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PRODUCTION STRUCTURE OF THE SAWMILLING
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PRODUCTION STRUCTURE OF THE SAWMILLING INDUSTRY OF THE LAKE STATES

By

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ABSTRACT

PRODUCTION STRUCTURE OF THE SAWMILLING INDUSTRY OF THE LAKE STATES

By

James Robert George M[c]Queen

This study examined the production structure of the sawmilling industry of the Lake States (Michigan, Minnesota and Wisconsin) in order to determine elasticities of substitution, elasticities of demand, technological change, the bias of technological change and returns to scale. A homogeneous translog cost function was estimated using pooled time-series data for the period 1963-1996.

Results for the Allen Partial Elasticity of Substitution (AES) indicate that labor and materials were inelastic substitutes while labor and capital were elastic complements. Materials and capital were also inelastic substitutes. Materials and capital have the greatest substitutability but only slightly more so than labor and materials.

The Morishima Elasticity of Substitution (MES) results indicate that all three inputs were inelastic substitutes with the greatest substitutability between capital/material. The results for the substitutability of labor/material and material/labor were similar to the AES results. The labor/capital and material/capital rates of substitution were much less than the capital/labor and capital/material rates.

The own-price elasticities of demand were all inelastic and negative indicating downward sloping demand curves. All other elasticities were inelastic and indicate that materials was a substitute for labor and capital but labor and capital were complements. Changes in the price of materials had a relatively large, but inelastic, effect on the

demand for capital with a cross-price elasticity of 0.56. Changes in the price of labor also had a relatively large effect on the demand for capital, but in a complementary fashion, with an elasticity of -0.46. Changes in the price of materials had a greater effect on the demand for labor than the other way around with cross-price elasticities of 0.55 and 0.30, respectively.

Variable costs increased by 0.8% per year over the study period *ceteris paribus*. The results for bias of technical change showed that it was materials and capital-using and labor-saving. The labor savings were not as high as other lumber producing regions of North America with an average value of -0.62%/year. The bias of technical change for materials was 0.31%/year and for capital, it was 0.30%/year. These figures are important in that they may limit the competitiveness of the industry in the Lake States with respect to other regions because labor productivity was not increasing as fast as it was elsewhere.

The hypothesis of constant returns to scale could not be rejected at the 1% level. This was common for studies of the sawmill industry but seems particularly common to regions where the industry was made up primarily of small mills. Constant returns to scale in a mature sawmill industry would lead to the outcome of many mills of similar size as all economies of scale have been exhausted and the industry has settled into an equilibrium firm size near the minimum of the long run cost function. Nevertheless, this does not explain why the average mill size in the Lake States is small compared to the Pacific Northwest and Southeastern U.S.

To my wife Lorie Srivastava and my parents, George and Janet McQueen.

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There are many people that deserve acknowledgement for their support and efforts in helping me complete my degree.

Dr. Karen Potter-Witter served as my major professor for most of my stay at Michigan State and she was very patient and encouraging of my efforts and provided valuable guidance as well as giving me the opportunity to interact with students in the lab and in the classroom. She was also responsible for securing the funding for this project.

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Dr. James Stevens was my first adviser at Michigan State and coauthor of my first refereed journal article. I look forward to meeting up with him out West.

My wife Lorie Srivastava was also instrumental in maintaining my good humour and making our time at the university very much fun.

My parents also always provided encouragement and never doubted my ability to finish, despite the fact that no phone conversation was complete without the polite query: "Are you done yet?". Parents!

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This is a study of the production structure of the sawmill industry of the Lake States (Michigan, Minnesota, and Wisconsin). Productivity and the demand for inputs are important aspects of the competitiveness of the industry as resource constraints increase.

At the root of economics is the concept of opportunity cost and the tradeoffs implied by that. Along those lines, the concept of sustainable forestry raises the question of the tradeoffs made in forest management in an environment of increasing scarcity. One of those tradeoffs is between harvesting timber or not. Forest managers and private landowners are making that decision all the time although not necessarily in the context of sustainable forest management. Nevertheless, if the decision is not to harvest, or to harvest later, the timber supply is constrained and that could have an effect on the mix of inputs used in the sawmill industry.

The purpose of the study is to provide an understanding of the relationships among the inputs to the sawmill sector, how those relationships changed over the study period, the effect of input price changes on input demand and the effect of output levels on industry costs. A translog cost function was estimated to determine the elasticities of substitution and the own and cross-price elasticities of demand for the major inputs (labor, materials and capital). In addition, total factor productivity, the bias of technological change and economies of scale were measured.

This chapter provides background on the sawmill industry in the Lake States from 1963-1996 with regards to input supply and demand, major changes in milling technology, and a comparison to other regions in the U.S. It also includes background on the research questions, motivation and objectives of the research and an outline for the dissertation.

1.1 The Industry

The sawmill industry of the Lake States has been an important part of the regional economy since the first European settlers arrived in the 19^{th} century. Today, it is not as important as other manufacturing industries, but still employs a large number of people. In 1996 there were almost 11,000 production workers employed in the sawmill industry in the Lake States as compared to 9,200 in Washington and 13,000 in Oregon. The value of shipments was $1.5 billion in 1996 while they were $2.8 billion in Washington and $3.3 billion in Oregon (ASM 1996).

The Standard Industrial Classification (SIC) system classifies industries in increasingly specific categories with increasing number of classifying digits. SIC 242 (Sawmills and Planing Mills) represents a three-digit industry, and is a subset of SIC 24 (Lumber and Wood Products). Thus, all of SIC 242 is contained in SIC 24. Other three digit industries within SIC 24 include Logging (SIC 241), Millwork, Plywood and Structural Members (SIC 243), Wood Containers (SIC 244), Wood Buildings and Mobile Homes (SIC 245), and Miscellaneous Wood Products (SIC 249). The hierarchy continues with four-digit industries as well.

This study is restricted to SIC 242 which encompasses sawmills and planing mills producing lumber, both hardwood and softwood. A sawmill takes sawlogs as its primary material input and using a variety of saws removes the unwanted wood to produce lumber for use in building construction, furniture building, flooring and so on. Sawmills do not include operations that peel logs for use as veneer nor do they produce structural panels such as plywood or engineered wood products such as oriented strand board (OSB). While sawmills and planing mills produce the manufactured wood product input for the furniture industry, the furniture industry is not part of SIC 24; it is part of SIC 25 (Furniture and fixtures).

In the early to mid-19th century, the states conducted surveying of land for assigning legal title and logging of white pine in particular began in earnest in the region. This continued until about the turn of the century when stocks of white pine were virtually exhausted. The production process at the time involved logging camps scattered throughout the forest with logging taking place primarily in winter. Logs were stored next to streams and rivers and floated downstream during spring runoff. Mills were typically located along large rivers or at the mouth of large rivers flowing into the Great Lakes (Stearns 1997).

During the mid-19th century, milling and sawing technology also changed. Mills switched from water power to steam power with the waste wood from milling providing the fuel. Later, the muley saw and the circular saw replaced the sash saw. The circular saw had a very wide kerf and wasted a lot of wood. It was eventually replaced with the band saw (Stearns 1997).

In the late 1970s and early 1980s there was a large change in the technology of modern sawmills in North America, primarily in the softwood lumber producing regions. The advent of computers drastically reduced labor requirements in many mills. Computerized cutting control allowed more lumber to be sawn from fewer logs and from logs that were previously unmerchantable. These changes, combined with the North American recession, resulted in a reduction in sawmill employment nationwide. In 1979 there were 223,000 people employed in sawmills in the United States, but by 1982 there were only 157,000 -a 30 percent reduction (ASM various years). Following the recession, employment levels increased somewhat but have not reached the 1979 level. For the Lake States, employment levels have rebounded for the most part (Figure 1-1). Particularly notable is the large increase in employment in Minnesota during the mid 1990s.

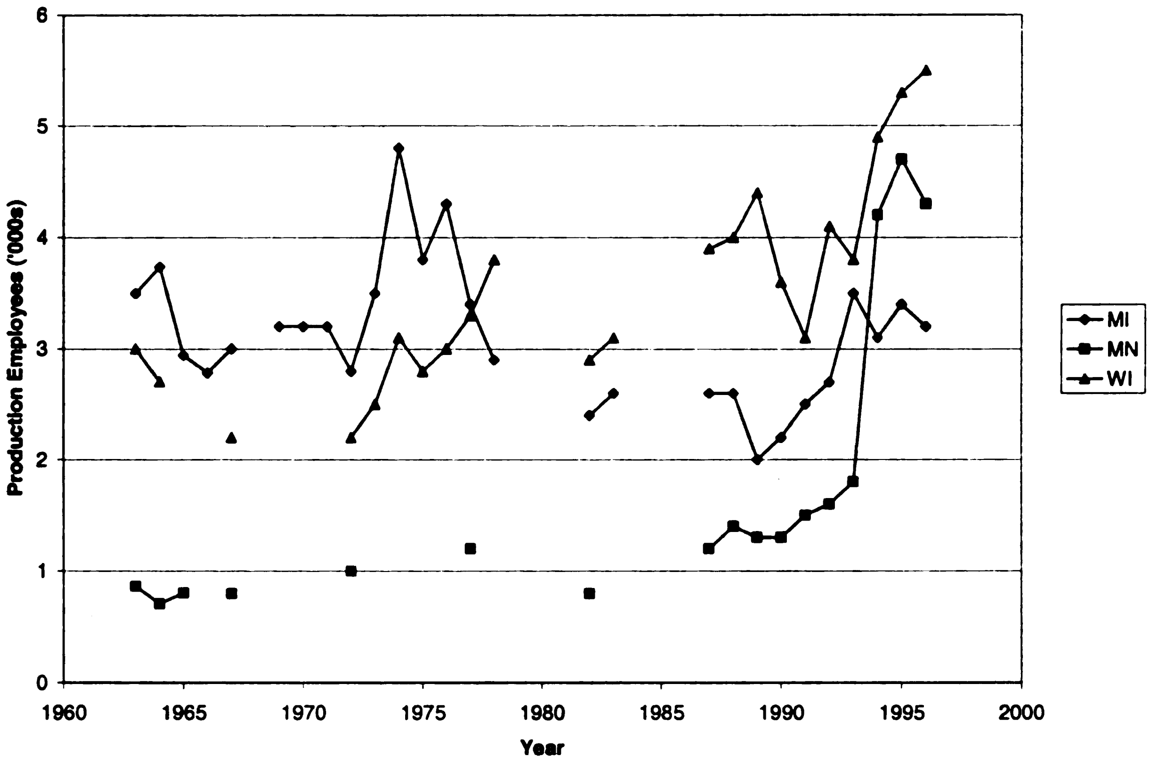

Figure 1-1. Number of Employees by State 1963-1996, SIC 242
(Annual Survey of Manufactures, various years) Breaks in lines represent years for which data were not available.

There were a total of 567 establishments in SIC 242 in the Lakes States in 1992 with 107 of them having twenty or more employees (Figure 1-2). Wisconsin had the highest proportion of establishments with more than twenty employees at 21%. Michigan had the least at 16%.

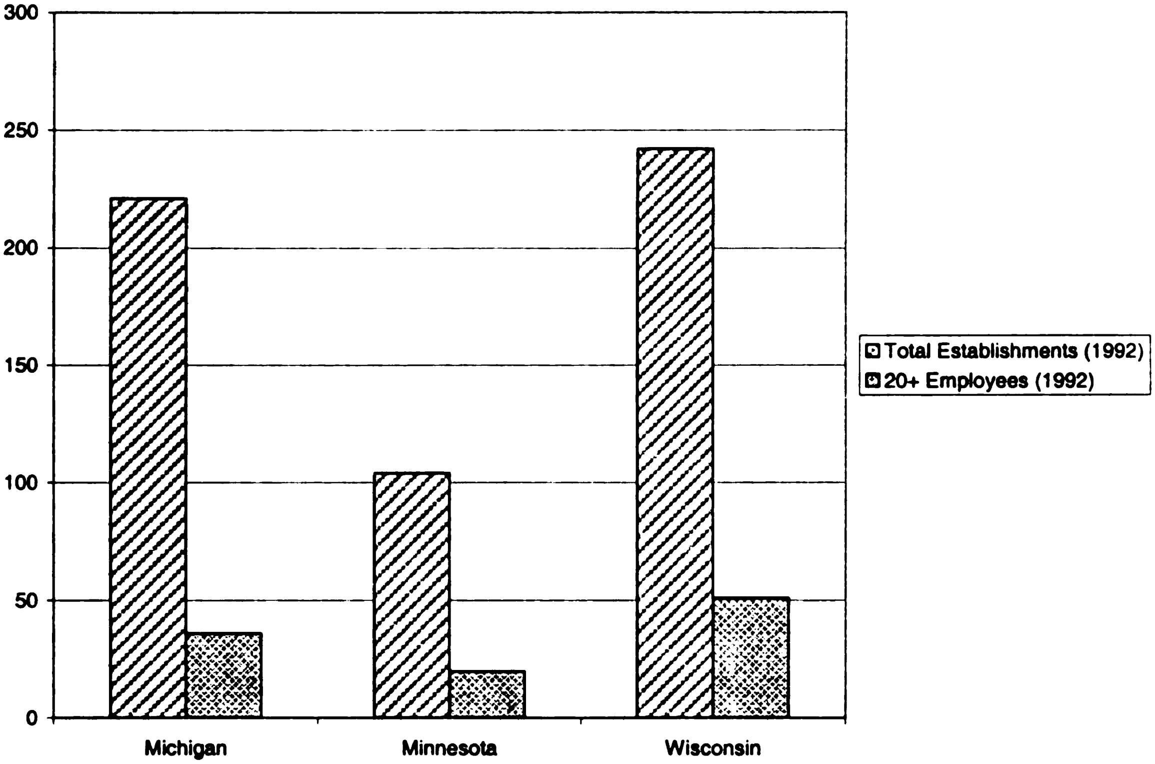

Figure 1-2. Number of Establishments by State 1992, SIC 242
(Census of Manufactures 1992)

Lumber output is probably the most important measure of the size of the industry in each state (Figure 1-3). Total production in the Lake States in 1996 was 1,582 million board feet (MMBF), approximately 75% of which was hardwood lumber (Census Bureau 1996). There was a sharp increase in production in all three states in 1993 (Figure 1-3). For Wisconsin and Minnesota, part of the production increase can be explained by large new capital expenditures in the mid 1990s. Another reason was a reconciliation among the MA24T (Lumber Production and Mill Stocks), the 1992 Census of Manufactures and state sawmill directories in 1994 (Census Bureau 1994). This reconciliation was a review of the statistical sample used to generate the state and national lumber production statistics and led to large upward revisions for output for each of the Lake States starting in 1993. A further reason for the sharp increase may be the large reduction of lumber production in the Pacific Northwest around that time because of reduced sales of timber from Federal lands that resulted from the strategy to protect northern spotted owl habitat. It was unclear if the revisions have any effect on the output statistics for years prior to 1993, but if a smooth upward trend in output was assumed, productivity numbers for years before 1993 have been underestimated to the extent that the reported output was lower than actual output.

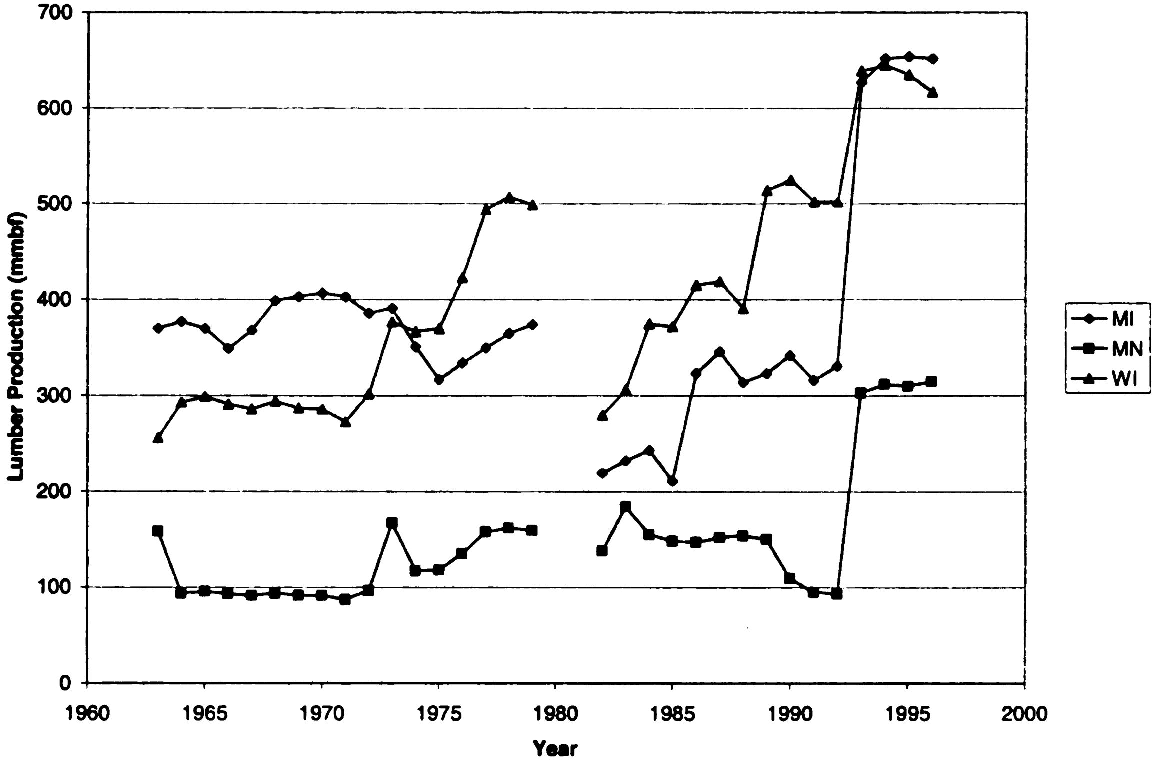

Figure 1-3. Lumber Production by State, 1963-1996, (MMBF)
(Census Bureau, MA24T, 1963-1996)

1.2 The Forest Resource

Within the Lake States there is variability in the timber resource. There are a total of 47.4 million acres of timberland[1] in the region and 56 billion cubic feet of growing stock[2] (Vasievich *et al.* 1997). Michigan has roughly double the timber volume of Minnesota (Table 1-1).

Hardwood forests predominate in the region (Table 1-1). The important hardwood species are aspen, red oak, white oak, ash, hickory, hard maple, soft maple, and basswood. Hardwoods are used typically for veneer, or for lumber for furniture, cabinets, moulding and flooring. Aspen is used largely to produce pulp, reconstituted panel products and oriented strand board. Overall, the region's standing timber is 72 percent hardwood by volume. In the softwood forest regions farther north, particularly in Minnesota, wood for pulp dominates but there is still a softwood lumber industry. Softwood is also used for wood products such as plywood and fiberboard.

Table 1-1. Volume of Standing Timber 1996 (million cubic feet)

STATE	Softwood	Hardwood	Total
Michigan	7,576	19,085	26,661
Minnesota	4,652	10,495	15,147
Wisconsin	4,452	14,059	18,511
Total	**16,680**	**43,639**	**60,319**

Source: USDA Forest Service FIA Database Retrieval System

The forestland in the Lake States is predominately privately owned and most is non-industrial private forest (NIPF) (Figure 1-4). NIPF is private land not owned by the forest industry.

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[1] Timberland is forestland capable of producing a minimum of 20 cubic feet of merchantable timber per acre annually and not subject to legal restrictions that preclude timber harvesting.

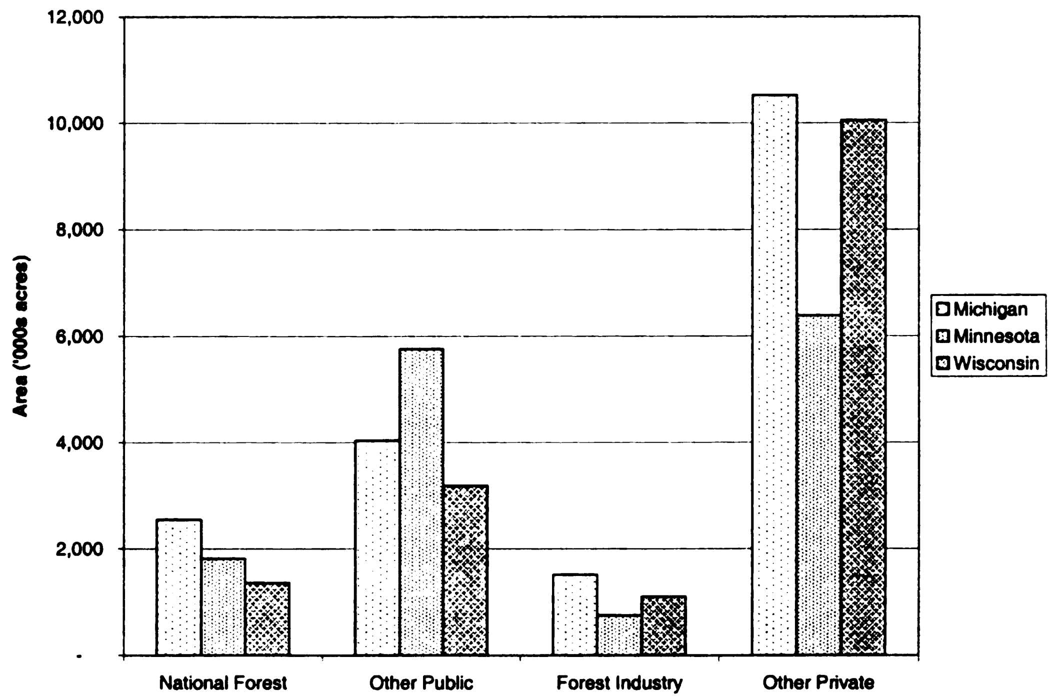

Figure 1-4. Forestland Area by State and Ownership 1996, (thousands of acres). (USDA, Forest Service)

Despite the fact that most forest land in the Lake States is privately owned, there is significantly more public forest land than in states immediately to the south. This is partly due to settlement patterns during the 19th century. Another significant factor was the reverting of land back to the state as a result of delinquent property tax payments. Serious delinquency problems resulted in a large area of land reverting to the state in the cutover areas of the Lakes States (Barlowe 1986).

There were over eight hundred million cubic feet of timber harvested in the Lake States in 1996 (Figure 1-5). The proportion of timber removals from each ownership type closely matches the proportion of forestland area in each ownership type. Nevertheless,

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[2] Growing stock includes trees with a minimum diameter at breast height of 5 inches with merchantable volume measured 1 foot above the ground up to a top diameter of 4 inches. Rot or other defects that reduce merchantable yield are subtracted from that volume.

for individual states there is more variation. In Michigan and Minnesota, National Forests had a greater percentage of removals than their proportion of the forestland base. This is an indication of the different resource management strategies and timber resources of the National Forests in these states.

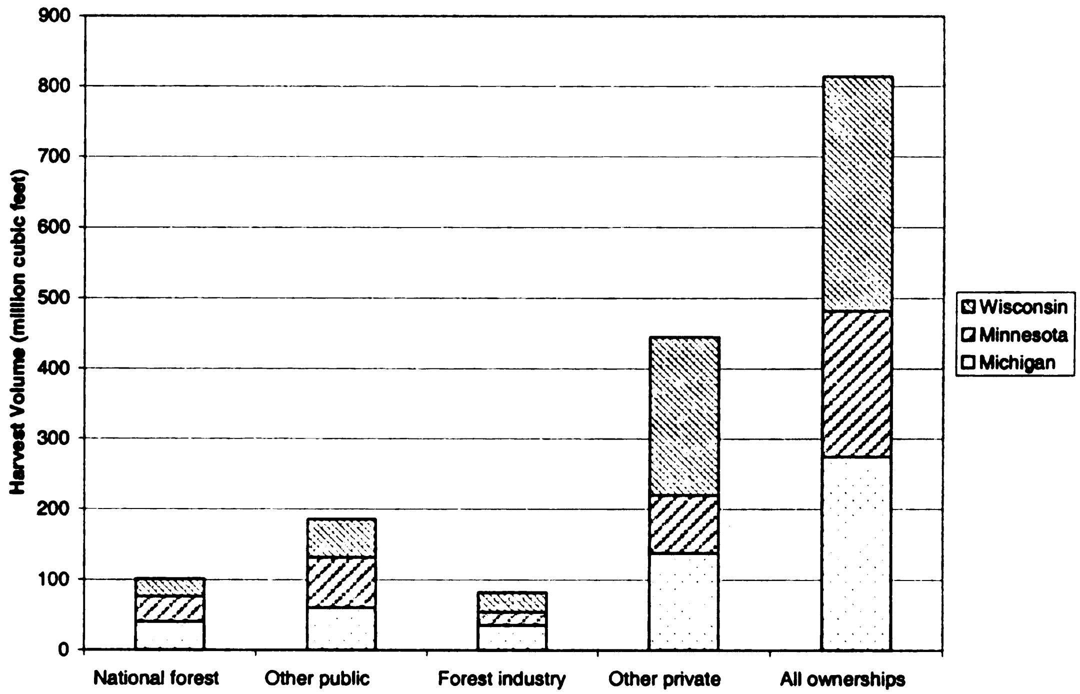

Figure 1-5. Timber Removals by State and Ownership 1996, (million cubic feet) (USDA Forest Service)

1.3 Timber Pricing

The cost-minimization model used in this study assumes that input and output markets are perfectly competitive. Over the study period with the dataset used here, materials have made up 64 percent of sawmill costs with the remainder being made up of labor and capital costs. Materials is almost entirely sawlogs but some mills will plane rough lumber so for them materials comprises both sawlogs and rough lumber. Baardsen (2000) criticizes studies that aggregate sawmill production and cost data at the national level, or regional level where the industry is a large contributor to the regional economy, because this would violate the assumption that input and output markets are perfectly competitive. In a region where the sawmill industry is large, wages may be determined partly by the industry itself, that is, the labor price is endogenous to the industry. In this case the sawmills are not price takers and this violates the assumption of perfect competition. For this study, it seems clear that the industry does not affect or otherwise determine wage rates because it is small compared to the rest of the economy in the Lake States and it is reasonable to assume that sawmills are price takers in the labor market. The same argument can be made for the capital market. Baardsen's criticism is most applicable to the market for materials (wood). This section examines the pricing mechanisms for timber on national, state and private lands in the Lake States. Some components of the pricing methods on public lands are determined within the region (logging costs, transportation costs) but others such as output price are determined in the lumber market as a whole and production from the Lake States sawmill industry is small relative to world or national production and so it is unlikely that it influences output price. Also, timber is bought and sold across state boundaries outside the study region. This serves to mitigate the influence sawmills in the Lake States may have over timber prices.

The method used to determine a sale price for timber depends on the ownership of the timber or timberland. Public land managers are constrained by law and regulations as to what methods they may use to sell public timber. Private landowners have very few, if any, restrictions on how they can sell their timber. There are two kinds of private forestland: industrial private forestland (IPF) and nonindustrial private forestland (NIPF).

IPF is land owned by pulp and paper companies or sawmills or some other owner that uses the land for timber production. NIPF is made up of landowners such as farmers, or other landowners for whom timber production is not the purpose of owning the land. IPF is not prevalent in the Lake States (7% by area) while NIPF makes up 55% of forestland and the rest, 38%, is public land (USDA Forest Service 1997). IPF area is not large compared to other ownerships and it is mostly used for production of pulpwood so the issue of transfer pricing for timber within vertically integrated lumber products manufacturers is not an issue for this study. Some NIPF sales are done with competitive bids with or without forester assistance, while others are not. Some sales may be made only if a logger approaches the landowner and offers to buy a few trees.

Pricing for timber from National Forests follows a stricter format. According to the National Forest Management Act of 1976, timber from National Forests cannot be sold for less than its appraised value (USDA For. Serv. 1978). On National Forests the traditional method of appraisal has been the residual value (RV) approach. In its simplest form, the RV method determines a minimum bid price based on the following formula:

$$SP-(MC+LC+P\&R)=S,$$

where *SP* is output price, *MC* is milling cost, *LC* is logging cost, *P&R* is a profit and risk margin and *S* is stumpage. Once a minimum bid price is set, bids are accepted on the timber sale (USDA For. Serv. 1982). The sale will normally be awarded to the qualified bidder with the highest bid. Note that to a sawmill, the sawlog cost they will see in a perfectly competitive market is:

$$LC+P\&R+S+TC-MC=SLC,$$

where *P&R* is profit and risk to the logger, *TC* is transportation cost to the mill and *SLC* is sawlog cost.

Increasingly, a different approach for appraising stumpage value of a stand of timber in National Forests is being used, although not in the East. The Transactions Evidence Appraisal method (TEA), which is like a hedonic pricing model, is used as an aid to timber appraisal. TEA uses actual sale prices from past sales to help determine the final sale price of a current sale. Obviously, no two tracts of timber are identical and the market conditions under which the sale is made will differ from previous sales. Nevertheless, with a database of sale characteristics such as species, volume, quality, terrain, distance from mills and market conditions, it is possible to predict the final stumpage price for a particular sale with a reasonable degree of accuracy (Bare and Smith 1999). The TEA tries to estimate the final sale price for a timber sale but it is up to individual timber buyers to determine their own willingness to pay and bid accordingly.

Pricing of timber from state lands in Michigan follows the "Comparative Method of Stumpage Appraisal" (Michigan DNR, Forest Management Division 2000b). The method is meant to give the State of Michigan fair stumpage return and the timber buyer normal profit. The factors used to appraise stumpage value are based on costs of the average operator for operations including felling and bucking, skidding, road maintenance, hauling, distance to nearest mill, quantity of timber, quality of timber, and market trend and competition (Michigan DNR, Forest Management Division 2000a). Market trend and competition takes into account competition for timber and also the supply of labor. When competition for timber is high and the labor supply is good, the stumpage appraisal is higher.

In Minnesota, sales of timber from state lands are conducted by several methods. These include regular auction sales, intermediate auction sales, informal sales, special fuelwood permits and special product permits (Minnesota Department of Natural Resources, Forestry 2000). Regular and intermediate auction sales can be conducted using either oral or sealed bidding and the winning bidder must pay 15% of the appraised value at the time of sale.

The Wisconsin Department of Natural Resources appraises stumpage rates based on sales data collected by foresters (Wisconsin Department of Natural Resources 1999). Stumpage rates vary based on local market conditions, distance to mills, and other site and timber quality factors. This is a transactions evidence approach similar to that used by the USDA Forest Service for estimating final sale prices for timber sold from national forests.

1.4 Timber Supply

Sustainable forest management (SFM) is growing in importance to forest managers and policymakers and some outcomes of the adoption of SFM may have an effect on the supply and availability of timber for the sawmill industry of the Lake States. The Great Lakes Forestry Alliance, as well as other governmental and non-governmental organizations, are involved in the development of principles, criteria and indicators for sustainable forest management (Williams *et al.* 1998). These criteria typically involve sustainability of ecosystems and biodiversity as well as the economic viability of forest industries. There is a conflict between these two criteria in that improvement of biodiversity may reduce the availability of timber for forest products industries. The extent to which this occurs will vary by political jurisdiction but there is clearly a conflict among many of the criteria for SFM developed by the United Nations and agreed upon in what has become known as the Montreal process (Canadian Forest Service 1995).

There are reasons, other than SFM, that timber supply may be restricted in the future. Changes in attitudes of private landowners in the future may restrict timber supply from NIPF. Fifty-five percent of the forestland in the study region is NIPF. There is a trend toward preservation of forest cover on these lands by new landowners and this could affect availability. Overall, forest managers in the Lake States foresee an 8 percent decrease in area of land available for harvest by 2020 (Vasievich, *et al.* 1997). Apart from potential decreases in overall volume of wood available, the size and quality of the available timber may be decreasing. Smaller diameter logs have lower lumber recovery factors (LRF) than larger diameter logs (Haynes 1990). This will be discussed in the next section.

The price of timber is affected by its supply, but also by the demand for timber. Changes in the price of lumber will affect the price paid for timber through the effect of output price on minimum stumpage prices and also through the change in demand brought about by output price changes. If output price increases, this will increase the minimum bid price for a timber sale (*ceteris paribus*) and it will also increase the demand for timber and therefore its price.

1.5 Productivity in the Sawmill Industry

In addition to the potential resource constraints outlined above, technological change, or productivity is important for the continued competitiveness of the sawmill industry. Until fifty years ago, labor productivity in the sawmill industry has lagged behind that of manufacturing in general in the United States. Between 1899 and 1954, labor productivity grew by 1.1 percent per year, approximately half the rate of the manufacturing sector as a whole (Kendrick 1961). Nevertheless, between 1958 and 1974, labor productivity in the forest products industries grew faster than that for all manufacturing industries (Duke and Huffstutler 1977). But, between 1988 and 2000, output per hour of labor for SIC 242 increased on average 1.8 percent per year, considerably less than the average of 3.3 percent per year for all manufacturing (BLS, Industry Productivity Database).

In addition to the increases in labor productivity, output of industrial wood product per unit of industrial roundwood input increased 39 percent in the period 1900-1998 (Ince 2000). This figure applies to all wood-using industries and is largely explained by increases in the use of residual products such as woodchips, and the success of paper recycling programs but innovations in sawmill technology during the study period have reduced wood waste and allowed more precise control over how each log is sawn. Improved milling technology resulted in better lumber recovery factors (LRF) in lumber producing regions of the United States. In the Pacific Northwest, softwood LRF increased from 6.67 to 7.87 board feet of lumber per cubic foot of timber from 1952-1985 and in the South, it increased from 5.05 to 6.02 during that same period (Haynes 1990). One of the goals of this study is to measure the technological change in the sawmilling industry of the Lake States and to determine if it is biased towards any particular input. Other studies have found that materials-using technological change is partly the result of decreased quality of the wood resource (Martinello 1987). One of the factors affecting quality is the average log size and Haynes (1990) found that in the hardwood lumber industry, LRF improves dramatically when the diameter of the logs being milled is larger.

In the late 1970s, for 11 to 15 inch diameter hardwood logs, the LRF was 3.3 board feet of lumber per cubic foot of timber but for logs greater than 19 inches in diameter, the recovery was 5.6 board feet of lumber per cubic foot of timber. That is almost a 70% improvement over the smaller diameter logs. Given the long history of timber harvests in the Lake States, it may be possible that the average size of the logs is decreasing and there may be decreasing LRF over the study period.

The improvement in productivity of labor and wood in the wood products industry of the United States has allowed the industry to overcome any increasing scarcity of those inputs but it is possible that further improvements may be difficult and that the scarcity will begin to manifest itself in higher timber prices, decreased profits and lower output. It is also possible that decreased supply will drive marginal mills out of business.

1.6 Research Questions

A basic concept in economics is that a reduction in the supply of a good will increase its equilibrium price, ceteris paribus. In the future, the supply of sawlogs to the sawmill industry could well be reduced because of factors outlined in the previous sections. Reduced supply of timber could lead to higher prices for wood which would affect demand for labor and capital so: **"What is the effect on equilibrium quantity demanded in the sawmill industry of changes in factor price?"**

The focus of this study is the production structure of the sawmill industry in the Lake States, and an important aspect of the production structure is how it has changed over time. The region is dominated by mixed hardwood forest, and hardwoods require different technology or more basically a different input mix from softwoods in order to be produced efficiently, given the characteristics of the input and output markets and regulatory system to which the sawmill is exposed. This mix changes over time and technological changes will have implications for employment and regional economies. Consequently, the second research question is: **"What has been the rate and nature of technological change in the sawmill industry of the Lake States during the study period?"**

Regional sawmill industries with positive scale economies can be characterized as having a small number of large producers. Constant returns to scale, or diminishing returns to scale tend to keep individual plant sizes smaller but the number of firms larger. In other words, output per mill is low relative to other regions. Therefore it is valuable to know: **"Does the sawmill industry of the Lake States exhibit any economies or diseconomies of scale?"**

There are no current studies of the production structure of the sawmill industry of the Lake States so some quantification of the demand for inputs to the industry and change in factor productivity will help policymakers assess the possible tradeoffs among the various aspects of sustainable forestry and the effects of changes in relative input prices.

1.7 Objectives

The research questions were answered by calculating elasticities of substitution, own and cross-price elasticities of demand for the major inputs of the sawmill industry, returns to scale and technological change including the bias of technological change. These results are important because they describe the ease and degree with which inputs can be substituted for one another when their relative prices change. Relative price changes can occur for many reasons including reduced timber supply, national monetary policy (interest rates) and the rate of growth of the economy. For the policymaker, the calculated results can provide insights to how the sawmill industry will react when policies are undertaken that may change relative prices of the inputs to the industry. The rate and bias of technological change in the sawmill industry of the Lake States is also important to policymakers because it gives an indication of the future demand for inputs to the industry. For example, if the bias of technological change is materials-saving, then there may be less pressure to increase timber harvests from public lands in the future. This may give policymakers some room to set aside lands for uses other than timber production or to reduce the emphasis on timber production on public land.

1.8 Dissertation Outline

The dissertation consists of three chapters in addition to the introductory chapter plus literature cited and appendices.

Chapter 2 begins by describing the conceptual framework and behavioral model used in developing the analytical model. A review of similar studies of the sawmill industry in the United States, Canada and elsewhere is included here including a table summarizing the important aspects of each study. This is followed by a description of the theoretical background of the analytical methods and a description of the analytical methods themselves. The data used in the model are discussed along with any data manipulation used to prepare the data for analysis.

Chapter 3 contains the actual model and results. The model selection procedure and all necessary statistical tests are included in this section. The calculation of the elasticities, productivity measures and returns to scale are presented here. A discussion of the results and comparison with other studies is also included here.

Chapter 4 includes a summary of the model results and conclusions based on the discussion in Chapter 3. Policy implications of the results are also discussed and areas of further research are identified.

2.0 THEORETICAL BACKGROUND, METHODS AND DATA

This chapter includes the conceptual framework that guided the study. This includes a description and discussion of the behavioral model and theoretical framework. Following that is a discussion of specific empirical methods used to test hypotheses related to the conceptual framework. The chapter ends with a discussion of the data, including sources and transformations required to make the raw data usable in the model.

2.1 Behavioral and Theoretical Framework

2.1.1 Producer Behavior

The primary behavioral assumption in this study is that sawmill managers will minimize costs with respect to a given output level and factor prices. This is a reasonable assumption that is more behaviorally restrictive than the assumption that they are profit maximizers. If we assume that sawmill managers are profit maximizers then they are able to adjust the quantity of both inputs and output to maximize profit. If we assume that they are cost minimizers, then they are only able to adjust the quantity of inputs to minimize costs given a fixed output level.

By minimizing costs, the producers are being both technically and allocatively efficient given an output level and input prices. When relative prices change, the rational producer will use different amounts of each input in order to produce the given output level at the minimum cost. In this case, we are allowing producers to vary the quantities of labor, sawlogs and capital used in the production process. The interest here is in the degree to which one input will substitute for another when relative prices change, or in other words, the elasticities of substitution.

Another assumption of the model is that producers are price takers for inputs and outputs. In other words, the input and output markets are perfectly competitive. There can still be variability in input and output prices though as a result of an institutional factor such as unionized labor forces in some areas or heterogeneity of the wood input based on species composition, age and size and also transportation costs. The point is that those factors are largely beyond the control of the mills and therefore they remain price takers (Banskota *et al.* 1985).

2.1.2 Production Function

In order to model the production structure of an industry it is necessary to have a conception of the underlying production function. In this case, lumber output Q is assumed to be produced by the inputs labor (L), materials (M) and capital (K). Production is also assumed to be a function of time (t). The time trend variable is meant to take account of technological change. This is a common way of accounting for technological change and the purpose is not to explain it but simply to measure it as a function of time.

The implicit production function is:

$F(Q,L,M,K,t)$ (1)

All inputs are treated as variable. At the firm level capital is not variable in the short run but the data used here are aggregated at the statewide industry level and new capital expenditure decisions are made every year by mill managers based on the state of their existing capital stock and the prices of other inputs which may be substitutes or complements to capital. New capital expenditures may be made sooner or later depending on those other factors. This leads to annual variability of the capital stock and therefore the user cost of capital.

2.1.3 Duality

The theoretical framework for this model makes use of the duality of production and cost. Rather than estimate a production function, this model estimates the dual cost function to obtain results regarding the substitution of inputs, input demand, technological change and returns to scale.

According to Varian (1992) the fundamental principle of duality in production is: "the cost function of a firm summarizes all of the economically relevant aspects of its technology". The advantage of estimating a cost function as opposed to a production function is that there exist several functional forms from which derived demand equations can be determined and are flexible in their treatment of various aspects of the production structure that we are interested in. One of these is discussed in the next section.

2.1.4 Transcendental Logarithmic Functional Form

The choice of functional form is important for applied economic research. The decision of which of many possible functional forms to use to model an economic process using a cost or profit function hinges on several considerations. These considerations can be grouped into four categories according to whether they relate to maintained hypotheses, estimation, data, or application (Griffin, *et al.* 1987).

Maintained hypotheses are *a priori* restrictions on the value and of the function and its parameters. In economic production analysis, maintained hypotheses for a production function could include homogeneity, homotheticity, restrictions on the elasticities of substitution and concavity. Key properties of a well-behaved cost function for a single-output technology are that it is homogeneous of degree one in input prices, has strictly positive input factor demands and that it is concave in input prices (Varian 1992). Homogeneous of degree one in input prices means that if all input prices double, for example, costs will double. This reflects the behavioral assumption that it is only relative factor prices and not the level of each price that matter to the mill owner when deciding how much of each input to employ. Strictly positive input factor demands means that demand for an input can never be negative, which is intuitive, but it also cannot be zero because it is not possible to create lumber without wood, for example. Concavity in input prices means that as the price of an input increases, costs will increase but at a decreasing rate as mill owners substitute away from the increasingly expensive input.

Global flexibility refers to the property of the functional form that does not restrict its value at any point nor does it restrict the value of its first or second derivatives. There is a tradeoff between flexibility and maintained hypotheses. On its own, greater flexibility is more desirable, however it may present estimation problems from the increased amount of information required and subsequent loss of degrees of freedom. We want the cost function to conform to economic theory. This requires the imposition of restrictions on the parameters to impose the properties of a well-behaved cost function.

The second category that needs to be considered when choosing a functional form is estimation. Availability of data and data properties need to be considered when choosing a functional form. A difficulty with many functional forms is that as a result of their flexibility, there are many parameters to be estimated and consequently there may be a problem with degrees of freedom. This can be mitigated somewhat by the imposition of some maintained hypotheses as mentioned earlier.

The third category involves data-specific considerations such as goodness-of-fit. In this case, the previous two categories have already limited the choice of functional form to a few and so this is not an important category for choosing functional form. The fourth category concerns the application in which the function will be used. The application in this study was an optimization problem that minimized a cost function for sawmills in the Lake States. The maintained hypotheses and flexibility were relevant to the application. The goals of this study were to measure elasticity of substitution, technological change, own and cross-price elasticities and allow for non-constant returns to scale and the translog cost function allowed that.

The transcendental logarithmic (translog) function was chosen for all the reasons cited above including its flexibility and suitability given the amount and type of data, in addition to the preponderance of literature using it in one form or another. It was necessary to use the translog in order to provide the flexibility to allow the data to determine the returns to scale as well as the nature and bias of technological change and the elasticities of substitution and demand. The main difficulty with using the translog is the relatively large number of parameters to be estimated, in this case, three variable inputs and a time trend variable. This necessitated the estimation of twenty-one parameters, including the constant. This large number of parameters can lead to a degrees of freedom problem. This problem can be overcome by a sufficiently large dataset, but also by restricting the flexibility of the functional form in areas that will not impinge upon the prospective analysis. These restrictions were outlined in the model selection section.

Other common alternative functional forms such as the constant elasticity of substitution (CES) functional form and the Cobb-Douglas functional form are not appropriate for this study for a variety of reasons. The CES function imposes difficulties with regards to estimation because it is not linear in the parameters. Also, its namesake characteristic is not applicable to this study as it holds for all input levels (Boisvert 1982). The Cobb-Douglas functional form is subsumed in the translog functional form in that if the parameters for the terms in the translog function that allow nonunitary elasticity of substitution between inputs are zero, the translog function will exhibit unitary elasticity of substitution (Griffin *et al.* 1987). The Cobb-Douglas functional form imposes unitary elasticity of substitution between all inputs and this may not be a valid assumption for the sawmill industry of the Lake States. The Cobb-Douglas function cannot be rejected out of hand because of that trait because the data may support unitary elasticity of substitution between inputs and the translog model will be tested for this behavior.

2.2 Applications of the Theory

There have been a number of papers written on the production structure and demand for inputs in the wood products industries of North America and elsewhere. Most focus on a specific region of the United States or Canada. It is typical in these analyses to use a cost function of some type but a profit function may also be used. The profit function method is rare but it may prove useful depending on data availability and the assumed behavior of sawmill managers. This style of analysis was used by Caves *et al.*

(1981) in studying the railway industry of the U.S. and follows the duality relationship between production functions and restricted cost functions derived by Lau (1978).

Among the studies of the sawmill industry outlined here are Stier (1980), Nautiyal and Singh (1985), Singh and Nautiyal (1985), Banskota *et al.* (1985), Martinello (1985), Abt (1987), Martinello, (1987), Meil and Nautiyal (1988), Puttock and Prescott (1992), Bigsby (1994) and Baardsen (2000). All of these studies used translog cost functions to estimate a variety of economic statistics of interest such as elasticities of substitution, elasticities of demand, technological change and returns to scale. Several assumptions are common to all these studies. It was assumed with this method that producers are efficient in that they minimize costs given an output level. It was also assumed that they are only able to minimize costs with respect to certain inputs. In the case of the above studies, the inputs include materials (usually wood but Baardsen (2000) uses sawlogs, lumber and "other materials" as separate inputs) labor, capital and sometimes energy. Table 2-1 summarizes the Characteristics of each of the above studies vary according to study region, industry studied, time period, data type (time-series, cross-section, panel) inputs and types of reported results (Table 2-1). All of the studies have imposed homogeneity of degree one in input prices which is a fundamental property of a well-behaved cost function (Varian 1984). They all also employ the translog functional form.

Research in other forest industry sectors has also been conducted by Stier (1985), De Borger and Buongiorno (1985), Kant and Nautiyal (1997), Smith and Munn (1998), and Andrade (2000). These are studies of the pulp and paper industry and the logging industry and the methods follow closely those of the sawmill studies listed in Table 2-1.

Table 2-1a. Summary of Sawmill Production Structure Studies

Author	Study Region	Industry Studied	Time Period	Data Type	Inputs[1]	Reported Results[2]
Stier (1980)	U.S.	SIC 242 Sawmills and planing mills (US Census Bureau)	1958-1974	Time-series	K, L	AES, elasticities of demand, technical change bias
Nautiyal and Singh (1985)	Canada	SIC 2513 Sawmills and planing mills (Statistics Canada)	1965-1981	Time-series	K, L, M, E	AES, elasticities of demand
Singh and Nautiyal (1985)	Canada	SIC 2513 Sawmills and planing mills (Statistics Canada)	1955-1982	Time-series	K, L, M, E	AES, elasticities of demand, economies of scale, individual input productivity
Banskota *et al.* (1985)	Alberta	Sawmills	1978	Cross-section; 83 mill-level observations	K, L, M, E	AES, elasticities of demand, returns to scale
Martinello (1985)	Canada	Sawmills and shingle mills	1963-1972	Time-series	K, L, M, E	AES, elasticities of demand, technical change, returns to scale
Abt (1987)	US: Appalachian, Southern and Western regions	SIC 242 sawmills and planing mills	1963-1978	Pooled time-series (panel)	K, L, M	Elasticities of demand and factor demand decomposition
Martinello (1987)	British Columbia Coast and Interior	SIC 2513 sawmills and planing mills (Statistics Canada)	1963-1979	Time-series	K, L, M	AES, elasticities of demand, returns to scale, technical change
Meil and Nautiyal (1988)	BC Coast, BC Interior, Ontario, Québec	Sawmills	1968-1984	Pooled time-series (panel)	K, L, M, E	AES, elasticities of demand, factor demand decomposition, returns to scale, technical change
Puttock and Prescott (1992)	Southern Ontario	Hardwood sawmills	1980-1984	Pooled time-series 21 sawmills	K, L, M, E	AES, elasticities of demand, returns to scale
Bigsby (1994)	Australia	Sawmills	1950-1985	Time-series	K, L, M, E	Elasticities of demand, returns to scale, technical change.
Baardsen (2000)[3]	Norway	Sawmills	1974-1991	Pooled time-series. Mill-level data	K, L, S, E, F, W, M, I	AES, MES, elasticities of demand, returns to scale and technical change

[1]K, L, M, E stand for capital, labor, materials (wood) and energy, respectively.
[2]AES is Allen Partial Elasticity of Substitution. MES is Morishima Elasticity of Substitution.
[3]S, E, F, W, M, I stand for sawlogs, electricity, fuel oil, lumber input, other materials and other inputs, respectively.

Table 2-1b. Summary of Sawmill Production Structure Studies

Author	Study Region	Industry Studied	Production Characteristics
Stier (1980)	U.S.	SIC 242 Sawmills and planing mills (US Census Bureau)	Non-Hicks neutral technological change.
Nautiyal and Singh (1985)	Canada	SIC 2513 Sawmills and planing mills (Statistics Canada)	Increasing returns to scale; nonunitary elasticity of substitution.
Singh and Nautiyal (1985)	Canada	SIC 2513 Sawmills and planing mills (Statistics Canada)	Increasing returns to scale; Hicks-neutral technological change; nonunitary elasticity of substitution.
Banskota *et al.* (1985)	Alberta	Sawmills	Increasing returns to scale; nonunitary elasticity of substitution.
Martinello (1985)	Canada	Sawmills and shingle mills	Increasing returns to scale; nonunitary elasticity of substitution, non-Hicks neutral technological change.
Abt (1987)	US: Appalachian, Southern and Western regions	SIC 242 sawmills and planing mills	Appalachian region exhibits decreasing returns to scale.
Martinello (1987)	British Columbia Coast and Interior	SIC 2513 sawmills and planing mills (Statistics Canada)	Interior sawmills constant returns to scale; Coast sawmills increasing returns to scale; nonunitary elasticity of substitution; non-Hicks neutral technological change.
Meil and Nautiyal (1988)	BC Coast, BC Interior, Ontario, Québec	Sawmills	Smallest mill-size class in Ontario decreasing returns to scale; nonunitary elasticity of substitution; non-Hicks neutral technological change.
Puttock and Prescott (1992)	Southern Ontario	Hardwood sawmills	Smaller mills have increasing returns to scale while larger mills exhibit decreasing returns to scale; nonunitary elasticity of substitution.
Bigsby (1994)	Australia	Sawmills	Increasing returns to scale; nonunitary elasticity of substitution; non-Hicks neutral technological change.
Baardsen (2000)	Norway	Sawmills	Increasing returns to scale; nonunitary elasticity of substitution; non-Hicks neutral technological change.

2.3 Empirical Methods

The basic empirical method used in the articles described in section 2.2 was used here. It was assumed that sawmill operators were cost minimizers and could adjust the level of labor, capital and materials in order to produce the given output in the least cost way.

The translog functional form was used in order to provide the flexibility with regards to returns to scale, bias of technological change and non-constant elasticities of substitution among inputs (Griffin *et al.* 1987).

2.3.1 Translog Cost Function Model

The input factor demands, elasticities of substitution, own-price and cross-price elasticities, technological change and economies of scale were derived through the estimation of a translog cost function. The inputs include labor, materials (sawlogs) and capital. There was also a time trend variable used for measuring the current state of technology. The model included the translog cost function and the cost share equations for all but one of the variable inputs. Only two of the share equations are linearly independent because by definition they sum to one. Therefore, one of the equations must be dropped and it can be calculated using the remaining two. It does not matter which input cost share equation is dropped. In this case, the capital cost share equation was dropped.

The model that was estimated is shown below.

$$\begin{aligned}\ln VC &= \beta_C + \beta_L \ln \mathrm{LP} + \beta_M \ln MP + \beta_K \ln KP + \beta_t t + \beta_Q \ln Q \\ &+ \tfrac{1}{2}[\beta_{LL} \ln LP^2 + \beta_{MM} \ln MP^2 + \beta_{KK} \ln KP^2 + \beta_{tt} t^2 + \beta_{QQ} \ln Q^2] + \beta_{Lt} \ln LP * t \\ &+ \beta_{LQ} \ln LP \ln Q + \beta_{Mt} \ln MP * t + \beta_{MQ} \ln MP \ln Q + \beta_{Kt} \ln KP * t + \beta_{KQ} \ln K \ln Q + \\ &\beta_{tQ} t * \ln Q + \beta_{LM} \ln LP \ln MP + \beta_{LK} \ln LP \ln KP + \beta_{MK} \ln MP \ln KP\end{aligned} \quad (2)$$

$$\begin{aligned}S_L &= \beta_L + \beta_{LL} \ln LP + \beta_{LM} \ln MP + \beta_{LK} \ln KP + \\ &\beta_{Lt} t + \beta_{LQ} \ln Q\end{aligned}$$

$$\begin{aligned}S_M &= \beta_M + \beta_{MM} \ln MP + \beta_{LM} \ln LP + \beta_{MK} \ln KP + \\ &\beta_{Mt} t + \beta_{MQ} \ln Q\end{aligned} \quad (3)$$

Where:
VC = variable cost defined as the sum of labor, materials and capital costs.
LP = labor price ($/hour)
MP = materials price (sawlog price) ($/MBF)
KP = capital price defined as the ratio between gross quasirent and capital stock
t = time trend (year)
Q = lumber output (MMBF)
S_L= labor cost share (labor cost divided by *VC*)
S_M= materials cost share (materials cost (sawlogs) divided by *VC*)

The model was estimated using full information maximum likelihood (FIML) estimation method using EViews 4.1© software. The maximum likelihood estimator has several desirable properties. It is asymptotically unbiased and efficient and it is consistent (Kennedy 1992). In the past, estimation by maximum likelihood methods was not popular due to the algebraic manipulations of the data required for estimation with some software packages. Nevertheless, it is increasingly popular as the computing power required for estimation has become available. The translog model estimated here is a system of equations and full information methods estimate the model equations together as opposed to estimating the parameters of each equation separately. The advantage of this is that the estimates will have a smaller asymptotic variance-covariance matrix (Kennedy 1992). Three-stage least squares (3SLS) is another major systems method of estimation. Both FIML and 3SLS incorporate all the information available in the system and estimate all the equations simultaneously but FIML can be asymptotically more efficient. This property makes the estimates invariable with respect to the cost share equation that was deleted from the model (Greene 1990). It seems that the aforementioned lack of computing power in the past has been the major reason that led other researchers to use an estimation technique other than FIML.

2.3.2 Demand Equations

In order to derive the input demand equation for input i, Shephard's Lemma was used (Shephard 1953):

$$x_i^* = \frac{\partial VC_i(Q,p)}{\partial x_i}, \qquad (4)$$

Where x_i^* is the optimal quantity of input i.

For the translog function used here, the equation is:

$$\frac{\partial \ln VC}{\partial \ln p_i} = \frac{\partial VC}{\partial p_i}\frac{p_i}{VC} = \frac{p_i x_i}{VC} \equiv S_i \qquad (5)$$

Where p_i is the price of input i.

This leads to the share equations used to estimate the model:

$$S_L = \beta_L + \beta_{LL} \ln LP + \beta_{LM} \ln MP + \beta_{LK} \ln KP + \beta_{Lt} t + \beta_{LQ} \ln Q$$

$$S_M = \beta_M + \beta_{MM} \ln MP + \beta_{LM} \ln LP + \beta_{MK} \ln KP + \beta_{Mt} t + \beta_{MQ} \ln Q$$

The derivation of the capital cost share equation is analogous:

$$S_K = \beta_K + \beta_{KK} \ln LP + \beta_{LK} \ln LP + \beta_{MK} \ln MP + \beta_{Kt} t + \beta_{KQ} \ln Q \qquad (6)$$

The actual cost share for capital can be calculated as $S_K=1-S_L-S_M$ because the cost shares must sum to one.

2.3.3 Elasticities

Several types of elasticities were calculated in order to describe the sawmill industry of the Lake States. Elasticities of substitution between input pairs were calculated to determine the extent to which inputs are technically substitutable for each other. There are two common forms of these elasticities: Allen-Uzawa Partial Elasticity of Substitution (AES) and Morishima Elasticity of Substitution (MES). Traditionally, the AES (Allen and Hicks 1934; Uzawa 1962) has been used but following Blackorby and Russell (1989), there has been increasing use of the MES. In addition to the elasticities of substitution, own and cross-price elasticities were calculated.

Explanation of the AES and MES elasticities of substitution and their calculation is given below along with methods for calculating the own and cross-price elasticities.

2.3.3.1 Allen-Uzawa versus Morishima Elasticity of Substitution

The AES is calculated from the cost function as:

$$A_{ij}(Q,p) = \frac{VC(Q,p)VC_{ij}(Q,p)}{VC_i(Q,p)VC_j(Q,p)},$$

where subscripts represent partial derivatives with respect to inputs i and j, Q is output quantity and p is the vector of input prices.

Then from this we can write:

$$A_{ij}(Q,p) = \frac{\xi_{ij}(Q,p)}{S_j(Q,p)}$$

Where $\xi_{ij}(Q,p)$ is the constant-output cross-price elasticity of demand and

$S_j(Q,p) = p_j VC_j(Q,p) / VC(Q,p)$ is the cost share of input j in total cost (Blackorby and Russell 1989).

The criticisms of the AES are threefold:

1) It does not measure the curvature of the isoquant
2) Provides no information about relative factor shares

3) Cannot be interpreted as the derivative of a quantity ratio with respect to a price ratio

Blackorby and Russell argue that the AES provides no information that is not provided by the constant-output cross-price elasticity. The AES has been used to classify net substitutes and complements but this application can be accomplished by the constant-output cross-price elasticity. The constant-output cross-price elasticity is both unit free and has a clear economic meaning. The AES is merely the constant-output cross-price divided by the cost share of input *j* and they argue that this is meaningless.

Blackorby and Russell propose an alternative elasticity of substitution originally derived by Morishima (1967). The MES is given by:

$$M_{ij}(Q,p) = \frac{p_i VC_{ij}(Q,p)}{VC_j(Q,p)} - \frac{p_i VC_{ii}(Q,p)}{VC_i(Q,p)} = \xi_{ji}(Q,p) - \xi_{ii}(Q,p)$$

One desirable property of the MES is that it allows for asymmetrical elasticities of substitution (*i.e.* $M_{ij} \neq M_{ji}$) in cases with more than two inputs. The AES imposes symmetry on the elasticity of substitution. This is counterintuitive. Variation of p_i in the ratio p_i / p_j will have two corresponding effects on the ratio x_i^* / x_j^*: the change in x_j^* given by $\xi_{ji}(Q,p)$ and the change in x_i^* given by $\xi_{ii}(Q,p)$. However, the effect of a change in the price ratio p_i / p_j by holding p_i constant and varying p_j is given by $M_{ji}(Q,p) = \xi_{ji}(Q,p) - \xi_{jj}(Q,p)$, thus, there is no requirement for $M_{ij} = M_{ji}$ (Blackorby and Russell 1989).

In recent production studies of the sawmill industry (Smith and Munn (1998), Baardsen (2000)) these criticisms of the AES were broached. In the case of Smith and Munn (1998) only the MES were presented and in Baardsen (2000) both the AES and

MES were presented. In this study, both types are presented in order to allow comparison with other studies.

2.3.3.2 Elasticity Calculations

The own-price and cross-price elasticities are calculated based on the following formulae:

$$\xi_{ii} = A_{ii} * S_i$$
$$\xi_{ij} = A_{ij} * S_j \qquad (7)$$

Where S_i is the cost share for input i and A_{ii} and A_{ij} (the AES) are given by:

$$A_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^2}$$
$$A_{ij} = \frac{\beta_{ij} + S_i S_j}{S_i S_j} \qquad (8)$$

Notice that the AES will vary with the relative factor shares S_i and S_j, so its value will depend on whether it is calculated at mean factor share levels or with individual yearly observations (Nautiyal and Singh 1985).

From Blackorby and Russell (1989) the MES is calculated as such:

$$M_{ij} = \xi_{ji} - \xi_{ii}$$
$$M_{ji} = \xi_{ij} - \xi_{jj} \qquad (9)$$

Once the estimation is complete the estimated parameters are used to calculate own-price and cross-price elasticities using the above formulae.

2.3.4 Technological Change

The rate and bias of technological change in the sawmill industry is the second research question answered by the study. In this model, the state of technology is represented by the trend variable t in the cost function. The translog functional form allows for biased technological change by relating each of the inputs to the time trend variable.

An overall measure of technological change (total factor productivity) is given by:

$$\tau = \left(1 - \frac{\partial \ln VC}{\partial \ln Q}\right)\frac{d\ln(Q)}{dt} - \frac{\partial \ln VC}{\partial t} \qquad (10)$$

Where τ is total factor productivity, VC is variable cost, Q is output and t is the time trend variable (Kant and Nautiyal 1997). The first term is the scale effect and the second term is the rate of technical change.

If τ is positive for fixed input prices and output, costs are decreasing over time, that is, productivity is increasing. If τ is negative, then costs are increasing over time for fixed input prices and output.

This statistic may be useful in some applications but generally it is more useful to measure productivity of each input separately. With many factors of production, productivity of some factors may increase over time while decreasing or remaining unchanged for others. Binswanger (1974) demonstrates the method for measuring biased technical change with many factors of production.

Technical change that affects all inputs equally is termed Hicks neutral. When technological change affects inputs to differing degrees, it is termed biased technological change. Single factor productivity is computed as:

$$\tau_i = \frac{\partial S_i}{\partial t}\frac{1}{S_i}, \qquad (11)$$

Where S_i is the cost share of factor i, t is the time trend variable and $\frac{\partial S_i}{\partial t} = \beta_{it}$.

If β_{it} is <0, then the technological change is factor *i*-saving. If β_{it} is >0, then the technological change is factor *i*-using.

2.3.5 Returns to Scale

A major characteristic of industrial processes is the efficiency with which they transform inputs as input levels increase. An industrial process exhibits increasing returns to scale if output increases by an amount greater than *k* when all inputs are increased by a factor of *k* ($k>1$). If output increases by less than *k*, the process is said to exhibit decreasing returns to scale. Constant returns to scale are exhibited when output increases by exactly *k*.

It seems counterintuitive that output should increase by a factor greater or less than k when all inputs are increased by *k*. If all inputs are increased, it should be possible to replicate the output produced by the original input quantities. Varian (1992) points out that not all inputs are under the producer's control. For example, it may not be possible to increase the area of land used for a plantation forest even though increasing other inputs will increase timber production. Strictly speaking, this situation does not describe decreasing returns to scale because all inputs are not being increased. In addition, the model used here does not include all inputs to the production process and it does not distinguish among differing quality of inputs. In the sawmill industry, increasing the volume of sawlogs going through the mill often means harvesting lesser quality stands with smaller trees or less desirable species. Despite the fact that the volume of wood may be doubled, lumber recovery factors may decrease and so the milling technology will exhibit decreasing returns to scale. Nevertheless, it is still possible to measure the returns to scale for the included inputs.

Information on economies of scale in an industry can yield valuable insights into the possible future structure of the industry in terms of number of plants and plant size. If a technology exhibits increasing returns to scale there is an incentive to increase plant size. On the other hand, decreasing returns to scale with respect to production labor and capital may prevent plant size from increasing, but the number of plants per firm may increase at the same time as the number of firms decreases because of increasing returns to scale in management labor. In this case, a firm is taken to be one organization that may operate more than one manufacturing facility.

A beneficial aspect of the translog cost function is that it does not restrict the technology to constant returns to scale. A Cobb-Douglas production function of the form:

$$Q = A(L^{\alpha} K^{(1-\alpha)}) \quad 0 < \alpha < 1$$

restricts the technology to constant returns to scale (in addition to constant rate of substitution between the inputs).

With the translog cost function, economies of scale are measured as the proportional increase in cost as a result of a small proportional increase in output. This is the elasticity of cost with respect to output. Christensen and Greene (1976) define scale economies as:

$$SCE = 1 - \frac{\partial \ln VC}{\partial \ln Q} \qquad (12)$$

This formulation will give positive numbers for increasing returns to scale and negative numbers for decreasing returns to scale.

2.4 Data

The data required for the model include: quantity of labor and logs used in the milling process, the prices of those inputs, new capital expenditures, the value of the capital stock of the milling industry, the price of capital, user cost of capital and the volume of output (lumber). Data were collected for three states (Michigan, Minnesota and Wisconsin) for the period 1963-1996. All financial data was discounted to 1996 using the PPI for all commodities. There are a total of 66 observations. For Michigan, there are 27 observations, 17 for Minnesota and 22 for Wisconsin. Each state had a different number of observations because for some years, data for SIC 242 were not published for some states. It was felt that rather than try to generate the missing data from reported data for SIC 24 for each state or national SIC 242 data it was better to just omit those years from the dataset.

The time period of the study was chosen partly due to data constraints. Prior to 1963, data from the Annual Survey of Manufacturers were not as readily available for SIC 242 at the state level. The time series ends at 1996 because at that time the Census Bureau changed from the SIC system to the North American Industrial Classification System (NAICS) and there is poor correspondence between SIC 242 and the new classifications.

There is also the issue of the level of aggregation of the data and the assumption of exogenous input prices. At the state level of aggregation it could be possible that the industry itself determines prices of at least some inputs (particularly wood). Baardsen (2000) claims that aggregating data beyond the mill level was inappropriate given the assumption of exogenous input prices. He quotes Varian (1984) as saying this is "unrealistic" (Varian 1984, p. 179). What Varian actually says is it "seems unrealistic" (*ibid*). This is a slightly more mild criticism and may not be completely applicable to the Lake States. In the case of the Lake States this may not be the case because there are no restrictions for the transport of wood to neighboring states and so timber sellers can simply sell to buyers across the state line if they feel that they can get a better price. This does not apply to all areas of all the states because transportation costs and information costs may become limiting factors for this movement of wood but there is export of timber to Indiana and Illinois which are not part of this study. In addition, Stone (1997), states that "changes in the supply of timber in other regions of the country (and world) influences Lake States timber markets". This is another indication that the timber market in the Lake States is not a closed system and that the industry in the region has limited influence on the prices it pays for inputs. Likewise, for labor, in most parts of the Lake States there are more employment opportunities available outside the sawmill sector or the wood products industry in general than there might be in the Interior of British Columbia, so the labor price can be taken to be exogenous to the sawmill sector. With 11,000 employees total in the Lake States in 1996 it seems unlikely that the industry as a whole can influence wage rates to any great degree. Certainly capital prices are not determined within a market endogenous to the Lake States sawmill industry. Studies aggregated at the national level or studies of regions such as the Pacific Northwest or British Columbia may be more subject to this criticism.

2.4.1 Labor Quantity

Labor quantity is defined as man-hours of production labor in SIC 242 (sawmills and planing mills) for each year. The data source was the Annual Survey of Manufactures (ASM) and the Census of Manufactures (CoM) from the Census Bureau.

2.4.2 Labor Price

Labor price, or wages, is calculated easily from the Census Bureau data for SIC 242. Labor price was calculated as dollars per hour for production workers. It was simply the payroll expense divided by the number of hours worked.

2.4.3 Sawlog Price

Sawlog price was calculated as the quotient of the cost of materials and volume of sawlogs entering mills in each state for years when the Forest Service Timber Product Output (TPO) data were available (USDA Forest Service North Central Forest Experiment Station Resource Bulletins, various years). The Census Bureau collects data on the gross cost of material inputs to the industry. This cost was almost entirely made up of sawlog costs. In order to calculate a price per thousand board feet (MBF), the total material cost was divided by the volume of sawlogs consumed in each year.

Sawlog prices for years when Forest Service TPO data for sawlog receipts were not available (see Table A-5) were calculated based on price data from Timber Mart North, state Departments of Natural Resources stumpage data, Forest Service stumpage data, Minnesota Forest Products Price Report, Wisconsin County stumpage data, the Wisconsin Forest Products Price Review and U.S. Timber Production, Trade, Consumption, and Price Statistics, 1950-85 (Ulrich 1987). A weighted average price was calculated based on proportions of each species and grade harvested in each state.

2.4.4 Capital Stock

The capital stock series was created using the perpetual inventory method developed by Christensen and Jorgenson (1969).

With the perpetual inventory method, capital stock in the current period (K_t) is a function of the investment in the current period (I_t), capital stock in the previous period (K_{t-1}), and the depreciation rate (μ):

$$K_t=I_t+(1-\mu)K_{t-1} \qquad (13)$$

Investment was taken to be new capital expenditures (NCE) for structures and equipment. Total NCE were available from both the CoM and the ASM for SIC 242 at the state level. Nevertheless, not all years were available for all states. In years for which NCE data were not available, data were generated by calculating the proportion of each state's NCE for SIC 242 to national NCE for SIC 242. The proportion for the years immediately preceding and following the missing data were then averaged and multiplied by the national NCE to arrive at NCE at the state level. NCE were further broken down into NCE for buildings and structures, and NCE for machinery and equipment due to different service lives for each type of capital. The breakdown into the two categories of capital was accomplished by using the national SIC 242 data on NCE for each category. Over the timeframe of the study, 17.5% of NCE were for buildings and structures and 82.5% for machinery and equipment. These proportions were fairly constant during this period.

There are three types of depreciation methods that could be used to depreciate the capital stock series: straight-line, geometric (of which double-declining balance depreciation is one type) and hyperbolic. Computationally, all require an estimate of the service life of the capital and in the case of geometric and hyperbolic depreciation, a parameter that controls the rate of depreciation.

As the name suggests, straight-line depreciation is linear so the depreciation rate is constant and equal to $1/L$ where L is the service life of the capital. This assumes the productive capacity of the capital decreases equally each year of its life.

Geometric depreciation is a form of accelerated depreciation which assumes that the productive capacity of the capital decreases more rapidly in the early stages than it does near the end of its service life. With geometric depreciation, the declining-balance rate is the same every year: $\delta_G=R/L$

where R is rate relative to the straight-line rate of $1/L$. Therefore, the double-declining-balance rate is $2/L$. As R increases, the depreciation rate increases and depreciation in the early stages of the life of the capital is increased. Geometric depreciation is measured as:

$d_{x,G}=\delta_G(1-\delta_G)^{x-1}$

Where $x=1,2,3....,L$

Hyperbolic depreciation is the opposite of accelerated depreciation. With hyperbolic depreciation, the capital retains more of its productive capacity in the early stages and as the capital ages, the depreciation accelerates. That is, the depreciation is delayed (as opposed to accelerated) in the early stage of its life. The hyperbolic depreciation rate is calculated as:

$$d_{x,D}=\frac{L-(x-1)}{L-\beta(x-1)}-\frac{L-x}{L-\beta x} \qquad (14)$$

Where $x=1,2,3....,L$ and β is the curvature parameter.

With a β of zero, hyperbolic depreciation reduces to straight-line depreciation. If β is 1, there will be no depreciation throughout the course of the service life of the capital with the exception of the final year when all depreciation will occur.

Intuitively, hyperbolic depreciation most closely matches the actual degradation of productive services from buildings and machinery in the sawmill industry. As capital ages, repairs become more frequent and more extensive. Abt (1987) employed hyperbolic depreciation to create the capital stock series for this reason.

The Bureau of Labor Statistics has established procedures for estimating net capital stock and depreciation profiles using hyperbolic depreciation (BLS 1997). The curvature parameter for depreciation of structures is assumed to be 0.75 and for equipment it is 0.5.

The service life of buildings and machinery for SIC 242 was also not easy to estimate but BLS procedures assume buildings and structures in SIC 242 have a service life of 28 years and machinery and equipment have a service life of 13 years.

In order to employ the perpetual inventory method of capital stock estimation, a benchmark, or starting value of the capital stock is required. Once a starting value of K is established, NCE and the depreciation rate are used to calculate the capital stock in each subsequent period. The path of the capital stock series is somewhat sensitive to the benchmark capital stock level at the beginning of the series, but any errors in the estimation of the benchmark are quickly dissipated by the NCE data.

In this case, gross book value (GBV) data were not available for SIC 242 for the Lake States. Capital stock data for SIC 242 in Kentucky and West Virginia are available and the starting values for each of the Lake States are based on the capital stock levels in those states. The majority of lumber produced in the Lakes States is hardwood and the same is true of Kentucky and West Virginia. Also, the production levels are relatively close as well. The input factor mix is assumed to be the same for the Lake States and Kentucky and West Virginia for the purposes of calculating the initial capital stock.

The starting value for the capital stock series for each state was calculated by determining the proportion of each of the Lake States' lumber production to the lumber production in Kentucky and also in West Virginia in 1963. After the proportions were calculated, they were multiplied by the 1963 capital stock data for Kentucky and West Virginia. The resultant figures were then averaged to arrive at an estimate of the capital stock in 1963 for each of the Lake States. These figures were then used to begin the estimation of capital stock in subsequent years using NCE data in the perpetual inventory method. Once capital stock for each category of capital was calculated, the figures were summed for each year and state to arrive at total capital stock.

After capital stock was calculated for each year and state, the price of capital was calculated. Following Stier (1985) capital price was calculated as the ratio between gross quasi-rent and capital stock. Gross quasi-rent was defined as value of shipments minus total employee compensation minus materials costs. Capital price is a ratio of two dollar values and as such has no units. It is the ratio of revenues (value of shipments), net of labor and materials cost, to capital stock. Value of shipments and employee compensation data came from the Census of Manufactures and the Annual Survey of Manufactures. Materials cost data were constructed as described above. Capital price does not need to be calculated for every year for every state because the final data set had some years missing for each state due to missing Census Bureau data. For Michigan, there were no Census Bureau data for SIC 242 for the years 1968, 1979-1981 and 1984-1986. Minnesota was missing Census Bureau data for SIC 242 for the years 1966, 1968-1971, 1973-1976, 1978-1981 and 1983-1986. Wisconsin was missing 1965-1966, 1968-1971, 1979-1981 and 1984-1986.

Gross-quasi rent (returns to capital) may be negative in some years and so it was necessary to smooth the capital price series by fitting a line using OLS estimation. The data for capital price presented in Appendix A is the smoothed capital price trend. It was necessary to calculate NCE for every year in order to employ the perpetual inventory method of estimating capital stock.

The user cost of capital was also calculated in order to create the cost variable for the left hand side of the cost function and to determine cost shares for each of the three inputs. Bigsby (1994) calculates the user cost of capital services in the Australian sawmilling industry as:

$$UC=(r + g_n - dP_{nt}/P_{nt})P_{nt}K_{nt} \qquad (15)$$

Where,
UC is user cost,
r is the interest rate on 10-year government bonds
g_n is the declining balance depreciation rate for capital n
dP_{nt}/P_{nt} is the annual rate of change of capital price for capital n
P_{nt} is the price of capital n at time t and,
K_{nt} is the value of the capital stock of capital n at time t.

For this study, Bigsby's formula needed to be modified to incorporate the hyperbolic depreciation scheme for depreciating the two kinds of capital used to construct the capital stock variable.

The final values were then converted to 1996 dollars using the PPI for all commodities.

2.4.5 Lumber Output

Output volumes came from the Census Bureau publication MA24T: Lumber production and mill stocks. Volumes are in MMBF International 1/4" log rule. A point to note regarding the lumber output statistics is that in 1994 the Census Bureau undertook a reconciliation among the MA24T, the 1992 Census of Manufactures, and state sawmill directories (Census Bureau 1994). The results of this reconciliation were large upward revisions of the output statistics from 1993. This may have the effect of underestimating productivity gains earlier in the study period relative to later in the study period

2.4.6 Variable Cost and Input Cost Shares

The left-hand side variables of the translog cost function and share equations were derived from the cost data for the inputs labor, materials and capital. Variable cost was the sum of labor, material and capital costs which were in turn the product of the price and quantity of each input. The input cost shares were the proportion of variable cost made up by each of the three inputs.

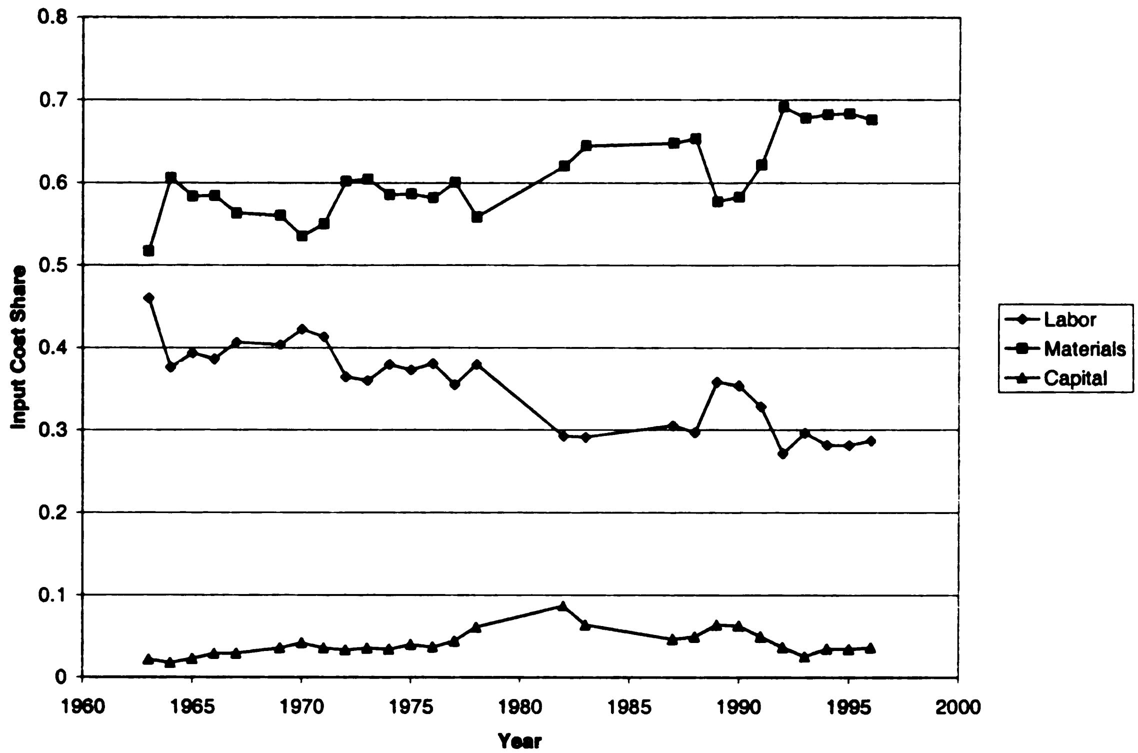

Figure 2-1. Input Factor Cost Shares for Michigan (1963-1996)

From examining the slope of the input cost shares and their change over time in, certain relationships are apparent (Figures 2-1, 2-2 and 2-3). Capital is a relatively unimportant input in terms of its contribution to costs and its share of input costs is reasonably steady, suggesting low substitutability between capital and the other inputs. On the other hand, there appears to be strong substitutability between labor and materials. The only significant aberration is for Wisconsin in the early late 1970s and early 1980s when there was a spike in the cost share for capital as a result of particularly large new capital expenditures in the late 1970s. The figures also seem to show a general increase in the cost share of materials and a decrease in the cost share of labor.

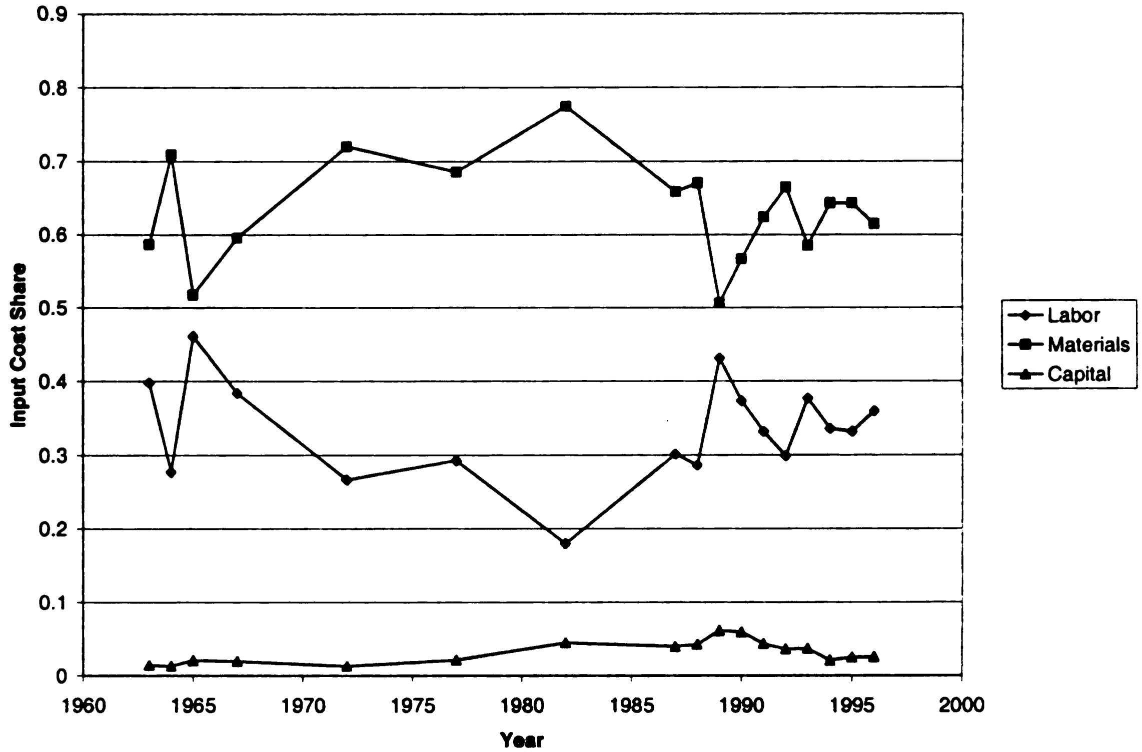

Figure 2-2. Input Factor Cost Shares for Minnesota (1963-1996)

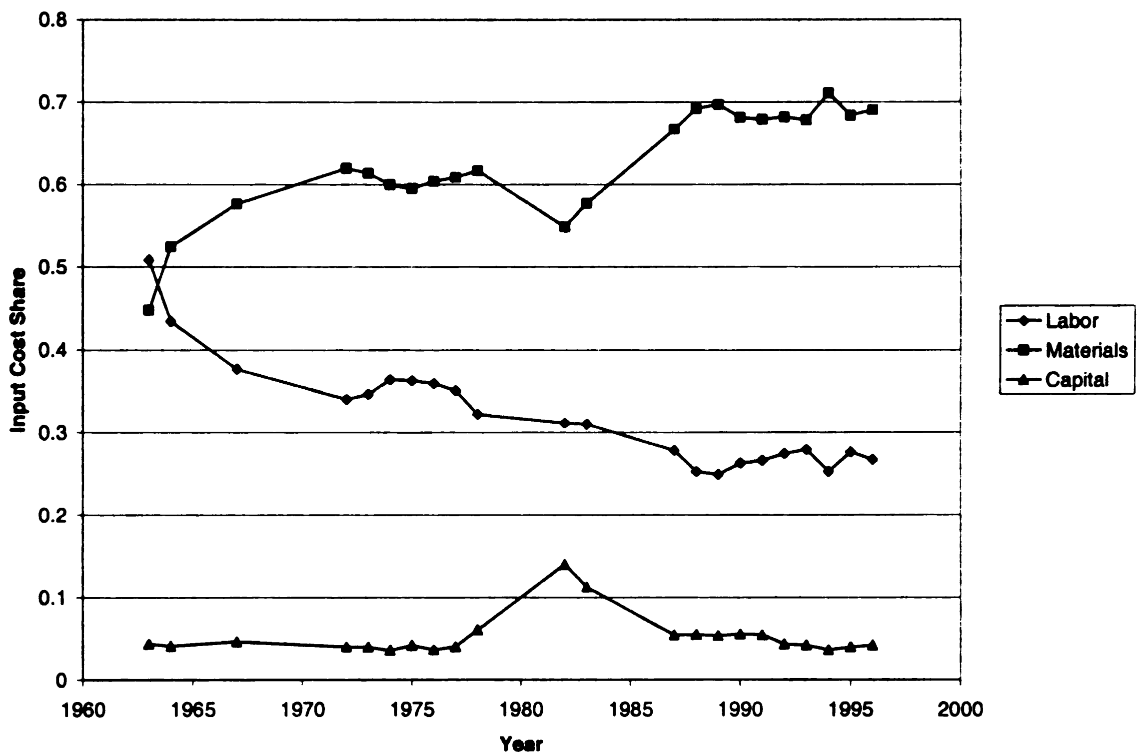

Figure 2-3. Input Factor Cost Shares for Wisconsin (1963-1996)

For Michigan and Minnesota, there was a decrease in the cost share of materials and a consequent increase in the cost share of labor around 1989. Wisconsin did not exhibit this same pattern. A possible explanation is that there was an increase in materials price in those two states that Wisconsin did not experience to the same degree. The reason for this increase is not known.

3.0 MODEL RESULTS AND DISCUSSION

This chapter presents the econometric model results including the results of the model that is homogeneous of degree one in input prices and several versions of the model in which increasingly restrictive assumptions have been imposed and tested for validity. Those restrictive assumptions include constant returns to scale and unitary elasticity of substitution. In addition to presenting the results of the model, the results are discussed and compared to results from other studies.

3.1 Maintained Hypotheses

There are several restrictions imposed on the model in order for it to conform to the theoretical requirements of a cost function. A cost function must be homogeneous of degree one in input prices. This means that if all input prices double, cost will double, holding output constant. In order for that condition to hold, the following parameter restrictions are imposed on the translog cost function (Nautiyal and Singh 1985):

$$\sum_i \beta_i = 1$$

$$\sum_i \beta_{iQ} = 0$$

and (16)

$$\sum_i \beta_{ij} = \sum_j \beta_{ji} = \sum_i \beta_{it} = 0$$

Where i and j represent the inputs labor, materials and capital,
Q is production and t is the time trend.

These restrictions are necessary for theoretical reasons but they provide the benefit of reducing the number of parameters that need to be estimated. The unrestricted model has twenty-one parameters and the imposition of the above restrictions reduces the number of parameters to be estimated to fifteen.

The original model that was estimated is shown below.

$$
\begin{aligned}
\ln VC = {} & \beta_C + (1-\beta_M - \beta_K)\ln LP + \beta_M \ln MP + \beta_K \ln KP + \beta_t t + \beta_Q \ln Q \\
& + \tfrac{1}{2}[(-\beta_{LM} - \beta_{LK})\ln LP^2 + (-\beta_{LM} - \beta_{MK})\ln MP^2 + (-\beta_{LK} - \beta_{MK})\ln KP^2 + \beta_{tt} t^2 + \beta_{QQ}\ln Q^2] + \\
& (-\beta_{Mt} - \beta_{Kt})\ln LP^* t + (-\beta_{MQ} - \beta_{KQ})\ln LP \ln Q + \beta_{Mt}\ln MP^* t + \beta_{MQ}\ln MP \ln Q + \beta_{Kt}\ln KP^* t + \\
& \beta_{KQ}\ln K \ln Q + \beta_{tQ} t^* \ln Q + \beta_{LM}\ln LP \ln MP + \beta_{LK}\ln LP \ln KP + \beta_{MK}\ln MP \ln KP
\end{aligned}
$$

$$
\begin{aligned}
S_L = {} & (1-\beta_M - \beta_K) + (-\beta_{LM} - \beta_{LK})\ln LP + \beta_{LM}\ln MP + \beta_{LK}\ln KP + \\
& (-\beta_{Mt} - \beta_{Kt})t + (-\beta_{MQ} - \beta_{KQ})\ln Q
\end{aligned}
\tag{17}
$$

$$
\begin{aligned}
S_M = {} & \beta_M + (-\beta_{LM} - \beta_{MK})\ln MP + \beta_{LM}\ln LP + \beta_{MK}\ln KP + \\
& \beta_{Mt} t + \beta_{MQ}\ln Q
\end{aligned}
$$

3.2 Model Selection Procedure

The model selection procedure is a stepwise testing of model assumptions in order to select the most appropriate model for the data set. The translog cost function used to model the production structure of the sawmill industry of the Lake States is flexible in that it allows for nonconstant returns to scale and nonunitary elasticities of substitution among the inputs. The modeling procedure starts with the unrestricted model and then adds successively more restrictive assumptions. Model (1) is the model that includes restrictions on the parameters that impose homogeneity of degree one in input prices. Considering that a well-behaved cost function must behave in that way, we take this model to be the unrestricted model in terms of testing the more restrictive assumptions of the other models. Model (2) imposes homogeneity of degree one in output. In other words, it imposes constant returns to scale. Model (3) imposes unitary elasticity of substitution among the inputs but relaxes the constant returns to scale assumption. Model (4) includes both the constant returns to scale and unitary elasticity of substitution restrictions.

The homogeneity restrictions were discussed in Chapter 2 and reiterated in equation (16) above. To restrict the model to constant returns to scale, (Model 2, below) the following parameter restrictions are imposed:

$\beta_{iQ} = 0$ and $\beta_{QQ} = 0$ (18)

Where *I* equals labor, materials and capital.

In order to impose unitary elasticity of substitution restrictions, (Model 3, below) the following parameter restrictions are imposed (Nautiyal and Singh 1985):

$\beta_{ij} = 0$ (19)

Where *I* and *j* equal labor, materials and capital.

The parameters of the translog cost function and the labor and materials share equations were estimated as a system of equations using Full Information Maximum Likelihood (FIML) estimation with EViews 4.1© software. Table-3-1 shows the values of the estimated parameters for each model along with the values of parameters calculated from the estimated parameters based on the restrictions of the corresponding model.

Table 3-1. Estimates of the Cost Function Parameters (1963-1996)

Parameter	Model 1	Model 2	Model 3	Model 4
β_C	2108.314 (2421.512)	2264.810 (2333.536)	2264.806 (2848.65)	2264.806 (2674.889)
β_L	2.346	4.411019	5.879236	5.879165
β_M	0.314 (3.833)	-3.309 (3.579)	-3.57029** (1.596226)	-3.57031** (1.503421)
β_K	-1.660 (2.056)	-0.102 (1.865)	-1.30894 (1.214176)	-1.30886 (0.925175)
β_t	-2.375 (2.495)	-2.498 (2.414)	-2.50249 (2.918127)	-2.50049 (2.746168)
β_Q	86.461*** (23.682)	78.231*** (27.169)	78.45354*** (21.58155)	78.45342*** (25.78444)
β_{Lt}	-0.000996	-0.00208	-0.00278	-0.00279
β_{Mt}	4.27E-05 (0.00200)	0.00195 (0.00186)	0.002093*** (0.000812)	0.002112*** (0.000758)
β_{Kt}	9.53E-04 (0.00108)	0.000128 (0.000975)	0.000689 (0.000628)	0.000682 (0.000466)
β_{tQ}	-0.0420*** (0.0120)	-0.0390*** (0.0137)	-0.03804*** (0.01077)	-0.03913*** (0.012977)
β_{tt}	0.00132 (0.00128)	0.00137 (0.00125)	0.001367 (0.001494)	0.001368 (0.00141)
β_{LL}	0.0665	0.056071	NA	NA
β_{MM}	0.0691	0.024512	NA	NA
β_{KK}	0.0360	0.036323	NA	NA
β_{LM}	-0.0498 (0.0368)	-0.0221 (0.0331)	NA	NA
β_{LK}	-0.0167 (0.0272)	-0.0339 (0.0268)	NA	NA
β_{MK}	-0.0193 (0.0231)	-0.00238 (0.0207)	NA	NA
β_{QQ}	-0.399 (0.357)	NA	-0.39319 (0.275956)	NA
β_{LQ}	0.00720	NA	-0.00551	NA
β_{MQ}	-0.00156 (0.0204)	NA	0.007813 (0.017006)	NA
β_{KQ}	-0.00564 (0.0123)	NA	-0.00231 (0.011845)	NA
Number of restrictions	none	3	3	6
Log of likelihood function	293.279	290.368	282.471	279.4977
Likelihood ratio statistic	NA	5.822	21.615	27.562
Critical χ^2 at (1%)	NA	11.341	11.341	16.812

Table 3-1 continued,

Notes: 1.Figures in parentheses are the standard errors of estimates. 2. A single asterisk signifies significance at the 10 percent level, a double asterisk at the 5 percent level, and a triple asterisk at the 1 percent level. 3. Parameters without standard errors were calculated from other parameters based on the imposed restrictions.

Two of the parameters are significant at the 5% level. This is not unusual for models of this type. Abt (1984) had two variables significant at the 5% level and five with standard errors less than the coefficient estimate in his model of the Appalachian region of the U.S. Justification of such models was made on economic grounds where theory dictates the economic properties of a well-behaved cost function and those properties were imposed on the statistical model. The estimation procedure first satisfied the imposed parameter restrictions and then attempted the best statistical fit of the data. Also, many of the variables used the same data (e.g. labor price and labor price squared) so there was a fair amount of multicollinearity built into the model. These factors had the effect of increasing the standard errors on the parameter estimates. Therefore, the calculated results should be treated with caution because of the low number of parameters that are significant at the 5% level.

The hypothesis testing in the model selection process was done using the likelihood ratio test. The likelihood ratio statistic was calculated as:

$$LR = 2(LL_{ur} - LL_r) \qquad (20)$$

Where LL_{ur} was the log of the likelihood function for the unrestricted model and LL_r was the log of the likelihood function for the restricted model. Multiplying the difference between the log likelihoods of the unrestricted and restricted models by two makes the LR statistic approximate a χ^2 distribution (Wooldridge, 2000). The critical value for the test was the value of the χ^2 distribution at the preferred level of significance

(1% in this case) and with the proper number of restrictions. Models (2) and (3) each had three linearly independent restrictions and Model (4) had six.

According to the likelihood ratio tests on each of the three restricted models, we could not reject the assumption of constant returns to scale (Model (2)) whereas the hypothesis of unitary elasticity of substitution among the inputs (Model (3)) was rejected at the 1% level. The model with constant returns to scale and unitary elasticity of substitution (Model (4)) was also rejected at the 1% level.

While the translog cost function that has had homogeneity of degree one in input prices imposed can allow for nonconstant returns to scale, the empirical evidence here suggests that the production structure of the sawmill industry in the Lake States can be estimated with a cost function that imposes constant returns to scale. The following calculations of elasticities of substitution, own and cross price elasticities among the inputs and technological change are based on the results from Model (2).

3.2.1 Other Cost Function Properties

In addition to being homogenous of degree one in input prices, a well-behaved cost function must have input demand functions that are strictly positive (Berndt and Wood 1975). Cost shares can never be zero or less than zero. The input demands (cost shares) of each input were calculated based on the parameter estimates of Model (2) and all were positive for each annual observation.

Another property of a well-behaved cost function is that it must be concave in input prices. In order to be concave, the principal minors of the Hessian matrix of the second order partial derivatives be negative definite. Nautiyal and Singh (1985) show that an equivalent test of concavity is that the matrix of AES be negative semi-definite. Given the reported AES (Table 3-2) the matrix fulfills that requirement with the principal minors alternating sign beginning with negative.

3.3 Data Pooling

All of the models estimated combined times-series data with cross-sectional data (*i.e.* panel data) in order to increase the number of observations and improve the degrees of freedom. Observations from the period 1963-1996 for Michigan, Minnesota and Wisconsin were combined into one dataset of 66 observations. Michigan has 27 observations, Minnesota has 17 and Wisconsin has 22. With this type of data pooling we assumed that the production structures of the sawmill industry in the three states were similar enough that they could be estimated together in one model Abt (1987). There are several methods available to test whether or not this is the case. One is the Chow test which requires that the three pooled cross-sections be run as separate models and then an F-test is used to determine if they are significantly different (Gujarati 1995). Another is the dummy variable method. Dummy variables for Michigan and Minnesota were added to Model (2) to measure possible shifts in the intercept as a result of differences related to the cross-section (state) represented by each observation. If the coefficient for one or both of the dummy variables is statistically significant, then the assumption of identical production structures is not valid. The results of this regression (Appendix B) showed that the coefficients on the dummy variables were not significant at the 10% level and so the cross-sections may be estimated together.

3.4 Elasticities of Substitution

From equations (8) and (9), the AES and MES can be calculated (Table 3-2).

Table 3-2. The Allen-Uzawa Partial Elasticity of Substitution and Morishima Elasticity of Substitution based on FIML estimates of Model (2) (at mean level of observations) 1963-1996.

Input	Labor Price	Material Price	Capital Price
Labor	NA	0.89 (0.80)	-1.36 (0.037)
Material	0.89 (0.89)	NA	0.91 (0.23)
Capital	-1.36 (0.13)	0.91 (0.90)	NA

Note: Morishima elasticities are in parentheses.

The AES suggested that all input pairs were substitutes except for labor and capital which were complements. The MES on the other hand suggested that all input pairs were substitutes. The MES are generally lower than their AES counterparts. Note that the MES allows for nonsymmetrical elasticity of substitution. That is, M_{ij} does not have to equal M_{ji}. This is more flexible than the AES which imposes symmetry on the elasticities of substitution between input pairs.

Nautiyal and Singh (1985) presented results for AES for the lumber industry in Canada and found that all inputs are substitutes for each other. Most other studies of the sawmill industry, including Stier (1980), Martinello (1987), and Puttock and Prescott (1992) had the same finding. Nevertheless, Banskota *et al.* (1985) found that in the Alberta sawmill industry, capital and materials are complements while all other input pairs are substitutes. Likewise, Campbell and Jennings (1990) found materials to be complements of both energy and capital in the Tasmanian sawmill industry. Baardsen (2000) also found many complementary input pairs, in particular between sawlogs and energy, labor and energy, and sawlogs and labor in his study of the Norwegian sawmilling industry. Studies of the substitutability between capital and labor in other industries also indicate that capital and labor are substitutes, with the exception of Denny and May (1977).

All of the own-price AES are negative. This is necessary for the corresponding own-price elasticities of demand to be negative and consequently for the input demand curves to be downward sloping. Most authors do not report the own-price AES but it is necessary to calculate them in order to calculate the own-price elasticities of demand.

The elasticity of substitution results are discussed in the following sections and the results of other authors are summarized (Table 3-3).

3.4.1 Labor-Material Substitution

The AES between labor and material calculated in this study was 0.89. The MES was 0.80 for labor/material and 0.89 for material/labor. There is a wide range of values in the literature for the AES between labor and material. Banskota *et al.* (1985) calculated it to be quite inelastic at 0.0614. Nautiyal and Singh (1985) found a value almost ten times greater at 0.60. In Meil and Nautiyal (1988) the values range from 0.248 to 0.488. Martinello (1987) estimated it to be 0.203 for BC Coast mills and 0.053 for BC Interior mills. Martinello (1985) estimated the elasticity to be zero for sawmill and shingle mills in Canada while Puttock and Prescott (1992) calculated a value of 0.595 for the hardwood sawmill industry of Southern Ontario. Abt (1984) found quite high values for each region of the U.S. he studied. The AES for labor and material for the Appalachian, Southern and Western regions was 0.80, 0.95 and 0.60 respectively. Except for Abt, the other studies are all of the Canadian lumber industry. The relatively high values for the U.S. industry indicate that it is more able to react to price changes than is the Canadian industry. The industry as modeled in this study is more able to substitute away from labor or materials if their prices increase than are the Appalachian and Western regions as modeled by Abt but the AES for the Lake States and Abt's Appalachian region were quite close. The value for the hardwood industry in Southern Ontario was also quite high indicating a similar substitutability between labor and materials. Baardsen (2000) was the only study that calculated an AES indicating that labor and materials were complements with a value of -0.10. Nevertheless, his estimate of MES for labor/materials was 0.66 and materials/labor was 0.55, indicating that they were substitutes.

3.4.2 Labor-Capital Substitution

The AES between labor and capital was negative, indicating that they are complements. The calculated value was -1.36. The MES calculations indicated that labor and capital are substitutes and the substitutions are quite inelastic with a value of 0.037 for labor/capital and 0.13 for capital/labor. Baardsen (2000) had the substitute/complement relationship differ between AES and MES for labor and materials with the AES results indicating they were complements and the MES results indicating they were substitutes. All other studies show labor and capital to be substitutes with the exception of Denny and May (1977). They estimated the AES between labor and capital for the Canadian manufacturing sector to be -0.533, indicating that they are complements. Nevertheless, the absolute value of the AES is in the range calculated by other authors. Martinello (1987) reported AES between labor and capital of up to 1.669 for the wood industries of BC. The AES and MES estimates of Baardsen (2000) were similar in magnitude to this study with an AES of 0.73, a labor/capital MES of 0.70 and a capital/labor MES of 0.75.

The only unusual result of the AES calculations from the model is the finding of complementarity between labor and capital. Complementarity between materials and capital, and energy and capital are found in other studies that used time series data and it may be the result of capacity expansion. The study period in this study (1963-1996) includes recessions in the early 1980s and 1990s that saw lumber output drop substantially, particularly in the early 1980s. At the same time, interest rates were very high and many sawmill workers were laid off. In this case it appears that the capital price and consequently the user cost of capital were increasing during this time while quantity of labor and of output were decreasing. The AES, nevertheless, assumes that output remains constant. A possible explanation is that the complementarity is due to labor and capital being used in fixed proportions. If mill-level data were available they may reveal that the labor used was directly proportional to the number or type (band or circular) of saws used at the mill which can be used as a proxy for capital stock (Puttock and Prescott 1992). Denny and May (1977) gave no explanation of their finding of complementarity between labor and capital except that it was unusual.

3.4.3 Materials-Capital Substitution

For materials and capital, the AES results indicate that they are inelastic substitutes with a value of 0.91. The MES value for materials/capital is more inelastic with a value of 0.23 but the MES for capital/materials is 0.90. The results for MES indicate that the sawmill industry of the Lake States reacts more to changes in material price than changes in the price of capital. This is in part because of the large share of costs comprised by materials. Materials make up 62% of costs on average over the study period. Labor represents 34% and capital only 4% of variable costs as defined in the model. Nautiyal and Singh (1988) found a more inelastic value of 0.17 for the Canadian lumber industry. Martinello (1985) calculated the AES between materials and capital to be 0.575 for sawmills and shingle mills in Canada and Baardsen's AES estimate for the Norwegian sawmill industry was close to that at 0.73 while his MES estimates for materials/capital and capital/materials were 0.70 and 1.00 respectively. Banskota *et al.* (1985) found materials and capital to be slightly complementary in the Alberta sawmill industry with an AES of -0.0544. Other authors have explained such results as a demonstration of an overall material and capital using expansion in the industry over the study period (Meil and Nautiyal 1988) but the Banskota *et al.* study used strictly cross sectional, mill-level data for the year 1978.

3.4.4 Elasticity of Substitution Discussion Summary

The AES presented above show that labor and capital are elastic complements in the Lake States and all other input pairs are substitutes. The own-price AES are all negatively signed which is necessary for the own-price elasticities of demand to be negative and the corresponding input demand curves to be downward sloping. There is a quite consistent rate of substitutability between labor and material for both the AES and MES. Also, the asymmetric nature of the MES shows that capital is much more reactive to price changes in labor and materials than the other way around.

Overall, the values calculated in this study are comparable to those calculated for other regions but there is particular concurrence with the Ontario and Québec regions studied by Meil and Nautiyal (1988), the southern Ontario hardwood sawmill industry studied by Puttock and Prescott (1992) and the Appalachian region studied by Abt (1987). The regions studied by Puttock and Prescott, and Abt are particularly of interest because they are most similar to the Lake States in terms of forest resources and land ownership. While most forest land in Canada is publicly owned, southern Ontario has a similar development pattern to the nearby states, which is characterized by many small landowners. This, combined with the differences between a hardwood forest resource and a softwood forest resource which predominates in most of the other regions modeled in the literature may be a reason for the differences between the two types of regions in terms of the substitutability of inputs, particularly materials and labor.

For ease of comparison, a summary of the elasticity of substitution results of other authors is below (Table 3-3).

Table 3-3 Allen Elasticity of Substitution Results of Selected Studies

Study	Labor/Materials	Labor/Capital	Capital/Materials
Stier, 1980	NA	0.105	NA
Nautiyal and Singh, 1985	0.60	0.93	1.24
Singh and Nautiyal, 1985	0.24	2.58	-0.62
Banskota *et al.*, 1985	0.0614	1.7274	-0.0544
Martinello, 1985	0.00	0.226	0.575
Martinello, 1987[1]	0.203 0.053	1.669 1.254	0.246 0.572
Meil and Nautiyal, 1988[2]	0.337		
Puttock and Prescott, 1992	0.595	NA	NA
Baardsen, 2000	-0.10	0.73	0.71
M[c]Queen, 2003	0.89	-1.36	0.91

[1]Top numbers are for BC Coast and bottom numbers are for BC Interior.
[2]Number is for smallest mill-size class in Ontario.

The complementarity of labor and capital indicates that they are employed in fixed proportions and this is again similar to the findings for the smaller mill size classes of Ontario and Québec modeled by Meil and Nautiyal.

3.5 Price Elasticities

The own-price and cross-price elasticities are calculated according to equation (7). The signs of the price elasticities are dependent on the signs of the AES. Therefore, the results in terms of whether inputs are substitutes or complements for each other mirror the results of the AES (Table 3-4).

Table 3-4. Own and Cross-Price Elasticities (at mean level of observations) 1963-1996.

Input	Labor Price	Material Price	Capital Price
Labor	-0.50	0.55	-0.06
Material	0.30	-0.34	0.04
Capital	-0.46	0.56	-0.19

All of the own-price elasticities are negative, indicating downward sloping demand curves. The cross-price elasticities are all positive indicating that the inputs are substitutes except for those between capital and labor which are negative indicating that those two inputs are complements. This is in accordance with the AES results. All the calculated elasticities are inelastic.

3.5.1 Own-Price Elasticities

Own-price elasticity of demand measures the percentage change in the quantity demanded of a good when its price changes by one percent. In this model, the change in quantity demanded of an input was measured as the change in the size of its cost share. The labor own-price elasticity of demand calculated in this study was -0.50 and was correctly signed for a downward sloping demand curve. It was also within the range reported in the literature. Nautiyal and Singh (1985) calculated an own-price elasticity of demand for labor of -0.48 for the Canadian lumber industry while Banskota *et al.* (1985) found it to be slightly more inelastic at -0.3644 for the Alberta sawmill industry. Abt (1987) calculated it to be -0.11 in the Appalachian region, -0.47 in the South and -0.39 in the West. Meil and Nautiyal (1988) calculated values for different regions of Canada ranging from -0.264 to -0.494. As with many of the elasticities of substitution calculated by them in that study, the values for the Ontario and Québec industries more closely matched the ones calculated for the Lake States as opposed to those of British Columbia. Baardsen (2000) reported the highest value in the reviewed literature with a value of -0.57 for the Norwegian industry.

The calculated own-price elasticity of demand for materials was -0.34. Nautiyal and Singh (1985) calculated a less inelastic value of -0.44. Meil and Nautiyal (1988) calculated a range of values from -0.065 to -0.229. The least inelastic value was for large mills in Québec. Unlike many of the elasticity of substitution results, their results for Ontario mills were not close to the findings of this study. The own-price elasticity for materials in Ontario mills ranged from -0.076 to -0.110. As with the other results that show elasticities quite a bit more inelastic than for the Lake States, one reason may be institutional factors that require mills to continue to process wood despite market conditions. In Canada, provincial governments typically require mills to harvest and process a certain amount of their annual allowable cut each year in order to ensure community stability and for forest management reasons. This makes them less able to substitute away from wood when the price increases. Nevertheless, Abt (1987) found the materials own-price elasticity for the Appalachian region in the U.S. to be very inelastic at -0.08. Abt's results for the Southern and Western regions were less inelastic at -0.25 and -0.20 respectively. Puttock and Prescott (1992) calculated it to be -0.202. Both Abt's and Puttock and Prescott's results are more inelastic than that of this study which contradicts some of the evidence that the Appalachian region of Abt and the Southern Ontario hardwood sawmill industry are close matches for the industry in the Lake States. It could be that the Lake States have somewhat of a hybrid industry in that hardwood lumber predominates in the southern areas of each state and softwood lumber becomes more prevalent as you move north and this is affecting the model results. In addition, NIPF dominates the forestland ownership classes in the southern parts of the states while state, national and commercial forestland is more prevalent farther north. Overall, the hardwood lumber industry predominates in the Lake States with over 75% of the total production by volume in 1996 (Census Bureau 1997). Baardsen (2000) found the least inelastic value in the literature with an own-price elasticity for sawlogs of -0.70. The Norwegian industry is dominated by softwood lumber.

The capital own-price elasticity is -0.19. Nautiyal and Singh (1988) found that the own-price elasticity of demand for capital in the Canadian industry was elastic with a value of -1.21. Martinello (1985) calculated a value of -0.297 for sawmills and shingle mills in BC. Singh and Nautiyal (1985) calculated a similar value of -0.2426 for the Canadian lumber industry using a long-run translog cost function. The result from Banskota *et al.* (1985) was -0.7590. Surprisingly, Baardsen (2000) did not find the largest value in the literature for this elasticity which he estimated to be-0.66 for Norwegian sawmills. Abt (1987), Meil and Nautiyal (1988) and Puttock and Prescott (1992) did not calculate price elasticities for capital.

3.5.2 Cross-Price Elasticities

Labor and materials were inelastic substitutes with a labor/materials cross-price elasticity of 0.55. This means that for a one percent increase in the price of materials, the quantity of labor demanded increases by 0.55%. The materials/labor cross-price elasticity was 0.30. Nautiyal and Singh (1985) found these two elasticities were more inelastic than those in this study with values of 0.30 and 0.14 respectively. Martinello (1985) found both of these elasticities were zero in keeping with his estimates of the AES between labor and materials. Banskota *et al.* (1985) determined that labor and material were substitutes, but very inelastic ones, with values of 0.0225 for labor/materials and 0.0258 for material/labor. Meil and Nautiyal (1988) also found these values to be inelastic but much less so than Banskota *et al.* with results for labor/materials ranging from 0.173 on the BC Coast to 0.278 in Québec. Their results for materials/labor ranged from 0.069 on the BC Coast to 0.240 in Québec. The Ontario numbers were in the 0.115 to 0.159 range. For the hardwood industry of southern Ontario, Puttock and Prescott (1992) calculated a labor/materials elasticity of 0.106 and a materials/labor elasticity of 0.227. For the Appalachian region of the U.S., Abt (1984) found the labor/materials elasticity of demand to be 0.47 and the materials/labor elasticity to be 0.35. The corresponding elasticities for the Southern and Western regions were 0.61 and 0.37, and 0.39 and 0.20. This study produced the same result as all the other studies in that labor and materials are substitutes but the degree of that substitutability is greater in the Lake States than the other regions. Although not a production study of the sawmill industry, McGuire *et al.*

(1999), also found that increased scarcity (both physical and economic) of veneer logs in Indiana, Illinois, Michigan, Minnesota and Wisconsin led to increased demand for sawmill labor in the form of increased effort to procure veneer logs.

The sign of the labor/capital and capital/labor cross-price elasticities indicate that they are inelastic complements. The value for the labor/capital elasticity is -0.06 and for capital/labor it is -0.46. Therefore the demand for labor is much less sensitive to the price of capital than the demand for capital is to the price of labor. As with the AES for labor/capital, most other studies reported cross-price elasticities that indicated they were inelastic substitutes. The exceptions are Banskota *et al.* (1985) and Meil and Nautiyal (1988). Banskota *et al.* reported a labor/capital cross-price elasticity of 0.6319 and a capital/labor elasticity of -0.2389. It is unclear how it was possible to have different signs on these two elasticities given that they were calculated as the product of the AES and the cost share for the second input: $(\xi_{ij} = A_{ij} * S_j)$. They reported a positive AES between labor and capital and all cost shares must be positive. Meil and Nautiyal also reported a number of results indicating that in some regions of Canada and for some mill size classes, labor and capital were complements. In BC, the larger mill size classes exhibited this trait and for Ontario and Québec almost all the mill size classes had a negative labor/capital cross-price elasticity. Only the smallest mill size class in Ontario had a result indicating they were substitutes with a value of 0.053. For the mill size classes in Ontario and Québec that indicated labor and capital were complements, the value of the elasticity varied from -0.033 up to -0.603. These values are in the range of those calculated in this study indicating that the labor and capital input markets in these regions are similarly sensitive to changes in their prices. The elasticities for the Lake States, nevertheless, indicate that capital is more sensitive to labor price changes than the other way around. This result follows from the AES between labor and capital and the fact that capital has a cost share of only 4% on average compared to 34% for labor.

The material/capital and capital/material elasticities are similar in magnitude but different in sign from the labor/capital and capital/labor elasticities. The value of the material/capital elasticity is 0.04 and the capital/material elasticity is 0.56. The results indicate that material and capital are substitutes and that capital is more sensitive to changes in material price than the other way around. The sensitivity to their respective price changes is the same as for labor and capital and for the same reason in that materials make up a much larger share of costs than capital. Nautiyal and Singh (1985) had results for Canada that reflect similar relative sensitivity to changes in cross-price with a material/capital elasticity of 0.17 and a capital/material elasticity of 0.63. Banskota *et al.* (1985) found material and capital to be complements with a material/capital elasticity of -0.0075 and a capital/material elasticity of -0.0228. This result is opposed to the result from Banskota (1984) that found material and capital to be substitutes. Banskota (1984) was a time series study while Banskota *et al.* (1985) was a mill-level cross-sectional study. He hypothesized that the differing results "reflects perhaps the long-run adjustments (cross-sectional studies) vis-à-vis short-run adjustments (time-series studies)" Banskota *et al.* (1985). Martinello (1985) also found the two inputs to be substitutes for the Canadian lumber industry with a material/capital elasticity of 0.078 and a capital material elasticity of 0.242 and Martinello (1987) found similar results for the BC Coast and Interior. Meil and Nautiyal (1988) had mixed results for the BC Coast and BC Interior with some mill-size classes indicating substitution between materials and capital and some indicating a complementary relationship. All of those elasticities were very small nonetheless with a range in absolute value of 0.002 to 0.065. For Ontario and Québec, material and capital were generally complements and the complementary elasticities varied from -0.078 to -0.869. For Norway, Baardsen (2000) had results similar to the others with a sawlog/capital elasticity of 0.04 and a capital/sawlog elasticity of 0.30. Abt (1987) found materials and capital to be complements in all three regions: the Appalachian region had a value of -0.10 while the Southern region's value was -0.03 and for the West it was -0.19.

3.5.3 Elasticity of Demand Discussion Summary

As with the own-price AES, all the own-price elasticities of demand are less than unity and negative indicating inelastic downward sloping demand curves. The cross-price elasticities are all inelastic and positive except between labor and capital which are inelastic and negative, in concurrence with the AES for those two inputs. Changes in the price of capital do not have very large effects on the demand for any of the inputs, including capital, whereas changes in the prices of the other two inputs have a much greater effect on the demand for capital.

Given that materials and labor are substitutes, the earlier discussion of reduced timber availability in the Lakes States as a result of changing forest management or landowner attitudes means that to a point, increases in materials prices may actually increase employment in the sawmill sector of the Lake States, assuming that output remains constant. There had been an increase in wood use and employment in the industry over the study period along with an increase in output. It is possible that part of the increase was the result of changing characteristics of the wood resource which required more of both inputs to produce the same amount of lumber. Decreasing average log diameter may be one characteristic that has changed over the course of the study period. Smaller diameter logs have lower lumber recovery factors (LRF) than larger diameter logs and so not only more wood, but more labor may be required to maximize the quantity of high grade lumber out of the smaller logs. This study is unable to determine how high or for how long timber prices can increase for this effect to hold. The substitutability of labor for materials and vice versa is higher in the Lake States than for the softwood producing regions of Canada. This may be due to the institutional factors controlling harvesting in the two jurisdictions. Almost all the timber harvested in Canada is from public land and sawmills are committed to harvest a certain percentage of their annual allowable cut (AAC) each year. This limits their response to price changes. Likewise, particularly in British Columbia, the labor force is unionized and so they are more limited in their response to labor price changes. In the United States, even in the Northwest where there is a large amount of federal land, sawmill managers have more leeway in adjusting to input price changes. Likewise in the Appalachian region and the South, the preponderance of private forestland means that sawmill operators can react to input price changes as opposed to being required to harvest when market conditions may not warrant because of other public policy reasons such as community stability.

For ease of comparison, a summary of the elasticity of demand results of other authors is presented below (Table 3-5 and Table 3-6).

Table 3-5 Own-Price Elasticity of Demand Results of Selected Studies

Study	Labor	Materials	Capital
Nautiyal and Singh, 1985	-0.48	-0.44	-1.21
Singh and Nautiyal, 1985	-0.8607	-0.6936	-0.2426
Banskota *et al.*, 1985	-0.3644	-0.0228	-0.7590
Martinello, 1985	-0.238	-0.374	-0.297
Martinello, 1987[1]	-0.309 -0.323	-0.069 -0.146	-0.528 -0.594
Abt, 1987[2]	-0.11	-0.08	NA
Meil and Nautiyal, 1988[3]	-0.440	-0.076	NA
Puttock and Prescott, 1992	-0.489	-0.202	NA
Bigsby, 1994	-0.58	-0.30	-0.69
Baardsen, 2000	-0.57	-0.70	-0.66
M^{c}Queen, 2003	-0.50	-0.34	-0.19

[1]Top numbers are for BC Coast and bottom numbers are for BC Interior.
[2]Numbers are for Appalachian region (Kentucky, Pennsylvania, West Virginia).
[3]Numbers are for smallest mill-size class in Ontario.

Table 3-6 Cross-Price Elasticity of Demand Results of Selected Studies

Study	Labor/ Materials	Materials /Labor	Labor/ Capital	Capital /Labor	Materials /Capital	Capital/ Materials
Stier, 1980			0.047	0.058		
Nautiyal and Singh, 1985	0.30	0.14	0.13	0.23	0.17	0.63
Singh and Nautiyal, 1985	0.1264	0.7659	0.2925	0.6085	-0.703	-0.3266
Banskota *et al.*, 1985	0.0225	0.0258	0.6319	-0.2389	-0.0228	-0.0075
Martinello, 1985	0.000	0.000	0.031	0.050	0.078	0.242
Martinello, 1987[1]	0.138 0.028	0.044 0.012	0.171 0.294	0.361 0.288	0.025 0.134	0.167 0.306
Abt, 1987[2]	0.11	-0.08	0.11	NA	-0.10	NA
Meil and Nautiyal, 1988[3]	0.199	0.115	0.053	NA	-0.205	NA
Puttock and Prescott, 1992	0.106	0.227	NA	NA	NA	NA
Bigsby, 1994	0.56	0.24	0.02	0.14	0.04	0.53
Baardsen, 2000	-0.04	-0.02	0.04	0.18	0.04	0.30
M[c]Queen, 2003	0.55	0.30	-0.06	-0.46	0.04	0.56

[1]Top numbers are for BC Coast and bottom numbers are for BC Interior.
[2]Numbers are for Appalachian region (Kentucky, Pennsylvania, West Virginia).
[3]Number is for smallest mill-size class in Ontario.

3.6 Productivity Growth

Growth in productivity, or technical change, is measured as the change in demand for inputs as a function of time holding output and prices constant. For example, if demand for labor is decreasing over time, that is an indication of labor-saving technological change. If demand for labor is increasing over time, then the technological change is labor-using. Improving productivity is an important way for the sawmill industry of the Lake States to remain competitive during a time of increasing resource constraints. This section includes a calculation of total factor productivity for the region as well as a measure of the bias of technological change among the inputs. This is useful information for policymakers as different policies will be required to enhance productivity of different inputs.

3.6.1 Total Factor Productivity

Total factor productivity is the overall measure of productivity for the given production technology and is measured by equation (10). In this model we cannot reject the assumption of constant returns to scale so $\left(\frac{\partial \ln VC}{\partial \ln Q}\right)$ equals 1 making the first term of equation (10) equal zero leaving:

$$\tau = -\frac{\partial \ln VC}{\partial t} \quad (20)$$

The derivative of the variable cost function with respect to t yields the following equation:

$$\frac{\partial \ln VC}{\partial t} = \beta_t + \beta_{tt}t + (-\beta_{Mt} - \beta_{Kt})\ln LP + \beta_{Mt}\ln MP + \beta_{Kt}\ln KP + \beta_{tQ}\ln Q \qquad (21)$$

Evaluated at the mean level of observations, total factor productivity as measured by Model (2) was 0.008. The interpretation of this number is that productivity is increasing because variable costs, holding output and input prices constant, are decreasing by approximately 0.8% per year. This is a small increase in overall productivity for the industry as a whole over the period of the study. It should be noted that this is an average rate of change over the study period while in reality technological change tends to be "lumpy". The goal of including a time trend in this study is to test for the existence of technological change and its effect on production costs. Under these circumstances, the constant rate of change assumption is not as limiting (Lopez 1980).

Most other studies report improvement in productivity to varying degrees. Martinello (1987) calculated annual total factor productivity improvement of 0.903% for British Columbia (BC) Coast sawmills but only 0.072% for BC Interior sawmills for the period 1963-1979. Nautiyal and Singh (1985) found no evidence of technological change in the Canadian lumber industry as a whole. In a study of individual softwood lumber producing regions in Canada from 1968-1984, Meil and Nautiyal (1988) found improvements in total factor productivity from 0.7% to 1.0% per year for BC Coast sawmills and from 0.2% to 0.4% in the BC Interior depending on the mill-size class. In Ontario, they found improvements of 0.6% to 1.0%. Québec also demonstrated improvements of 0.8% to 1.0% except in the largest mill-size category where there was an annual reduction of productivity of 0.1% per year. For British Columbia, the productivity improvements generally increased as mill-size class increased. There was no such correspondence for Ontario and Québec.

3.6.2 Technical Change Bias

In addition to overall change in productivity, the bias of that change can be calculated as well and is more interesting in terms of the policy implications of technological change. Bias of technological change is calculated as in equation (11).

The bias of technological change for each of the inputs as well as annual total factor productivity change show that technology has been improving over the study period (Table 3-4). The bias of technical change is interpreted as the annual percentage change in the cost share of the particular input.

Table 3-7. Technical Change 1963-1996

Input	Bias of Technical Change (%/yr)	Total Factor Productivity Change (%/yr)
Labor	-0.62	0.80
Material	0.31	
Capital	0.30	

The bias of the technical change in the sawmill industry as calculated here appears to be labor-saving and capital and materials-using. These results show that the cost share for material was increasing by 0.31%/year over the study period and for capital the increase is 0.30%/year. The cost share for labor is decreasing by 0.62%/year which is lower than most other studies. These values are quite low but nevertheless concur with previous information on the relatively low lumber recovery factor (LRF) in hardwood regions, the North Central region in particular, and the findings of other authors specifically modeling regions where hardwoods predominate. In the Appalachian region Abt (1987) found technical change to be labor-saving and material-using with values of -1.5%/year for labor and 0.8%/year for materials. Meil and Nautiyal (1988) had similar results for their study of the softwood producing regions of Canada. They found that for the smallest mill size class in Ontario, the bias of technological change for materials was 0.8%/year and -1.7%/year. for labor. That is, the cost share for these inputs was changing by that amount each year on average. Most other studies found that the bias in technological change was labor-saving and capital-using but it was also usually material-saving.

Meil and Nautiyal (1988) state that an alternative way to interpret factor-using technical change bias is that technical progress decreases with factor price increases. Therefore, in the Lake States, where the technical change bias is materials and capital using, industry and policymakers should pay attention to factors affecting the price of these inputs, particularly materials, if the sector is to maintain or improve productivity and competitiveness in the future.

The technological change bias in the Lake States is labor-saving but not as much as was found in other studies. In the studies that disaggregate mills into two or more mill-size classes, the general finding was that labor was more productive in larger mills. The model selection process used here was unable to reject the assumption of constant returns to scale but nevertheless it behooves mill managers to explore possibilities for improved labor productivity via scale expansion or other means.

The results for technical change bias for materials may indicate a change in the composition of the timber resource over time that is leading to greater wood use to produce the same amount of lumber. Perhaps the logs being milled are becoming smaller, or the species mix is becoming less favorable over time. This is a point that requires further research to clarify. Martinello (1987) cites decreasing size and quality of timber in British Columbia as the reason for his results that showed technological change being capital-using, labor-saving and (approximately) material-neutral in Coastal sawmills. The finding of materials using technological bias is also a concern given the prospect of reduced timber availability in the future in the Lake States. According to Skog (1997) computer-aided manufacturing and computer controlled processing are the key to reducing the effect of timber scarcity. He points out that the technology won't necessarily decrease the amount of wood consumed but will increase the proportion of high-grade material that is recovered and therefore offset the increasing price of sawlogs.

3.7 Returns to Scale

The model selection procedure found that the production structure of the sawmill industry of the Lake States could be estimated with a model that imposes constant returns to scale. This result concurs with the findings of studies for other regions of North America, but of particular note is the concurrence with the results of other studies of the hardwood lumber industry.

In the Lake States, lumber output per mill has generally increased over the study period but there have been several declines and increases in average output over that period (Figure 3-1).The chart of output per mill may distort the truth to the extent that the reconciliation of the lumber production figures reported in MA24T with the Census of Manufactures and the state sawmill directories resulted in upwards revisions to the production numbers starting in 1993. In that case, the output per mill before 1993 was understated relative to the years after 1993. Also, as stated earlier, there were large new capital expenditures in the 1990s in the Lake States for several large sawmills and this will increase the average output even though most mills may not be producing more lumber.

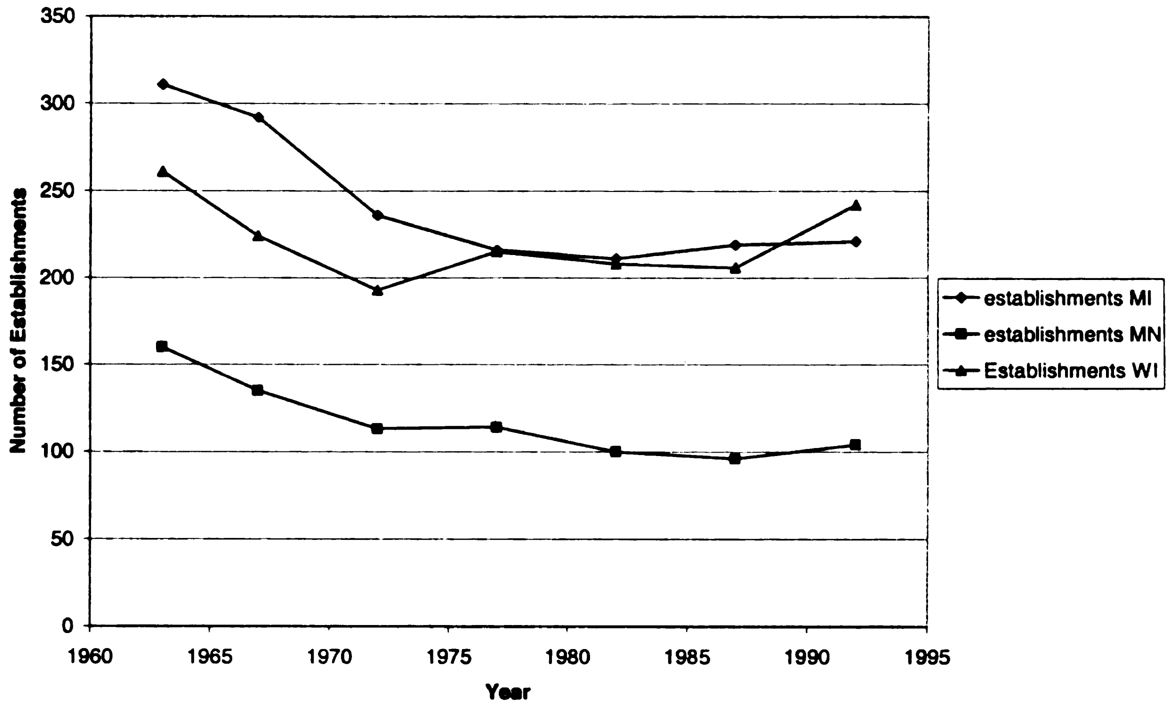

Figure 3-1. Number of Establishments, SIC 242 (1963-1992)
Source: Census of Manufactures (various years)

Given the number of establishments in each state over the study period (Figure 3-1) and the lumber output per mill (Figure 3-2), it is clear that the sawmill industry of the Lake States has not had the kind of reductions of mill numbers and increase in average output that other regions of the United States, Canada and other countries have had. For example, in Australia, numbers of sawmills decreased by two thirds between 1951 and the mid 1980s while output per mill increased almost four times over that same time period (Bigsby 1994). In Washington, the number of establishments decreased by 41% from 1963-1992 and output per mill increased 108%. Also, in West Virginia, the number of establishments decreased 50% over the same time period and output per mill increased by 79%. In the Lake States, the number of establishments decreased by 23% and output per mill increased by 52% (Census of Manufactures, various years).

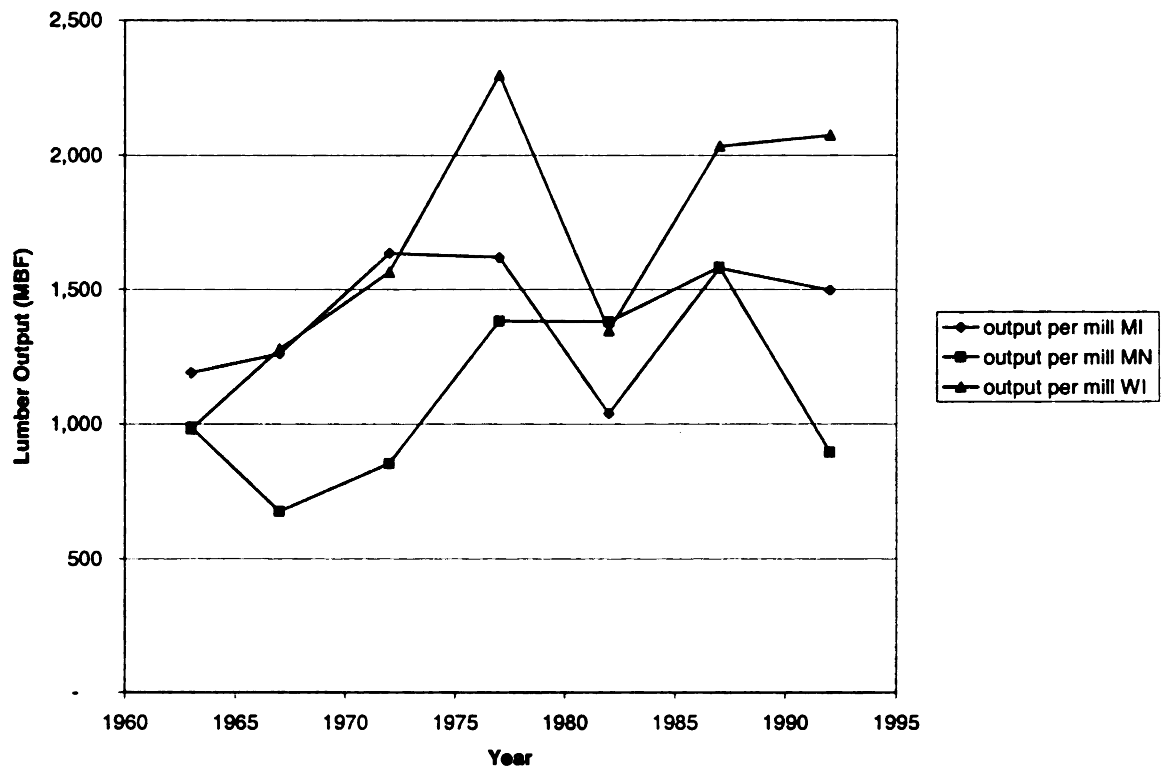

Figure 3-2. Lumber Output per mill. MI, MN and WI, 1963-1992. (MBF/mill)
Source: Census of Manufactures and MA24T, Lumber Production and Mill Stocks (various years)

Nautiyal and Singh (1985) reported constant returns to scale for their models of the lumber industry in Canada. Meil and Nautiyal (1988) reported constant returns to scale for some of the softwood lumber regions of Canada but not all. Martinello (1987) also calculated constant returns to scale for the lumber industry of the BC Interior but the Coastal region exhibited increasing returns to scale. Puttock and Prescott (1997) found constant returns to scale for the southern Ontario hardwood lumber industry for mills producing less than 1600 MBF of lumber per year but increasing returns to scale for mills producing more than that. Banskota *et al.* (1985) found a similar result in a study of the Alberta sawmill industry. No mills with production less than 850 MBF had significant scale economies while almost all mills with production greater than 850 MBF exhibited increasing returns to scale. In the only study of the sawmill industry in a hardwood region in the United States, Abt (1987) found decreasing returns to scale for the period 1963-1978 for the Appalachian region comprising Kentucky, Pennsylvania and West Virginia.

The average annual output of sawmills in the Lake States is 1600 MBF per mill. This figure is less than the output level required to exhibit increasing returns to scale in Puttock and Prescott's model of the hardwood industry in Ontario but almost double that of the model of the Alberta lumber industry by Banskota *et al.* The Lake States lumber industry is primarily based on hardwoods whereas that of Alberta is primarily softwood-based. The softwood lumber industry is characterized in comparison to the hardwood industry as having larger, more capital intensive mills in general. Nevertheless, the smaller mill size exhibiting increasing returns to scale in Alberta as opposed to southern Ontario may indicate the relative ease with which softwood logs can be handled and milled compared to hardwood logs.

The model selection process determined that the hypothesis of constant returns to scale cannot be rejected at the 1% level. The following analysis demonstrates the method of determining returns to scale with a restricted variable cost function as used in this study. The results from Model (1) were used to show how returns to scale may be calculated.

Recall that returns to scale is calculated as the percentage change in costs given a percentage change in output as given in equation (12). The derivative of the cost function in Model (1) with respect to output yields equation (22):

$$\frac{\partial \ln VC}{\partial \ln Q} = \beta_Q + \beta_{QQ} \ln Q + (-\beta_{MQ} - \beta_{KQ}) \ln LP + \beta_{MQ} \ln MP + \beta_{KQ} \ln K + \beta_{tQ} t \qquad (22)$$

Evaluated at the means of observations and using the parameter values from Model (1), equation (22) yields a value of 0.93. Therefore, the overall returns to scale estimated by the model is 0.07, or 7%. This means that for a 100% increase in output, variable costs will increase by only 93%. Therefore, there was a cost saving of 7%. This is a slightly positive returns to scale indicating that sawmills in the Lake States are on the declining portion of the average cost curve. This calculation must be interpreted with caution because the model selection process determined that the industry could be modeled assuming constant returns to scale and the coefficients on a number of the variables used to make the calculation are not significant at the 5% level.

Even though constant returns to scale cannot be rejected with this dataset, there could still be incentives for sawmills to expand based on other inputs not explicitly modeled in the variable cost function such as managerial skill. Given that the study period is over thirty years long and the assumed service lives of both machinery and structures are less than that, there has been opportunity for mills to increase in size without premature retirement of productive capital. It may be that the periodic recessions that have hit the industry, particularly in the early 1980s have made risk-averse mill owners reluctant to expand their operations or buy out competitors despite possible reductions in average costs.

4.0 CONCLUSIONS AND POLICY IMPLICATIONS

This chapter summarizes the main findings of the study and draws conclusions based on those findings. Some policy implications of the findings are discussed. A brief discussion of future research to answer questions raised by this research is also included.

4.1 Summary of Results

This study determined estimates of elasticities of substitution, elasticities of demand, technological change, the bias of technological change and returns to scale for the sawmill industry of the Lakes States from 1963-1996. Based on the results presented in Chapter 3, a homothetic, homogenous (constant returns to scale), nonunitary elasticity of substitution cost function can be used to model the production structure of the sawmilling industry of the Lake States (Michigan, Minnesota and Wisconsin). This estimated cost function satisfies all of the properties of a well-behaved cost function and the results are consistent with economic theory and the estimates found in the literature.

Based on Allen Partial Elasticities of Substitution (AES), labor and materials, and materials and capital are inelastic substitutes while labor and capital are elastic complements in the Lake States sawmilling industry. The complementarity between labor and capital indicates that these factors are employed in fixed proportions. The substitutability between labor and materials is relatively high in relation to most other studies, but comparable to studies of hardwood regions in North America.

The Morishima Elasticities of Substitution (MES) indicate that all inputs are inelastic substitutes. The MES allows for asymmetrical elasticities of substitution between input pairs and the results demonstrate that changes in the price of capital have relatively little effect on labor and materials use, whereas changes in labor and materials price have a relatively large effect on the use of capital. The MES between labor and materials are similar in magnitude to the AES results.

The elasticities of demand show that labor and materials, and materials and capital are substitutes while labor and capital are complements. All of the own-price elasticities are negative which is necessary for downward sloping demand curves. All of the own and cross-price elasticities are inelastic.

There was a small annual decrease in variable costs holding output constant over the study period. This indicates that total factor productivity was increasing. The results for bias of technical change indicate that the technological change over the study period has been materials and capital-using and labor-saving although the labor savings have not been as dramatic as other regions.

The model selection procedure found that the assumption of constant returns to scale (homogeneity of degree one in output) could not be rejected at the 1% level and so all the results are based on that model. This is not uncommon in the literature although some regions exhibit increasing returns to scale (e.g., BC Coast) while the Appalachian region exhibited decreasing returns to scale.

4.2 Conclusions and Policy Implications

The results also seem to indicate, and this is corroborated by Abt (1987), that there are significant differences in the production structure of the sawmill industry between regions. This is understandable given the differences in the wood resource in the Pacific Northwest for instance, and the Lake States. The findings of the study show that there is greater substitutability between labor and materials in the Lake States than in the softwood lumber regions. Therefore, policies affecting the sawmill industry should be tailored to the region they are located. The same policy will affect sawmills differently in Washington than it will in Michigan. For example, in the Lake States and other hardwood regions, policies that promote research and development on sawmill technology may help increase the productivity of the industry more than similar investments in softwood regions which typically are already more capital intensive than the hardwood industry. In general, policies that address the weaknesses of the Lake States' industry with respect to the sawmill industry in other regions will be more effective in improving its efficiency than national policies. Naturally, for state governments, the results of this study point to some weaknesses or peculiarities of the hardwood industry and these findings can be used to gauge the applicability of policies implemented in other jurisdictions to the Lake States.

To the extent that decreased harvest levels on public land increases timber prices, such a policy may actually increase employment given the substitution effect reported in this study. It is difficult to say to what extent this effect may apply because the results for the substitution between inputs are contingent on output levels remaining constant. Large decreases in timber harvests could lead to the shutdown of mills that have less of an ability to substitute away from wood and consequently have higher costs.

Given that such a large amount of forestland in the Lake States is privately owned, policies affecting harvest levels on public land are only part of the picture. As was discussed in Chapter 1, there is concern that harvests from private lands will decrease as landowners' preferences shift towards the aesthetic value of standing timber as opposed to the financial value of harvested timber. In this case, government policymakers have no direct control over harvest patterns and so instruments such as tax incentives for forest management would be necessary. These types of incentives already exist to help achieve forest management goals on private land. Using the results of this study it may be possible to gauge the effects of such policies more accurately.

The finding that labor and capital are complements in the sawmilling process of the Lake States also differentiates the region from other lumber producing regions of the United States. Changes in the price of all inputs affects the demand for all other inputs and so policymakers must be cognizant of this. In the case of labor and capital, the effects are synergistic. Apart from the direction of demand changes when the price of labor or capital changes, the magnitude is important. Changes in the price of capital have less of an effect on the demand for labor than the other way around. Therefore policies affecting one or other of these two inputs will have a varying degree of effect depending on which input they apply to. For example, changes in the Federal Reserve prime rate will not directly affect employment in the sawmill industry as much as changes in payroll taxes will affect demand for capital.

The results for technological change bias in the Lake States indicate that the technology change is material-using. This may be the result of a degradation in the size, quality and/or species composition of the forest resource in the Lake States. If this is the case, adaptation of the types of computer-aided processing systems common in modern softwood lumber mills could help overcome negative changes in the quality or availability of the wood resource.

The technical change was also capital-using and labor-saving which was a common finding in the literature for the sawmill sector. The labor savings are not as high as in other regions and this could limit the competitiveness of Lake States sawmilling in the future. Also, although this model does not consider quality of labor, the capital-using labor-saving technological change bias tends to leave the less-skilled workers behind. Problems like this are not as grave in the Lake States as they might be in a region more dominated by the forest industry where there are fewer alternative employment opportunities.

The industry exhibits constant returns to scale although the exact reason for this is unclear. It may be the result of uncertain and unstable market conditions and the ability of small mills to use fully depreciated capital equipment. This finding makes sense in light of the relatively small change in mill number and output per mill compared to other states. Until the reasons for the lack of improvement in output per mill and technological progress compared to other regions are determined, it does not make sense to employ policies that encourage larger mills. On the other hand, if there were diseconomies of scale, then larger mills would improve the overall efficiency of the industry.

4.3 Further Research

The above conclusions indicate that further research into the reasons for the limited technological change and lack of economies of scale would be beneficial for policymakers to determine ways to maintain the competitiveness of the sawmill industry in the Lake States.

It would be beneficial to model the hardwood and softwood industries of the Lake States separately as it seems clear from the literature that they exhibit differing production structures. In the Lake States, hardwoods make up over 75% of the volume harvested so the results are biased in favor of hardwood sawmills but it would be interesting to compare the two industries within the same region.

This model used lumber as the only output of the sawmilling sector. Due to lack of data, other outputs such as wood chips could not be included. Woodchips are an increasingly important joint product for sawmills and in the United States, the large harvest reductions on National Forests, particularly in the West, may increase the importance of wood chips even for hardwood sawmills.

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APPENDIX A: Model Data

Table A-1. Summary of Data Calculations

Variable	Source[1]	Units	Calculation
Labor Quantity	CoM, ASM	hours	Raw data
Sawlog Quantity	Forest Service TPO reports(see Table 5 Appendix A)	Millions of cubic feet	Converted to millions of board feet using a conversion factor of 158 cubic feet per thousand board feet International scale
Labor Price	CoM ASM	$/hour	Total production labor hours divided by production labor cost
Sawlog Price	CoM, ASM, Timber Mart North, state Departments of Natural Resources stumpage data, Forest Service stumpage data, Minnesota Forest Products Price Report, Wisconsin County stumpage data, the Wisconsin Forest Products Price Review and U.S. timber production, trade, consumption, and price statistics, 1950-85 by Alice H. Ulrich.	$/thousand board feet	Prices for years in which Forest Service Timber Product Output data were available were calculated by dividing materials cost (reported in CoM and ASM) by the volume of sawlog receipts at sawmills as reported in the publications listed at the bottom of Table 5 in Appendix A. For other years, sawlog price was calculated from prices reported by the sources listed in column two. The price used in the model was a weighted average price based on the volume of each species harvested in that year. For years in which harvest data are not available, it was assumed that the proportion of each species volume in the total harvest was the same as the closest year for which harvest data were available.
Capital Stock	CoM and ASM	Millions of dollars	The capital stock series was calculated as described in Section 2.4.4.
Capital Price		$/$ Capital price was a ratio of the gross quasirent to capital stock	The capital price was calculated as described in Section 2.4.4.
User cost of Capital		Millions of dollars	The user cost of capital was calculated as described in Section 2.4.4.

[1]CoM is the Census of Manufactures; ASM is Annual Survey of Manufactures;

Table A-2. Model data for Michigan (27 observations) All figures are in 1996 dollars.

Year	Sawlog Cost (millions)	Labor Cost (millions)	User cost of capital (millions)	Sawlog price $/MBF international	Wage Rate $/hr.	Capital Price	Lumber Production (MMBF)
1963	60.00	53.37	2.68	51.60	7.78	0.40	370
1964	92.46	57.38	2.82	51.41	7.86	0.41	377
1965	74.27	50.01	3.00	51.71	8.58	0.42	370
1966	68.22	45.07	3.55	52.72	7.87	0.43	349
1967	70.96	51.23	3.89	57.12	8.83	0.44	368
1969	81.21	58.47	5.50	57.42	9.28	0.46	403
1970	70.60	55.72	5.85	60.44	8.32	0.47	407
1971	75.88	56.98	5.23	73.84	10.00	0.48	403
1972	96.51	58.40	5.65	74.26	10.81	0.48	386
1973	101.02	60.16	6.30	74.25	8.85	0.49	391
1974	109.03	70.65	6.80	89.87	7.60	0.50	351
1975	95.69	60.79	6.97	97.84	6.08	0.51	317
1976	108.68	71.06	7.48	93.57	7.64	0.52	334
1977	96.97	57.26	7.69	98.94	8.68	0.53	350
1978	72.35	49.14	8.49	108.37	9.83	0.54	365
1982	77.44	36.52	11.32	112.82	8.12	0.58	219
1983	94.29	42.61	9.75	127.60	8.70	0.59	232
1987	105.94	49.94	7.89	150.30	9.99	0.62	346
1988	107.13	48.62	8.41	144.14	9.72	0.63	314
1989	73.39	45.53	8.41	194.14	10.59	0.64	323
1990	78.18	47.43	8.72	104.74	10.54	0.65	342
1991	101.46	53.60	8.42	164.49	10.31	0.66	316
1992	146.79	57.64	8.12	212.64	10.67	0.67	331
1993	193.15	84.31	7.52	227.35	11.39	0.68	627

Table A-2 continued,

1994	161.73	66.82	8.56	242.37	10.61	0.69	652
1995	162.70	66.97	8.49	201.81	9.85	0.70	654
1996	155.52	66.00	8.66	262.24	10.31	0.70	652

Table A-3. Model data for Minnesota (17 observations) All figures are in 1996 dollars.

Year	Sawlog Cost (millions)	Labor Cost (millions)	User cost of capital (millions)	Sawlog price $/MBF international	Wage Rate $/hr.	Capital Price	Lumber Production (MMBF)
1963	14.47	9.82	0.39	38.08	6.37	0.19	158
1964	21.63	8.46	0.44	35.14	5.31	0.20	172
1965	11.80	10.52	0.51	36.95	8.77	0.22	170
1967	18.96	12.23	0.67	39.19	8.16	0.25	190
1972	57.24	21.18	1.10	48.04	11.15	0.32	169
1977	46.12	19.68	1.56	82.85	8.55	0.40	203
1982	50.57	11.75	3.06	153.06	7.83	0.47	138
1987	51.08	23.35	3.25	154.23	9.73	0.54	152
1988	56.58	24.13	3.79	159.48	8.94	0.56	154
1989	31.69	26.97	4.04	165.00	10.37	0.57	150
1990	39.53	26.02	4.35	148.45	9.64	0.59	109
1991	57.70	30.69	4.28	176.09	10.58	0.60	95
1992	73.22	32.91	4.22	170.02	10.61	0.62	93
1993	56.54	36.41	3.82	191.54	10.11	0.63	303
1994	188.28	98.32	6.42	212.77	10.57	0.65	312
1995	201.53	104.04	8.29	311.17	11.07	0.66	310
1996	186.80	109.30	8.26	221.81	14.57	0.68	315

Table A-4. Model data for Wisconsin (22 observations) All figures are in 1996 dollars.

Year	Sawlog Cost (millions)	Labor Cost (millions)	User cost of capital (millions)	Sawlog price $/MBF international	Wage Rate $/hr.	Capital Price	Lumber Production (MMBF)
1963	36.17	41.04	3.29	42.15	7.12	0.56	256
1964	46.74	38.74	3.43	43.00	7.29	0.56	293
1967	52.61	34.41	4.01	46.00	8.00	0.58	286
1972	79.57	43.64	4.99	58.80	10.39	0.60	302
1973	84.00	47.39	5.33	68.78	8.94	0.60	377
1974	94.71	57.52	5.57	74.14	9.28	0.61	367
1975	79.94	48.76	5.57	79.50	8.55	0.61	370
1976	84.60	50.37	5.15	77.95	8.84	0.62	423
1977	97.28	56.08	6.44	85.72	8.50	0.62	494
1978	118.68	61.93	11.79	103.90	8.98	0.63	507
1982	81.42	46.23	20.75	142.16	8.40	0.65	280
1983	92.18	49.54	17.85	147.57	8.54	0.65	306
1987	184.74	77.14	14.68	229.68	10.02	0.67	419
1988	226.97	82.90	17.50	321.41	9.21	0.68	391
1989	220.44	78.76	16.39	306.15	9.60	0.68	514
1990	197.64	76.31	15.63	290.80	9.91	0.69	525
1991	178.36	69.93	13.84	288.60	9.99	0.69	502
1992	208.77	84.01	12.76	286.40	10.12	0.69	502
1993	195.56	80.55	11.55	328.76	10.46	0.70	639
1994	292.48	103.84	14.19	371.13	10.28	0.70	645
1995	281.90	113.98	15.55	253.82	10.18	0.71	635
1996	285.44	110.50	16.46	242.82	10.33	0.71	617

Table A-5. Sawlog Receipts by Sawmills in the Lake States (million cubic feet)

Year	Michigan	Minnesota	Wisconsin
1963	NA	NA	NA
1964	NA	NA	NA
1965	57.4	NA	NA
1966	NA	NA	NA
1967	NA	NA	47.8
1968	NA	NA	NA
1969	62.3	NA	NA
1970	NA	NA	NA
1971	NA	NA	NA
1972	64	NA	NA
1973	NA	30.9	68
1974	NA	NA	NA
1975	NA	30.9	NA
1976	NA	72.7	NA
1977	78.7	NA	NA
1978	NA	NA	NA
1979	NA	NA	NA
1980	NA	NA	NA
1981	NA	NA	94.4
1982	NA	NA	NA
1983	NA	NA	NA
1984	83.2	NA	NA
1985	NA	NA	NA
1986	NA	NA	93.2
1987	NA	NA	NA
1988	98.3	55.7	93.4
1989	NA	NA	NA
1990	107.4	40.7	97.8
1991	NA	NA	NA
1992	100.1	52.3	105.7
1993	NA	NA	NA
1994	99.4	NA	117.4
1995	NA	NA	NA
1996	93.7	NA	NA

NOTE: Michigan data are from U.S. Forest Service publications NC-109, NC-121, NC-144, NC-162 and NC-189. Minnesota data are from U.S. Forest Service publications NC-127, NC-143 and NC-186. Wisconsin data are from U.S. Forest Service publications NC-90, NC-112, NC-124, NC-147, NC-164 and NC-187.

APPENDIX B: Model Output

Table B-1. Model (1)Homogeneous of degree one in input prices

System: TRANSLOG				
Estimation Method: Full Information Maximum Likelihood (Marquardt)				
Sample: 1 66				
Included observations: 66				
Total system (balanced) observations 198				
	Coefficient	Std. Error	z-Statistic	Prob.
C(30)	2108.314	2421.512	0.870660	0.3839
C(2)	0.313963	3.832977	0.081911	0.9347
C(3)	-1.660164	2.055510	-0.807665	0.4193
C(4)	-2.374990	2.495036	-0.951886	0.3412
C(5)	86.46128	23.68232	3.650879	0.0003
C(12)	-0.049805	0.036801	-1.353351	0.1759
C(13)	-0.016692	0.027173	-0.614293	0.5390
C(23)	-0.019330	0.023070	-0.837865	0.4021
C(55)	-0.399316	0.357169	-1.118002	0.2636
C(44)	0.001318	0.001285	1.026278	0.3048
C(25)	-0.001560	0.020411	-0.076412	0.9391
C(35)	-0.005637	0.012326	-0.457304	0.6475
C(24)	4.27E-05	0.002001	0.021316	0.9830
C(34)	0.000953	0.001080	0.882113	0.3777
C(45)	-0.042048	0.011960	-3.515642	0.0004
Log Likelihood		293.2787		
Determinant residual covariance		2.77E-08		
Equation: LNVC=C(30)+(1-C(2)-C(3))*LNLP+C(2)*LNSLP+C(3)*LNKP+C(4)*T +C(5)*LNPROD+.5*((-C(12)-C(13))*LNLP^2+(-C(12)-C(23))*LNSLP^2+(-C(13)-C(23))*LNKP^2+C(55)*LNPROD^2 +C(44)*T^2+2*C(12)*LNLP*LNSLP+2*C(13)*LNLP*LNKP+2 *C(23)*LNSLP*LNKP)+(-C(25)-C(35))*LNLP*LNPROD +(-C(24)-C(34))*LNLP*T+C(25)*LNSLP*LNPROD +C(24)*LNSLP*T+C(35)*LNKP*LNPROD+C(34)*LNKP*T +C(45)*T*LNPROD				
Observations: 66				
R-squared	0.875233	Mean dependent var	4.959911	
Adjusted R-squared	0.840983	S.D. dependent var	0.636805	
S.E. of regression	0.253938	Sum squared resid	3.288718	
Durbin-Watson stat	1.732487			

Table B-1 continued,

Equation: LCSHR=(1-C(2)-C(3))+(-C(12)-C(13))*LNLP+ C(12)*LNSLP+C(13)*LNKP+(-C(25)-C(35))*LNPROD+(- C(24)-C(34))*T			
Observations: 66			
R-squared	0.459702	Mean dependent var	0.336903
Adjusted R-squared	0.394494	S.D. dependent var	0.061467
S.E. of regression	0.047830	Sum squared resid	0.132686
Durbin-Watson stat	1.192809		
Equation: SLCSHR=C(2)+(-C(12)- C(23))*LNSLP+C(12)*LNLP+C(23) *LNKP+C(25)*LNPROD+C(24)*(T)			
Observations: 66			
R-squared	0.363991	Mean dependent var	0.620487
Adjusted R-squared	0.322285	S.D. dependent var	0.061068
S.E. of regression	0.050273	Sum squared resid	0.154172
Durbin-Watson stat	1.295637		

Table B-2. Model (2) Homogeneous of degree one in input prices; Constant returns to scale

System: CRS				
Estimation Method: Full Information Maximum Likelihood (Marquardt)				
Sample: 1 66				
Included observations: 66				
Total system (balanced) observations 198				
	Coefficient	Std. Error	z-Statistic	Prob.
C(30)	2264.810	2333.536	0.970549	0.3318
C(2)	-3.309063	3.578758	-0.924640	0.3552
C(3)	-0.101956	1.864704	-0.054677	0.9564
C(4)	-2.498411	2.413737	-1.035080	0.3006
C(5)	78.23072	27.16900	2.879411	0.0040
C(12)	-0.022130	0.033104	-0.668498	0.5038
C(13)	-0.033941	0.026799	-1.266531	0.2053
C(23)	-0.002382	0.020683	-0.115176	0.9083
C(44)	0.001366	0.001248	1.094570	0.2737
C(24)	0.001949	0.001861	1.047317	0.2950
C(34)	0.000128	0.000975	0.131813	0.8951
C(45)	-0.039016	0.013672	-2.853637	0.0043
Log Likelihood		290.3679		
Determinant residual covariance		3.03E-08		
Equation: LNVC=C(30)+(1-C(2)-C(3))*LNLP+C(2)*LNSLP+C(3)*LNKP+C(4)*T+C(5)*LNPROD+.5*((-C(12)-C(13))*LNLP^2+(-C(12)-C(23))*LNSLP^2+(-C(13)-C(23))*LNKP^2+C(44)*T^2+2*C(12)*LNLP*LNSLP+2*C(13)*LNLP*LNKP+2*C(23)*LNSLP*LNKP)+(-C(24)-C(34))*LNLP*T+C(24)*LNSLP*T+C(34)*LNKP*T+C(45)*T*LNPROD				
Observations: 66				
R-squared	0.871292	Mean dependent var	4.959911	
Adjusted R-squared	0.845074	S.D. dependent var	0.636805	
S.E. of regression	0.250651	Sum squared resid	3.392598	
Durbin-Watson stat	1.597738			
Equation: LCSHR=(1-C(2)-C(3))+(-C(12)-C(13))*LNLP+C(12)*LNSLP+C(13)*LNKP+(-C(24)-C(34))*T				
Observations: 66				
R-squared	0.421001	Mean dependent var	0.336903	

Table B-2 continued,

Adjusted R-squared	0.372751	S.D. dependent var	0.061467
S.E. of regression	0.048681	Sum squared resid	0.142190
Durbin-Watson stat	1.122292		
Equation: SLCSHR=C(2)+(-C(12)-C(23))*LNSLP+ C(12)*LNLP+C(23)*LNKP+C(24)*(T)			
Observations: 66			
R-squared	0.335968	Mean dependent var	0.620487
Adjusted R-squared	0.303838	S.D. dependent var	0.061068
S.E. of regression	0.050953	Sum squared resid	0.160965
Durbin-Watson stat	1.216725		

Table B-3. Model (3) Homogeneous of degree one in input prices; Constant elasticity of substitution

System: UNIELASTICITY				
Estimation Method: Full Information Maximum Likelihood (Marquardt)				
Sample: 1 66				
Included observations: 66				
Total system (balanced) observations 198				
	Coefficient	Std. Error	z-Statistic	Prob.
C(30)	2264.806	2848.650	0.795045	0.4266
C(2)	-3.570293	1.596226	-2.236709	0.0253
C(3)	-1.308943	1.214176	-1.078050	0.2810
C(4)	-2.502492	2.918127	-0.857568	0.3911
C(5)	78.45354	21.58155	3.635213	0.0003
C(55)	-0.393186	0.275956	-1.424815	0.1542
C(44)	0.001367	0.001494	0.915222	0.3601
C(25)	0.007813	0.017006	0.459447	0.6459
C(35)	-0.002308	0.011845	-0.194846	0.8455
C(24)	0.002093	0.000812	2.577139	0.0100
C(34)	0.000689	0.000628	1.097292	0.2725
C(45)	-0.038039	0.010770	-3.531861	0.0004
Log Likelihood		282.4714		
Determinant residual covariance		3.85E-08		
Equation: LNVC=C(30)+(1-C(2)-C(3))*LNLP+C(2)*LNSLP+ C(3)*LNKP+C(4)*T+C(5)*LNPROD+.5*(C(55)*LNPROD^2 +C(44)*T^2)+(-C(25)-C(35))*LNLP*LNPROD +(-C(24)-C(34))*LNLP*T+C(25)*LNSLP*LNPROD+ C(24)*LNSLP*T+C(35)*LNKP*LNPROD+ C(34)*LNKP*T+C(45)*T*LNPROD				
Observations: 66				
R-squared	0.874809	Mean dependent var		4.959911
Adjusted R-squared	0.849307	S.D. dependent var		0.636805
S.E. of regression	0.247203	Sum squared resid		3.299891
Durbin-Watson stat	1.749547			
Equation: LCSHR=(1-C(2)-C(3))+(-C(25)-C(35))*LNPROD+(-C(24)-C(34))*T				
Observations: 66				
R-squared	0.389426	Mean dependent var		0.336903
Adjusted R-squared	0.338545	S.D. dependent var		0.061467

Table B-3 continued,

S.E. of regression	0.049991	Sum squared resid	0.149944
Durbin-Watson stat	1.173326		
Equation: SLCSHR=C(2)+C(25)*LNPROD+C(24)*(T)			
Observations: 66			
R-squared	0.279240	Mean dependent var	0.620487
Adjusted R-squared	0.256358	S.D. dependent var	0.061068
S.E. of regression	0.052662	Sum squared resid	0.174716
Durbin-Watson stat	1.188819		

Table B-4. Model (4) Homogenous of degree one in input prices; Constant returns to scale; Constant elasticity of substitution

System: CRSUNIELASTICITY				
Estimation Method: Full Information Maximum Likelihood (Marquardt)				
Sample: 1 66				
Included observations: 66				
Total system (balanced) observations 198				
	Coefficient	Std. Error	z-Statistic	Prob.
C(30)	2264.806	2674.889	0.846692	0.3972
C(2)	-3.570305	1.503421	-2.374787	0.0176
C(3)	-1.308860	0.925175	-1.414717	0.1572
C(4)	-2.500494	2.746168	-0.910539	0.3625
C(5)	78.45342	25.78444	3.042666	0.0023
C(44)	0.001368	0.001410	0.970449	0.3318
C(24)	0.002112	0.000758	2.785713	0.0053
C(34)	0.000682	0.000466	1.463747	0.1433
C(45)	-0.039126	0.012977	-3.015044	0.0026
Log Likelihood		279.4977		
Determinant residual covariance		4.21E-08		
Equation: LNVC=C(30)+(1-C(2)-C(3))*LNLP+C(2)*LNSLP+C(3)*LNKP+C(4)*T+C(5)*LNPROD+.5*(C(44)*T^2)+(-C(24)-C(34))*LNLP*T+C(24)*LNSLP*T+C(34)*LNKP*T+C(45)*T*LNPROD				
Observations: 66				
R-squared	0.869116	Mean dependent var		4.959911
Adjusted R-squared	0.850747	S.D. dependent var		0.636805
S.E. of regression	0.246019	Sum squared resid		3.449942
Durbin-Watson stat	1.574837			
Equation: LCSHR=(1-C(2)-C(3))+(-C(24)-C(34))*T				
Observations: 66				
R-squared	0.371778	Mean dependent var		0.336903
Adjusted R-squared	0.341380	S.D. dependent var		0.061467
S.E. of regression	0.049883	Sum squared resid		0.154278
Durbin-Watson stat	1.125985			
Equation: SLCSHR=C(2)+C(24)*(T)				
Observations: 66				
R-squared	0.258612	Mean dependent var		0.620487

Table B-4 continued,

Adjusted R-squared	0.247028	S.D. dependent var	0.061068
S.E. of regression	0.052991	Sum squared resid	0.179716
Durbin-Watson stat	1.146907		

Table B-5. Model (2) with State dummy variables; Homogenous of degree one in input prices; Constant returns to scale

System: CRSSTATEDUMMY				
Estimation Method: Full Information Maximum Likelihood (Marquardt)				
Sample: 1 66				
Included observations: 66				
Total system (balanced) observations 198				
	Coefficient	Std. Error	z-Statistic	Prob.
C(30)	2264.805	2234.575	1.013528	0.3108
C(2)	-3.567502	3.899298	-0.914909	0.3602
C(3)	-1.294633	2.186002	-0.592238	0.5537
C(4)	-2.502194	2.304138	-1.085957	0.2775
C(5)	78.45018	28.05464	2.796335	0.0052
C(12)	-0.016024	0.033744	-0.474873	0.6349
C(13)	-0.027729	0.026760	-1.036189	0.3001
C(23)	-0.013698	0.023525	-0.582256	0.5604
C(44)	0.001370	0.001188	1.152995	0.2489
C(24)	0.002056	0.002040	1.008155	0.3134
C(34)	0.000752	0.001138	0.661186	0.5085
C(45)	-0.039143	0.014097	-2.776678	0.0055
C(66)	0.006537	0.097342	0.067150	0.9465
C(77)	-0.026683	0.199078	-0.134032	0.8934
Log Likelihood		289.7422		
Determinant residual covariance		3.09E-08		
Equation: LNVC=C(30)+(1-C(2)-C(3))*LNLP+C(2)*LNSLP +C(3)*LNKP+C(4)*T+C(5)*LNPROD+ .5*((-C(12)-C(13))*LNLP^2+(-C(12)-C(23))*LNSLP^2 +(-C(13)-C(23))*LNKP^2+C(44)*T^2+2*C(12)*LNLP *LNSLP+2*C(13)*LNLP*LNKP+2*C(23)*LNSLP*LNKP) +(-C(24)-C(34))*LNLP*T+C(24)*LNSLP*T+ C(34)*LNKP*T+C(45)*T*LNPROD+C(66)*MIDUM +C(77)*MNDUM				
Observations: 66				
R-squared	0.873106	Mean dependent var		4.959911
Adjusted R-squared	0.841383	S.D. dependent var		0.636805
S.E. of regression	0.253619	Sum squared resid		3.344779
Durbin-Watson stat	1.581137			

Table B-5 continued,

Equation: LCSHR=(1-C(2)-C(3))+(-C(12)-C(13))*LNLP+C(12)*LNSLP +C(13)*LNKP+(-C(24)-C(34))*T			
Observations: 66			
R-squared	0.417108	Mean dependent var	0.336903
Adjusted R-squared	0.368533	S.D. dependent var	0.061467
S.E. of regression	0.048844	Sum squared resid	0.143146
Durbin-Watson stat	1.114952		
Equation: SLCSHR=C(2)+(-C(12)-C(23))*LNSLP+C(12)*LNLP+C(23) *LNKP+C(24)*(T)			
Observations: 66			
R-squared	0.353613	Mean dependent var	0.620487
Adjusted R-squared	0.322336	S.D. dependent var	0.061068
S.E. of regression	0.050271	Sum squared resid	0.156688
Durbin-Watson stat	1.248145		