (LUMTFC). Only the Cobb-Douglas functional form produced useful results. The estimated functions, based on 164 observations, were:

(A-10)	LUMTC =	$19{,}690\ LUMVOL^{0.7905}$	$F = 89.4$	$R^2 = 0.35$
(A-11)	LUMTVC =	$17{,}631\ LUMVOL^{0.7555}$	$F = 75.0$	$R^2 = 0.32$
(A-12)	LUMTFC =	$195.9\ LUMVOL^{0.7907}\ LUMFPCT^{1.0008}$	$F = 110.0$	$R^2 = 0.58$

All estimated coefficients have the expected signs and were significant at the 95% confidence level. The coefficients for LUMVOL in all equations suggest that economies of scale exist for lumber yard operations.

A.7 Other Costs

Only 39 observations of costs for an "other phase" were reported (e.g. finger joining), ten observations for 1990, eight for 1991 and nineteen for 1992. Of these observation only nine reported phase output. Thus, average costs cannot be meaningfully calculated for this phase. Figure A-6 presents the percentage distribution of total costs for other phases by cost category. Variable costs accounted for 74% of total costs with fixed costs making up the remaining 26%. Depreciation costs were significantly higher and head office administration costs lower than was found in the other phases.

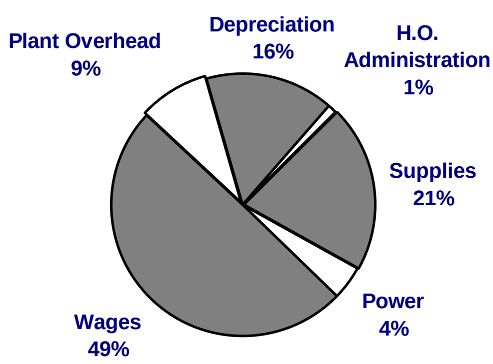

FIGURE A-6
OTHER PHASE COST BREAKDOWN BY COST CATEGORY