EFFICIENCY ANALYSIS
OF PRIMARY WOOD PRODUCERS IN BRITISH COLUMBIA
USING DATA ENVELOPMENT ANALYSIS

by

NEDA SALEHIRAD

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Abstract

The Canadian wood industry has faced several changes during the last decade. These changes include increasing global competition, changes in macro and micro practices, market restructuring, and technological advancements. One of the most affected sectors by these changes in the business environment is the primary wood manufacturing sector in British Columbia. This study examines the performance of this sector over the period of 1990-2002. The base methodological approach used is Data Envelopment Analysis.

The study has two major objectives: first, to evaluate the efficiency of BC primary wood producers in 2002 and in relation to some environmental and managerial factors. Second, to analyze the efficiency trend of BC primary wood producers during the 1990-2002 period and identify the underlying causes. The first part of the study reveals some technical inefficiencies for the BC primary wood sector, but predominantly high scale efficiencies. Technical efficiency may be improved by increasing lumber and chip production, as well as enhancing the labour productivity. BC forest regions were significantly different in terms of efficiency; the northern interior regions showed the highest efficiency, followed by the regions in the southern interior. The coastal forest regions had the lowest efficiency.

The second part of the study suggests a productivity decline in 1991 for the sector, followed by a steady state until 1996 when continuous growth began. The major reason for the productivity growth was technological advancement rather than technical efficiency improvement. The analysis of the mills which were shut down in 2002, demonstrated that most of them had been performing below average provincial efficiency levels, either due to lack of technical capabilities or the scale of operations.

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For my parents

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به نام خداوند جان و خرد، که ستودن نداند کس او را چو هست:

خرد را و جان را همی سنجد اوی   در اندیشه سخته کی گنجد اوی.

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Chapter 1

Introduction

1.1 Background on the Canadian Wood Industry

Wood products manufacturing is the second largest sector among the Canadian forest industries. This sector has experienced a steady growth over the last decade (Figure 1.1).

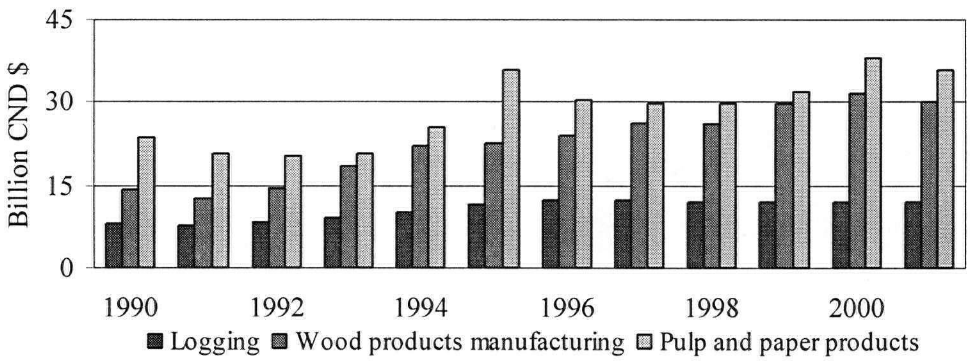

Figure 1.1 - Manufacturing value of different sectors in the Canadian forest industries. Source: Industry Canada, 2004*a*.

The wood sector covers a wide range of companies engaged in (1) sawing logs into lumber or similar products and preserving them, (2) making veneer, plywood, reconstituted wood panel products and engineered wood assemblies, (3) manufacturing wood kitchen cabinets, counters and bathroom vanities, (4) and producing other wood products such as millwork, wood containers and pallets, manufactured mobile homes and prefabricated wood buildings (Industry Canada, 2004*a*). The value of each of these groups of wood products manufactured in Canada is shown in Figure 1.2.

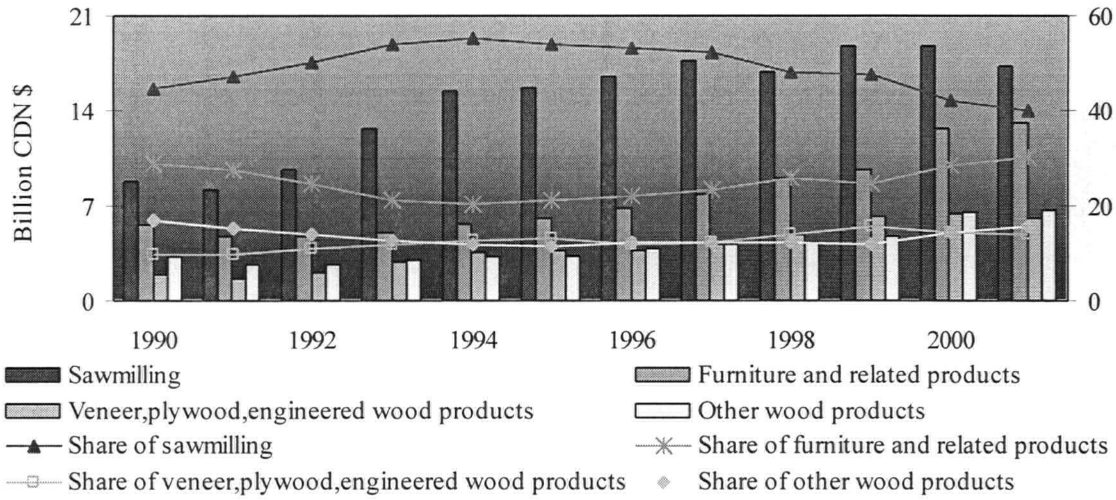

Figure 1.2 - Manufacturing value of different wood products in Canada. Source: Industry Canada, 2004*a*.

Lumber and its derivative products comprise the biggest group of wood products. However, their share in the total manufacturing value has decreased since 1994 while that of furniture and engineered wood products has shown continuous growth (Figure 1.2). This demonstrates that the traditionally commodity products-based industry may be moving towards value-added products.

1.2 The Problem

Efficiency is a measure of performance. It is the ability of a machine, person, system, or organization, usually referred to as "unit", to produce more output using less input given the available technologies. In this context, technology generally refers to the state of the art capabilities, either in the production process and delivery of products/services or in the management system of a unit, that affect performance in one way of another. Examples of efficiency measures include profit per piece of product, output per worker hour and output per worker employed. Therefore, efficiency can generally be formulated as follows (1.1) (Cooper et al., 2000):

$$Efficiency = \frac{Output}{Input} \tag{1.1}$$

Efficiency has commonly been used as a performance indicator of an organization as a whole in performance assessment studies. Such studies evaluate the activities of organizations to measure their efficiency, analyze the results to identify inefficiency reasons, and may provide suggestions for efficiency improvement. Efficiency assessment studies have been conducted in various industries, both public and private, in service and manufacturing sectors. These include business firms, government agencies, hospitals and educational institutions (Cooper et al., 2000).

For the past decade, the Canadian wood industry has faced a constantly changing business environment. This has required the industry to assess, monitor and maintain operational efficiency to keep up with these changes. These changes have occurred due to a number of factors:

- Competition in the market: there is growing competition due to the emergence of new players in the international trade of wood products (Figure 1.3). Regions such as China, Russia, Brazil and Oceania compete with Canada relying on their competitive advantages, e.g. better access to lower cost resources (labour and material) (Figure 1.4).

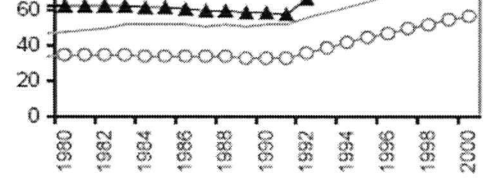

Figure 1.3 - Total number of exporting countries in Wood Industry. Source: FPAC, 2003.

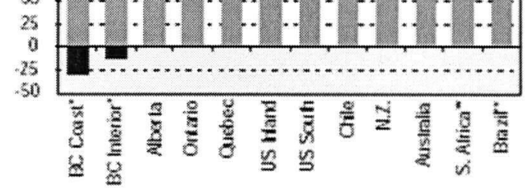

Figure 1.4 - Cost and sawmill margin by region/country as of May 1998. Source: Wood Markets, Not dated.

- Macro and micro practices within the industry: policies such as governmental regulations, forest ownership and international trade strategies have recently been changing in the Canadian wood industry. These changes have partly been motivated by the Softwood Lumber Dispute with the U.S. – generally known as a series of four disputes since 1982 with the last one in 2001 still unresolved. The efforts in modifying the aforementioned policies aim at improving the competitive position of Canada and the Canadian forest/wood companies (British Columbia Ministry of Forests, 2002). Such changes in top-level policies of the industry could affect the micro practices in the individual company level. For example, companies' strategies on target export markets, available suppliers, and compliance with related regulations might have changed according to new macro policies.
- Structure of the market: the Canadian wood industry is encouraged to move from a commodity product-base towards value-added wood products. This shift in the focus of the industry is partly due to provincial government policies in provinces such as Ontario and British Columbia who support the development of higher-end processing industries (Northern Ontario Business, 2003; Invest British Columbia, 2004). It is also a result of the increasing shortage in supply of large diameter logs and significant technological advancements, which have encouraged the expansion of value-added engineered wood products (WFI, 2003).
- Production technology: the Canadian wood industry has made substantial advances in technology. Its strategic plans have strongly encouraged technology developments with the goal of boosting revenue for the past two decades. Automating production processes, speeding up manufacturing equipment and improving productivity are examples of such efforts. In addition, various optimization systems have been developed and increasingly employed in manufacturing process design and operations management (Forintek Canada, Corp., 2003).

These factors indicate the need for efficiency assessment studies in the Canadian wood industry in different ways. The growing competition in the international wood products market requires the Canadian wood industry to continually evaluate its performance and to insure an efficient and competitive performance according to international standards. Policy makers also require efficiency assessment studies in order to examine the performance of the industry under alternative policies, and to thereby identify efficient policies and make informed decisions in developing or revising them. Efficiency studies are also necessary for managers of individual companies to monitor and improve performances of companies. Managers could also benefit from such studies to assess the performance of their organization in response to changes in the business environment, e.g. those in market structure and production technology. In general, efficiency studies help to evaluate whether the industry and organizations operate efficiently and competitively, and to develop improvement policies that are appropriate to the business environment.

Despite the importance of efficiency studies for the Canadian wood industry, there are no such studies in recent years to the best knowledge of the author. The latest study in this field was that of Bernstein (1994), which evaluated the efficiency of the Canadian softwood lumber sector from 1963 to 1987. Therefore, the present research was designed to explore the efficiency of the wood industry in Canada and how it had changed during the last decade. In addition, all the efficiency studies on the Canadian wood industry have used aggregate data in the regional or national level (see Table 2.1). In contrast, this study aimed to employ detailed performance data from individual companies. Furthermore, this study focused on the efficiency of primary wood producers in British Columbia (BC) as one of the major players in this industry.

Primary wood manufacturing is the largest sector in the Canadian wood industry providing more than 55% of the industry's annual manufacturing value since 1990. About half of this value is produced in BC (Natural Resources Canada, 2003). The primary wood manufacturing sector in BC is one of the sectors most affected due to the challenges faced by the industry in recent years. The export to the U.S., which has traditionally been a major market for BC lumber, has become unstable (Figure 1.5). In addition, the number of operating sawmills in the province has substantially declined by about 22% (Figure 1.6). Different reasons could explain this phenomenon such as price declines for various lumber products (Ministry of Finance and Corporate Relations, 2001), high tax due to the Canada-U.S. Softwood Lumber Dispute, and inadequate access to logs (Marshall, 2002). However, no study has looked at this phenomenon from a performance perspective. More specifically, it has not been examined whether BC sawmills performed efficiently enough under different circumstances to stay in the market, or how the productivity of the sector changed over time in response to the environment.

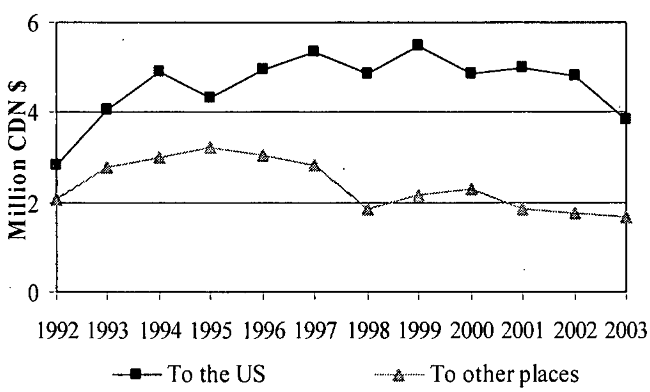

Figure 1.5 - BC lumber export. Source: Industry Canada, 2004*b*.

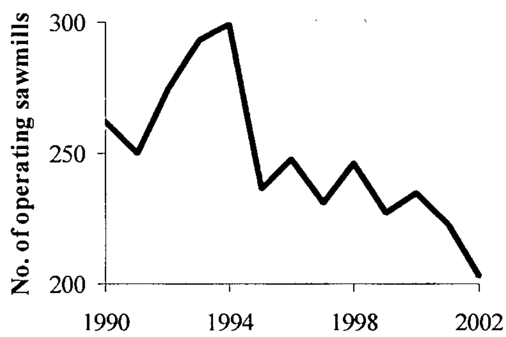

Figure 1.6 - Number of operating sawmills in British Columbia. Source: BC Ministry of Forests, 2004[1].

1.3 Research Objectives

This research focused on two main objectives:

1. To analyze the efficiency of primary wood producers in BC.

This objective was defined in response to the lack of an inclusive quantitative measure of the efficiency of the BC primary wood producers in recent years. This work would provide a comprehensive view of the efficiency and competitiveness of the producers in BC relative to each other. For this purpose, the Data Envelopment Analysis (DEA) method was applied. DEA is a recent and powerful method of efficiency measurement, which provides a relative measure of efficiency for a

[1] These statistics are based on a dataset provided by the BC Ministry of Forests. Descriptive statistics of this dataset are given in section 4.4.1.

comparable set of units considering multiple performance factors. The analyses were based on performance data from 2002, the most recent available. The specific objectives of this analysis were:

1.1. To measure the efficiency of BC sawmills in 2002.

1.2. To find the dominant inefficiency factor- scale of operations or technical ability- for BC sawmills.

1.3. To examine the difference of BC sawmills efficiency across forest regions.

1.4. To measure the effect of number of operating days on the efficiency of BC sawmills.

2. To analyze the efficiency change and productivity growth of primary wood producers in BC.

This study was designed to provide an insight on the trend of efficiency and productivity growth of BC primary wood producers over recent years. It was also expected to identify the sources of the observed growth/regress. For this purpose, alternative dynamic Data Envelopment Analysis methods were applied to a performance dataset of the period of 1990 to 2002. The specific objectives of this analysis were:

2.1. To measure the efficiency of BC sawmills over the period of 1990-2002.

2.2. To analyze the trend of the efficiency of BC sawmills.

2.3. To evaluate the productivity change of BC sawmills and its dominant reasons.

2.5. To examine the efficiency of shut down sawmills.

1.4 Dissertation Outline

The organization of the rest of the dissertation is as follows: chapter 2 introduces alternative methods of efficiency measurement and reviews efficiency studies in wood industry. In particular, the advantages and limitations of the Data Envelopment Analysis method for efficiency measurement, and its applicability to wood industry are discussed in sections 2.2.3 and 2.5 respectively. Chapter 3 focuses on the first objective- analysis of the efficiency of BC sawmills, which uses a static DEA approach. The problem and the importance of addressing it are explained. The methodology of the study is described, and finally the results and a discussion are presented. Chapter 4 concerns the second objective of the research- analysis of the efficiency change and productivity growth of the BC sawmills, that uses a dynamic DEA approach. This chapter includes an introduction to the significance of this study, the methodology and similar previous studies, and finally the analyses and results. To conclude, Chapter 5 draws the conclusions of the research and discusses the limits to the study and results. Suggestions for further studies in this field are also provided.

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Chapter 2

Literature Review on Efficiency Measurement in Wood Industry*

2.1 Background

The efficiency of an organization can be evaluated with different methods. Some of these methods provide a partial efficiency measure. They usually look at two performance factors and the way they affect each other in the underlying organization(s). Examples of such methods are financial ratios analysis and productivity ratios analysis. These methods, although conventional in financial analysis studies, have not frequently been used in efficiency studies on the wood industry.

Other efficiency measurement methods provide an efficiency measure for the overall performance of an organization. Such methods have commonly been used to evaluate units in the wood industry, and can be classified in two groups: parametric and non-parametric. This classification is according to the approach that the methods take to measure efficiency. While in the parametric approach, a mathematical function is defined that specifies the relationship between inputs and outputs, no such functional form is defined in the non-parametric approach.

* A version of this chapter has been submitted for publication. Salehirad, N. and Sowlati, T. (2004) Efficiency analysis in the Canadian wood industry – a review. Forest Science.

This chapter introduces the common methods of efficiency measurement in wood industry, and provides a review on the state of the art of efficiency studies in this sector. Sections 2.2.1 and 2.2.2 present an overview on the efficiency measurement methods with the parametric and non-parametric approaches, respectively. The advantages and limitations of the DEA method, a non-parametric method used in this research, are specifically discussed in section 2.2.3. The literature on efficiency analysis in wood industry is reviewed in section 2.3. Two more sections are included at the end of this chapter in order to identify gaps in efficiency studies of wood products sector and to identify possible directions for future research. Section 2.4 reviews efficiency studies in other forest sectors, and section 2.5 provides a comparative analysis between these studies and those in the wood industry. For the sake of clarity, the reviewed studies are discussed in two groups, those with a parametric approach and those with a non-parametric approach.

2.2 Efficiency Measurement Methods

2.2.1 Parametric Approach

Efficiency measurement methods with a parametric approach relate inputs and outputs of the unit(s) under study with a mathematical function. This function represents the technology of the unit(s) and defines how they transform inputs to outputs. The parameters of such a function are estimated using the units' performance data.

Methods with a parametric approach could incorporate several performance factors in the functional form and thereby measure the overall efficiency of an organization; they could also provide partial efficiency measures, concerning each of the incorporated factors. To measure the efficiency of a unit, such methods compare the unit's level of performance to an expected level. The expected level is calculated from the defined functional form. This function can be a production function, or equivalently a cost function. This is based on the duality theory, which states that the technology of a given firm can be explained by its cost function as well as it can be explained by its production function, if the firm behaves with the interest of minimizing the total cost (Shephard, 1953).

The production function F defines the maximum amount of output, u, that can be produced by the technology during a certain period if the vector of input quantities $x \equiv (x_1, x_2, ..., x_N)$ is utilized during that period (2.1). The inputs are often a subset of the production input elements assumed in economic analyses, i.e. material, labour, capital or its variations, and energy.

$$u = F(x) \tag{2.1}$$

The minimum cost function f gives the minimum total cost, c, that a firm should bear for producing the output level u. It is also dependent on the set of input prices $p \equiv (p_1, p_2, ..., p_N)$, and inherently on the production function F to find the required inputs involved (2.2).

$$c = f(u, p) \tag{2.2}$$

Equivalent to a cost function, a profit function may also be used in this context. This function, π, provides the profit level Π of producing u units of outputs, given the set of input prices p and output price p_{output} (2.3).

$$\Pi = u \, . \, p_{output} - c = \pi(u, p_{output}, p) \tag{2.3}$$

For econometric analyses, it is often easier to use a cost function than a production function. This is because one can reasonably assume that the parameters of the cost function, i.e. output level and input prices, are exogenously determined. However, the parameters of a production function, i.e. input levels, are not exogenous to the production process; the inputs are quite likely subject to choice by the firm and, therefore, endogenous to the production process. Thus, estimation of a production function would lead to simultaneous equation bias if no other assumption were set on the production environment (Singh and Nautiyal, 1986).

The functions mentioned above can be of different types and flexibilities as studied in Econometrics. The cost function, for example, is usually a homogenous, non-decreasing and concave function of factor prices. One commonly used form is a translog cost function. Readers may refer to econometric textbooks, for example Kennedy (2003), for a thorough discussion on this topic.

Efficiency measurement methods with a parametric approach may incorporate several inputs and one output or several outputs and one input; however, they cannot accommodate multiple inputs and multiple outputs. To eliminate this limit, some studies have used the input (or output) distance function method, which is also a parametric analysis. The common cost/profit function methods also impose behavioural assumptions, such as cost minimizing or profit maximizing, and other restrictions on the employed functional form that might not hold true in practice. To relax these restrictions, there have been efforts to use more sophisticated functional forms. However, these forms could cause other problems such as inconsistency in the results and complications in interpreting the findings (Stier and Bengston, 1992). Efficiency measurement methods with a parametric approach are quite demanding in terms of data requirements. This can be problematic since often cost and price data are hard to access for practical analysis. However, once data are gathered, a parametric efficiency analysis can provide useful production measures, such as economies of scale, technical progress and input substitution measures.

2.2.2 Non-parametric Approach

A non-parametric approach to efficiency measurement entails no requirement for specifying a functional form between inputs and outputs, nor does it require any behavioural assumptions about underlying units. The only method that takes a non-parametric approach to efficiency measurement is Data Envelopment Analysis.

DEA was introduced in 1978 by Charnes, Cooper and Rhodes (Charnes et al., 1978). It is a method for assessing the relative efficiency of a set of comparable units, called decision making units (DMU). DEA can provide a comprehensive picture of the operation at individual DMU level with engaging multiple performance factors in the efficiency measure (2.4).

$$Efficiency = \frac{Weighted\ sum\ of\ outputs}{Weighted\ sum\ of\ inputs} \tag{2.4}$$

DEA provides an efficiency score for each unit by comparing it with its peers. It identifies a frontier that comprises the best performers. Those units which lie on the frontier are recognized as efficient and otherwise as inefficient. Each inefficient unit receives a score according to its distance from the efficient frontier. DEA suggests a virtual efficient target for each inefficient unit, which is the projection of it on the frontier. This target unit can be stated as a linear combination of some of the efficient units on the frontier. The set of these efficient units is thus called the reference set of the related inefficient unit.

Given a set of n units with r inputs and s outputs, for each DMU_k ($k = 1,...,n$), the inputs are denoted with x_{ik} ($i = 1,...,r$) and the outputs with y_{jk} ($j = 1,...,s$). Accordingly, a basic DEA ratio model can be formulated (2.5) (Cooper et al., 2000).

$$
\begin{aligned}
\max\ z_o &= \frac{\sum_{j=1}^{s} u_j . y_{jo}}{\sum_{i=1}^{r} v_i . x_{io}} \\
s.t. \quad & \frac{\sum_{j=1}^{s} u_j . y_{jk}}{\sum_{i=1}^{r} v_i . x_{ik}} \leq 1 \qquad k = 1,...,n \\
& v_i, u_j \geq 0 \quad i = 1,...,r \quad j = 1,...,s
\end{aligned}
\tag{2.5}
$$

DMU_o with x_{io} ($i = 1,...,r$) inputs and y_{jo} ($j = 1,...,s$) outputs is the unit under evaluation. The objective function is to maximize the efficiency of DMU_o, which is the ratio of its weighted outputs to its weighted inputs. The decision variables of the model are input and output weights, v_i ($i = 1,...,r$) and u_j ($j = 1,...,s$), also known as multipliers. These variables are to be determined to maximize z_o, the efficiency of DMU_o, while ensuring an efficiency score of not greater than 1 for all the other DMUs with the same multipliers.

Model (2.5) is a fractional model; it needs to be transformed to a linear programming model to be solved. This is done by equating the denominator of the objective function ratio to a constant, usually 1, and maximizing the numerator (2.6) (Cooper et al., 2000).

$$
\begin{aligned}
\max\ z_o &= \sum_{j=1}^{s} u_j . y_{jo} \\
s.t. \quad & \sum_{i=1}^{r} v_i . x_{io} = 1 \\
& \sum_{j=1}^{s} u_j . y_{jk} - \sum_{i=1}^{r} v_i . x_{ik} \leq 0 \quad k = 1,...,n \\
& v_i, u_j \geq 0 \qquad i = 1,...,r \quad j = 1,...,s
\end{aligned}
\tag{2.6}
$$

This form of a DEA model is called the multiplier form and provides information on the weights (multipliers) of inputs and of outputs. A frontier form of the model can be obtained while converting the model to its dual form. The dual form is more helpful in identifying efficient targets and reference sets for each inefficient DMU (2.7) (Cooper et al., 2000).

$$\begin{aligned}
&\min\ w_o = \theta - \varepsilon\sum_{i=1}^{r} s_i^- - \varepsilon\sum_{j=1}^{s} s_j^+ \\
&s.t.\ \ \theta.x_{io} - \sum_{k=1}^{n} \lambda_k.x_{ik} - s_i^- = 0 \qquad i=1,\dots,r \\
&\quad \sum_{k=1}^{n} \lambda_k.y_{jk} - s_j^+ = y_{jo} \qquad j=1,\dots,s \\
&\quad s_i^-,\ s_j^+, \lambda_k \ge 0 \ \ i=1,\dots,r\ \ j=1,\dots,s\ \ k=1,\dots,n
\end{aligned} \tag{2.7}$$

Here θ and λ_k ($k=1,\dots,n$) are the dual variables of model (2.6). θ is the proportion by which the inputs should be decreased in order for DMU_o to be efficient. λ_k ($k=1,\dots,n$) shows the share of DMU_k in defining an efficient target for DMU_o. Slack variables, s_i^- ($i=1,\dots,r$) and s_j^+ ($j=1,\dots,s$), indicate extra possible decreases in inputs and increases in outputs, respectively. Parameter ε in the objective function stands for a very small real number. To measure the efficiency of all DMUs, this model should be run n times, once for each DMU.

In the above DEA models, the improvement is sought through decreasing inputs while maintaining the same level of outputs. Therefore, they are called input-oriented. However, it is also possible to explore efficiency improvement by increasing outputs keeping the same level of inputs. Such models are called output-oriented. The multiplier form of an output-oriented model is presented below (2.8) (Cooper et al., 2000).

$$\begin{aligned}
&\max\ w_o = \phi + \varepsilon.\sum_{j=1}^{s} s_j^+ + \varepsilon.\sum_{i=1}^{r} s_i^- \\
&s.t. \qquad \phi.y_{jo} - \sum_{k=1}^{n} \lambda_k.y_{jk} + s_j^+ = 0 \quad j=1,\dots,s \\
&\qquad\qquad \sum_{k=1}^{n} \lambda_k.x_{ik} + s_i^- = x_{io} \qquad i=1,\dots,r \\
&\qquad\qquad \lambda_k, s_i^-,\ s_j^+ \ge 0 \quad k=1,\dots,n \quad i=1,\dots,r \quad j=1,\dots,s
\end{aligned} \tag{2.8}$$

Here Φ represents the proportion by which DMU_o needs to increase its outputs in order to become as efficient as its best peers in the set. Therefore, $1/\Phi$ represents the efficiency score of DMU_o.

All DEA models presented so far compare each DMU with all the other units in the set regardless of their scale size. Thus, their efficiency measures are called aggregate efficiency. These models are compatible with an assumption of constant returns to scale (CRS). This means that every DMU would be able to increase its outputs by a particular proportion, given an increase rate in its inputs, no matter what its scale is (Farrell, 1957). A DEA model with a CRS characteristic is called CCR. If the assumption of CRS does not hold in a case, a DMU can be compared within its own scale range. Therefore, a variable returns to scale (VRS) model could be used. An efficiency measure resulted from such a model is called technical efficiency, and the model itself is called BCC. BCC models require an extra constraint (2.9) in their frontier form (Cooper et al., 2000).

$$\sum_{k=1}^{n} \lambda_k = 1 \tag{2.9}$$

The ratio of a DMU's aggregate efficiency to its technical efficiency is called scale efficiency (2.10). It shows the degree of inefficiency that the DMU is facing purely due to its scale of operations. Therefore, the aggregate efficiency of a DMU can at most reach its technical efficiency (Charnes et al., 1994).

$$Scale\ Efficiency = \frac{Aggregate\ Efficiency}{Technical\ Efficiency} \tag{2.10}$$

Figure 2.1 demonstrates a graphical representation of DEA output oriented CCR and BCC models. In this graph, DEA is used to analyze an operation with one input shown on the x-axis and one output shown on the y-axis. Each DMU is located on the coordination plane based on its associated level of input and output. A VRS model frontier (BCC) is consisted of technically efficient units, represented by the solid line. Therefore, those DMUs such as A and C that lie on the frontier are efficient. However, a DMU such as B that is enveloped by the frontier is inefficient. A CRS model forms a frontier of overall best performers, represented by the solid double line. This frontier encompasses the units that are efficient both technically and scale-wise. In this case, unit A remains efficient while units B and C are inefficient.

Efficient targets for inefficient units may be adopted according to the orientation of the model used. For example for unit B, if the level of input is desired to be kept constant, using an output oriented model would measure a technical efficiency score of OQ/OP; its respected target efficient unit, thus, would be B1, as the projection of B on the VRS frontier. The aggregate efficiency score, on the other hand, would be the ratio of OQ/OR suggesting B2 as the efficient target. The scale efficiency of B in this case is equal to OP/OR. However, if it were desired to keep the level of output constant, an input oriented model would be the appropriate model. In this case, the technical efficiency score of unit B would be OM/ON, which determines B3 as its efficient target. Accordingly, the aggregate efficiency of B would be OL/ON. This suggests B4 as the efficient target for B. The resultant scale efficiency is OM/OL.

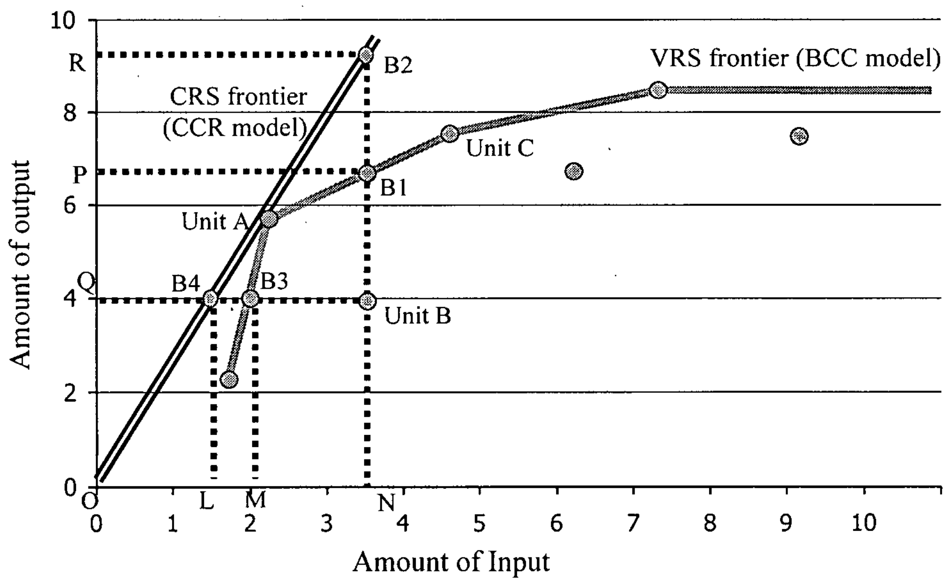

Figure 2.1 - A graphical illustration of DEA models.

There are two important extensions to DEA: Window Analysis and Stochastic DEA (or Stochastic Frontier Analysis- SFA). Window Analysis (WA) is a method that uses DEA for efficiency assessment over time. Using this dynamic method, the efficiency trend can be analyzed. Stochastic DEA (or SFA) deals with measuring efficiency with stochastic inputs and outputs. Different approaches have been developed for SFA and efficiency measurement under uncertainty (Cooper et al., 2000).

There has been a wide application area of DEA in performance assessment and benchmarking of service and manufacturing sectors such as health care, education, hospitality, banking, aviation, production plants, etc. Readers are referred to DEA books such as Charnes et al. (1994) and Cooper et al. (2000), for more discussion in this regard.

2.2.3 Advantages and Limitations of the Data Envelopment Analysis Method

One advantage of DEA over the other efficiency measurement methods is that DEA can accommodate multiple inputs and multiple outputs, while the other methods cannot. These inputs and outputs can be in different units of measurement. DEA provides a single efficiency score for each unit, which encompasses all performance aspects incorporated into the model. These scores facilitate the comparison of underlying units.

In addition, DEA does not require price or cost data that are often hard to access. It also does not require priori knowledge of the weight factors or the relative importance of inputs/outputs. These attributes increase the applicability and practicality of this method.

Another feature of DEA that attracts analysts and managers is its ability to identify potential improvements for inefficient units. DEA constructs efficient targets for inefficient units according to best performance of actual peer units. This is a significant tool for making improvement policies and for benchmarking a set of units (Charnes et al., 1994).

However, there are shortcomings for the DEA method as well. One difficulty arises from the definition of a "comparable" set of units. DEA can be applied to a set of comparable units, which validates contrasting them against each other. A comparable set of units refers to units with "similar technology" and subject to the "same environment". Still, technology and environment are terms hard to define and confine. Hence, the justification for using a particular set of units in a DEA efficiency study is often left to the judgment of practitioners involved in that case.

DEA also requires a considerable amount of data explaining different performance aspects of each unit. On the other hand, the factors included in DEA models should not be correlated, so that one performance aspect is not repeatedly represented. DEA also needs a relatively large number of units to be able to differentiate them well based on the total number of inputs and outputs. Cooper et al. (2000) suggests that the number of DMUs should be greater than twice the total number of inputs and outputs for this purpose.

The DEA models may assign weights to inputs/outputs that are not meaningful in practice. To prevent this problem, one may add constraints to a DEA model implying such pragmatic or managerial requirements. One other limit to DEA is that it does not identify any improvements for those units recognized as efficient. However, there are new developments in the theory of DEA to overcome this aspect (Sowlati and Paradi, 2004).

In addition, the DEA method typically employs deterministic data and performs deterministic efficiency analyses, except that one extends the analyses to stochastic DEA (i.e. Stochastic Frontier Analysis).

Further discussion on advantages and limitations of DEA is presented throughout this manuscript. The applicability of DEA to the wood industry, which is the basis of this research, is discussed in section 2.5. Also, since this study employs two different DEA approaches, called static DEA and dynamic, additional advantages and limitations specific to these approaches shall be discussed in sections 3.2.1 and 4.2 respectively. Finally, section 5.1 describes how these limitations affected the results of this study.

2.3 Efficiency Studies in Wood Industry

The efficiency of the wood industry in Canada and other regions has been examined in various studies and with different methods. This section provides a review on the efficiency studies of the Canadian wood industry and some of those of other regional wood industries. These studies are grouped in two sections. Section 2.3.1 reviews the efficiency studies with a parametric approach while section 2.3.2 presents a review on studies with a non-parametric approach.

Aside from these two approaches, one other methodological approach is recognizable in some studies on the efficiency of organizations in the wood industry. These studies have used ratio analysis to explore partial efficiency measures in wood working companies. For example, Steele et al. (1988) compared the lumber recovery factor (LRF) in sawmills across the U.S. They found significant differences in the conversion rates of different log sizes and among regions. LRF was also employed by Schlosser et al. (2002) to study the lumber manufacturing industry of the Russian Far East and Siberia. They suggested that the overall LRF could be increased by better operator training, effective maintenance programs for equipment, and improvements in technology.

Factor productivity, or output per unit of the input factor, is another instance of a partial efficiency measure, which was used in Abt et al. (1994) for an inter-regional comparison of the sawmilling sector in North America. They measured single-factor and total factor productivity growth rates of U.S. South, U.S. West, BC Coast, BC Interior, ON and QC during the period 1965-1988. The factors were labour, wood materials, and capital. Despite different rates of growth for single-factor productivities, a uniform rate of overall productivity growth was observed across regions.

2.3.1 Studies with Parametric Approach

The studies that used a parametric approach to evaluate the efficiency of the Canadian forest related industries, including wood industry, largely lie in the category of applied production analysis.

Some of these studies used cost functions to assess the productivity growth in the sector (Rao and Preston, 1984; Martinello, 1985, 1987; Banskota et al., 1985; Nautiyal and Singh, 1985; Singh and Nautiyal, 1986; Meil and Nautiyal, 1988; Meil et al., 1988; Puttock and Prescott, 1992) and some used profit functions (Constantino and Haley, 1988, 1989; Bernstein, 1994). In all these studies, increasing returns to scale were observed except for the BC Interior which had constant returns to scale (Martinello, 1987; Meil et al., 1988). Increasing returns to scale implies that, if all inputs are multiplied by a certain percentage, the output will increase by a higher percentage; constant returns to scale indicates that the output will increase by the same percentage as that of inputs. Banskota et al. (1985) argued that, although increasing returns to scale was a motivation for encouraging mill expansions, it would result in decreasing employment opportunities due to substitutability of labour with capital.

None of these studies identified a positive technical change (increase in efficiency) in the wood sector in Canada during 1950's to early 1980's. This finding was rather surprising in view of the emergence of improved production techniques such as chipper headrigs, computerized sawing, automatic sorting systems and circular saw guides in that time frame. Still, the finding could be accepted, according to Singh and Nautiyal (1986), if considering that technical change did not only reflect the aforementioned technical advancements but also the effects of other factors like worker skills, managerial ability and changes in log and output size and quality. Meil et al. (1988) also mentioned the cyclical fluctuations of demand in the industry and the misallocation of inputs as possible reasons for the inefficiency in the Canadian sawmilling sector. Nonetheless, an exclusive study of BC sawmills suggested a positive technical change (efficiency improvement) in this region (Martinello, 1987; Meil et al., 1988). Meil and Nautiyal (1988) also found a positive technical change for large Canadian mills in general.

All the studies in this group found that the labour productivity in the Canadian wood manufacturing sector, at large, had increased, while the productivity of capital, wood and energy (i.e. partial efficiency measures) and also the total factor productivity had decreased over time. Yet, Martinello (1987) reported that the BC sawmilling sector experienced a growth in material productivity.

One limitation of these studies is the lack of consideration of multiple outputs, except in Meil and Nautiyal (1988) where a single aggregate output composed of lumber, ties and wood chips was used. The DEA method can also be used to enable integrating several input/output factors.

Parametric approach has been used in some efficiency studies on the sawmilling sector in regions other than Canada as well (Greber and White, 1982; Merrifield and Haynes, 1983, 1985; Campbell and Jennings, 1990; Bigsby, 1994; Baardsen, 2000). These studies incorporated labour, material and capital in a cost function to analyze the production parameters.

The common findings of the studies on the American wood industry include an increase in labour productivity, but a decrease in capital productivity (changes in partial efficiencies). They also show a positive technical change, which implies an improvement in efficiency, and an increasing return to scale (Greber and White, 1982; Merrifield and Haynes, 1983; Merrifield and Haynes, 1985). An exception to these observations was the lumber sector in the U.S. Pacific Northwest-west side that showed no significant technical change and decreasing returns to scale (Merrifield and Haynes, 1985). Merrifield and Haynes (1983) showed that the cost efficiency of the U.S. wood industry had improved by increases in construction and housing demand and changes in private forest inventories. These factors were more influential in stimulating the industry than increases in the amounts of stumpage sold from National Forests.

Similar to the American sawmilling sector, the Australian sawmills had also experienced a considerable positive technical change (efficiency improvement) and increasing returns to scale (Bigsby, 1994).

In contrast, a different trend was observed in Tasmanian sawmills. Campbell and Jennings (1990) reported a decline in the total productivity of this sector, caused by a decrease in labour and capital productivity. Also, a negative technical change (decline in efficiency) was observed, due to deteriorated quality of logs and (governmental) regulatory restrictions on the utilization of inputs (logs, energy and capital). Nonetheless, the sawmilling sector in Tasmania was similar to that in America and Australia in experiencing significant increasing returns to scale.

The situation of sawmilling sector in Norway was the same as in Tasmania: a negative technical change and increasing returns to scale (Baardsen, 2000). A summary of these parametric efficiency studies is presented in Table 2.1.

Table 2.1 - Summary of parametric efficiency studies of wood products sector

Study	Industry	Region	Time Period	Method	Other Attributes or Findings
Greber and White, 1982	Lumber and wood products	U.S.	1951-1973	Parametric-Translog production function	Number of firms decreased while their average size increased.
Merrifield and Haynes, 1983	Lumber, Plywood	U.S. Pacific Northwest	1950-1976	Parametric-Translog production function	A market model incorporating supply and demand equations was constructed.
Rao and Preston, 1984	Wood Industry, Pulp and paper	Canada	1957-1979	Parametric-Translog total cost function	Technical change was a result of changes in factors such as input quality, capacity utilization and management abilities.
Martinello, 1985	Logging, Sawmilling, Pulp and Paper	Canada	1963-1982	Parametric-Translog total cost function	Sawmills experienced increasing returns to scale, and a negative technical change.
Merrifield and Haynes, 1985	Lumber, Plywood	U.S. Pacific Northwest	1950-1979	Parametric-Translog total cost function	Production technology of lumber and plywood sectors was different; modern mills were more productive than the older ones.
Nautiyal and Singh, 1985	Lumber	Canada	1965-1981	Parametric-Translog cost function	No technological progress, but substantial economies of scale was observed.
Banskota et al., 1985	Sawmills	Alberta	1978	Parametric-Translog cost function	Larger mills had more significant scale economies.

Study	Industry	Region	Time Period	Method	Other Attributes or Findings
Singh and Nautiyal, 1986	Lumber	Canada	1955-1982	Parametric-Translog cost function	No technological progress was observed; labour productivity increased; inputs were misallocated due to slow adaption of firms.
Martinello, 1987	Sawmills	BC Coast and Interior	1963-1979	Parametric-Translog total cost function	Log quality and size, and also cost efficiency declined over time
Constantino and Haley, 1988	Sawmills	BC Coast, U.S. Pacific Northwest	1957-1982	Parametric-Translog profit function	Developed a wood quality index, and incorporated that as an input factor in the efficiency model.
Meil and Nautiyal 1988	Lumber	BC Coast and Interior, ON, QC	1968-1984	Parametric-Translog variable cost function	Regions had different production structure; bedsides, larger mills had a differing production behaviour.
Meil et al., 1988	Sawmills	BC Interior	1948-1983	Parametric-Translog variable cost function	Labour productivity increased while material and energy productivity decreased; misallocation of inputs was observed.
Constantino and Haley, 1989	Sawmills	BC Coast, U.S. Northwest	1957-1982	Parametric-Translog profit function	U.S. Northwest's productivity was higher than the BC's and grew faster; a possible reason for this was better log quality in the U.S.

Study	Industry	Region	Time Period	Method	Other Attributes or Findings
Campbell and Jennings, 1990	Sawmills	Tasmania	1961-1985	Parametric-Translog long run cost function	Sawlog could partially be substituted by energy and capital; this is encouraging for the industry in view of the emerging log shortage.
Puttock and Prescott, 1992	Lumber	ON South	1980-1984	Parametric-Translog cost function	Used mill capacity in addition to wood, labour and energy as inputs.
Bernstein, 1994	Lumber	Canada	1963-1987	Parametric-Profit function	Took a new approach to control price-cost margins in the model.
Bigsby, 1994	Sawmills	Australia	1950-1984	Parametric-Translog cost function	Technical change was capital and energy using, and labour and material saving.
Baardsen, 2000	Sawmills	Norway	1974-1991	Parametric-Translog cost function	Aggregating the input factors would result in a not representative production technology.

2.3.2 Studies with Non-parametric Approach

No DEA study has yet looked at the efficiency of the Canadian sawmilling sector. Thus, this work is the first one of its kind. However, the production efficiency of non-Canadian sawmilling sectors has been explored in a number of studies using DEA (Obersteiner, 1999; Fotiou, 2000; Nyrud and Bergseng, 2002; Nyrud and Baardsen, 2003). Some of these studies also tried to relate efficiency measures to other factors such as forest region (Obersteiner, 1999), market (Fotiou, 2000) and operation's size (Nyrud and Bergseng, 2002). For this purpose, they used different statistical methods for group comparison. In general, these studies identified increasing returns to scale technology in sawmilling sector. The efficiency of labour and capital also showed a growth over time.

In a study on Siberian sawmilling sector, Obersteiner (1999) observed large scale inefficiencies. The most efficient forest regions were the ones with the most development projects of the forest industry and large wood processing plants. Still, a huge efficiency gap was observed between the Siberian and the Western mills. Major efficiency improvement was suggested through labour productivity increase; although it was also argued that this would lead in worsening the unemployment situation in rural areas. An important aspect of this study was to assess the correlation between efficiency and some external factors, i.e. average log volume, average transportation distance, utilization of basic machinery and share of hardwoods processed. No significant correlation was revealed. In terms of Russia's dominant competitiveness factors, during the transition period from a planned economy to a market based economy, the analyses highlighted two factors: restructuring in demand for Russian products and technological upgrades.

The efficiency of value added sector of the wood industry has also been studied. Hernandez-Sancho et al. (2000) looked at the effect of environmental regulations on the efficiency of wooden goods and furnishing industry in Spain. They found that when waste reduction regulations were in effect, the efficiency of firms decreased due to reallocation of inputs. However, those firms associated with a technological institute or located at industrial districts were less affected. A summary of these studies is presented in Table 2.2.

Table 2.2 - Summary of non-parametric efficiency studies of wood products sector

Study	Industry	Region	Time Period	Method	Other Attributes	Findings
Obersteiner, 1999	Roundwood lumber	Siberia	1989,1992	DEA- CCR, BCC (output oriented); Parametric-translog production function	119 mills, 5 inputs, 1 output	Most efficient forest regions were the most profitable; no consistent results from parametric analysis.
Fotiou, 2000	Sawmills	Greece	n/a	DEA- BCC (output oriented); ANOVA	17 mills, 2 inputs, 1 output	Mills which purchased lumber from both local and foreign markets, and/or had automated material handling systems received higher efficiency scores.
Hernandez-Sancho et al., 2000	Furniture	Spain	1995	DEA-CCR, BCC (output oriented)	42 producers, 4 inputs, 5 outputs	Four different wastes were incorporated as undesirable outputs.
Nyrud and Bergseng, 2002	Sawmills	Norway	1974-1991	DEA-CCR, BCC (input oriented); Regression	220 mills, 6 inputs, 3 outputs	DEA efficiency scores were analyzed with respect to mills' size using statistical tests.
Nyrud and Baardsen, 2003	Sawmills	Norway	1974-1991	DEA-CCR, BCC (input oriented); Malmquist Index	220 mills, 6 inputs, 3 outputs	Analyses were based on a panel dataset; annual productivity growth was investigated using Malmquist index for 66 of the mills.

2.4 Efficiency Studies in Other Forest Sectors

The forest industry at large is made up of logging, wood manufacturing and pulp and paper sectors. This section reviews the efficiency studies in logging and pulp and paper sectors, in order to recognize the gaps in the literature on the efficiency of wood industry and identify possible directions to develop and extend such studies. All the non-parametric (DEA) efficiency studies in these sectors and a group of parametric efficiency studies are examined in this section. A comparative analysis of the efficiency studies in all these sectors is presented in section 2.4.

2.4.1 Logging

The parametric efficiency studies on the logging sector in North America consist of Woodland (1975), Stier (1980), Martinello (1985), and Kant and Nautiyal (1997). Findings of these studies are summarized in Table 2.4.

Another group of studies with parametric approach used stochastic production frontiers (Carter and Cabbage, 1995; Grebner and Amacher, 2000; Siry and Newman, 2001). Grebner and Amacher (2000) compared the cost efficiency of New Zealand's forest harvesting sector in two eras: before and after deregulation and privatization. Their results showed that cost efficiency decreased after each reform. Siry and Newman (2001) studied the efficiency of Polish state timber production during the period of central planning through the transition period to a more competitive market. They found substantial technical inefficiency along with some scale inefficiency. Strong support was provided for the continued privatization of forest operations, but policies like smaller forest districts, employment reductions and logging equipment purchases were found counterproductive. See Table 2.3 for a summary of these studies.

Table 2.3 - Summary of parametric efficiency studies of logging sector

Study	Industry	Region	Time Period	Method	Other Attributes or Findings
Woodland, 1975	10 major industry, forestry as one	Canada	1246-1269	Parametric-Translog cost function	In addition to labour, incorporated capital as two inputs: structures and equipment.
Stier, 1980	10 major industries	U.S.	1958-1974	Parametric-Translog total cost function	Compared "logging camps and contractor" with other U.S. industries.
Martinello, 1985	Logging, Sawmills Pulp and Paper	Canada	1963-1982	Parametric-Translog total cost function	Logging sector showed large increasing returns to scale; labour productivity improved.
Carter and Cabbage, 1995	Logging	U.S.	1979, 1987	Parametric-Stochastic production frontier	Evaluated pulpwood harvesting industry; technical inefficiency was observed despite technological progress.
Kant and Nautiyal, 1997	Logging	Canada	1964-1992	Parametric-Translog cost function	Technical change and rates of productivity growth were negative, plausibly due to changing conditions of harvesting sites.
Grebner and Amacher, 2000	Forest harvesting	New Zealand	1977-1995	Parametric-Stochastic production frontier	Compared effects of privatization, deregulation, and removal of log export bans on cost efficiency.
Siry and Newman, 2001	Timber	Poland	1993-1995	Parametric-Stochastic production frontier	Smaller forest districts, employment reduction and equipment purchases were ineffective, but privatization was encouraged.

An important part of the efficiency studies in the logging sector is the application of DEA to explore the efficiency of the logging industry (Lebel and Stuart, 1998; Otsuki et al., 2002; Hailu and Veeman, 2003). The findings of these studies are not comparable since they had different focuses: LeBel and Stuart (1998) tried to relate technical efficiency to scale of operations. They argued that low capacity utilization had a negative impact on technical efficiency. Otsuki et al. (2002) studied the relation of timber production efficiency and the government plans of facilitating property right. Such policies were found to have a positive effect on efficiency. Hailu and Veeman (2003) realized positive effects of forest density and the proportion of hardwood production on efficiency.

There are also studies on the performance of Forestry Boards (Kao and Yang, 1991, 1992; Kao et al., 1993; Kao, 1994, 1998, 2000*a*, 2000*b*; Shiba, 1997; Viitala and Hanninen, 1998; Zhang, 2002; Bogetoft et al., 2003). Such forestry boards usually have the responsibility for forest harvesting and logging activities in addition to some other supervisory and management role. Overall, technical inefficiency was observed in all the studies. Besides, there was variant scale inefficiency involved. The over time studies reported a gradual reduction in inefficiency.

An interesting finding of Zhang's study (2002) was that the efficiency of Chinese forestry boards had increased after the economic reforms, due to reductions in labour size and shrinking the administration costs. Also, Bogetoft et al.'s study (2003) was important in analyzing the effect of merging forestry offices on their DEA efficiency. They decomposed the efficiency of a provisional merged office into scale, harmony and technical efficiencies. The technical efficiency was the dominant component of the efficiency of the merged office. Therefore, although scale and harmony effects of merging could contribute to the efficiency of a merged office, it would still remain inefficient if facing technical inefficiency. The authors suggested that the technical efficiency of a merged office could be improved only if there would be knowledge sharing among mergers. Table 2.4 provides a summary of these studies.

Table 2.4 - Summary of non-parametric efficiency studies of logging sector

Study	Industry	Region	Time Period	Method	Other Attributes	Findings
Kao and Yang, 1991	Forest Districts	Taiwan	1978-1988	DEA-BCC (input oriented)	13 DMUs, 4 inputs,3 outputs	Measured efficiency of forest districts.
Kao and Yang, 1992	Forest Districts	Taiwan	1978-1988	DEA-BCC (input oriented)	13 DMUs, 4 inputs,3 outputs	Suggested reorganization for districts based on equalizing their efficiency opportunities.
Kao et al., 1993	Forest Districts	Taiwan	1978-1987	DEA-CCR, BCC (input oriented)	17 DMUs, 4 inputs,4 outputs	Evaluated efficiency of forest management.
Kao, 1994	Forest Districts	Taiwan	1978-1987	DEA-BCC (input oriented)	17 DMUs, 4 inputs,3 outputs	Added boundaries for the input/output weights to find the practical improvement for each DMU.
Shiba, 1997	Forest Owners	Japan	Average data over 1991-1994	DEA-CCR (input oriented)	28 DMUs, no. of input/output varied.	Used 3 different DEA models with 1 output/11 inputs, 2 outputs/5 inputs and 2 outputs/ 11 inputs.
Kao, 1998	Forest Districts	Taiwan	n/a	DEA-BCC (output oriented)	13 DMUs, 4 inputs, 3 outputs	Measured the efficiency of sub-districts, and districts. Each district had 4 or 5 sub-district.

Study	Industry	Region	Time Period	Method	Other Attributes	Findings
Lebel and Stuart, 1998	Logging	U.S.	1988-1994	DEA-CCR, BCC (output oriented)	109 DMUs, 3 inputs,1 output	Low capacity utilization had a negative impact on technical and scale efficiency.
Viitala and Hanninen,1998	Forestry Boards	Finland	1993-1994	DEA-CCR, BCC (input oriented); Tobit Model	19 DMUs, no. of input/output varied.	Measured the efficiency of each board base on its activities separately and combined.
Kao, 2000*a*	Forest Districts	Taiwan	n/a	DEA- CCR, BCC (input oriented), Also modified version.	8 DMUs, 4 inputs, 3 outputs.	Assessed efficiency of multi-plant firms.
Kao, 2000*b*	Forest Districts	Taiwan	1989,1992	DEA-CCR, BCC (output oriented); Malmquist Index	8 DMUs, 4 inputs, 3 outputs.	Both methods gave compatible results; an increase in efficiency was observed.
Zhang, 2002	Forestry Boards	China	Average data over 1985-1987, and 1995-1997	DEA-CCR, BCC (input oriented)	40 DMUs, 1 input, 3 outputs	Investigated the efficiency of silvicultural activities in state-owned bureaus using a panel data.

Study	Industry	Region	Time Period	Method	Other Attributes	Findings
Otsuki et al., 2002	Timber	Brazil	1995	DEA- BCC, CCR (output oriented); Tobit analysis	255 DMUs, 4 inputs, 7 outputs	Private land titles and governmental expenditure on securing property rights positively affected technical efficiency.
Hailu and Veeman, 2003	Boreal logging	NF,QC, ON,MN, SK,AB	1977-1995	DEA-BCC (input oriented); Malmquist index; Tobit analysis	114 DMUs, 2 inputs, 1 output	Efficiency was substantially different among regions, and affected negatively by engineering construction per area, but positively by forest density and ratio of hardwood production; significant increasing returns to scale was realized.
Bogetoft et al., 2003	Forestry Offices	Denmark	1997-1999	DEA- new model suggested (input oriented).	14 offices (42 DMUs), 3 inputs, 3 outputs	Inefficiency was widespread and could in some cases be improved through mergers.

2.4.2 Pulp and Paper

Studies with a parametric efficiency method which focused on the Canadian pulp and paper consist of two groups. One group used cost functions incorporating conventional measures of labour, material and capital as inputs and one output (Sherif, 1983; Rao and Preston, 1984; Martinello, 1985; Nautiyal and Singh, 1986; Frank et al., 1990; Oum et al., 1991; Hailu and Veeman, 2000*a*). The other one used input distance functions incorporating several outputs (Hailu and Veeman, 2000*b*; Hailu, 2003).

Earlier studies indicated positive technical change (i.e. efficiency improvement) with increased labour and material productivity, but decreased capital and energy productivity (representing partial efficiencies) (Sherif, 1983; Rao and Preston, 1984; Martinello, 1985). However, Hailu and Veeman (2000*a*) reported a negative total factor productivity for 1960's through 70's, but a positive one for 1980's and 90's.

A group of the parametric studies focused on integrating environmental performance of firms into their efficiency. Hailu and Veeman (2000*b*) and Hailu (2003) concluded that considering undesirable outputs in the analysis would lead to higher productivity measures for the Canadian pulp and paper as compared to conventional efficiency measure, which ignored pollution abatement activities. A summary of these studies is given in Table 2.5.

The DEA studies in the pulp and paper sector include Hsue and Buongiorno (1994), Brannlund et al. (1995), Yin (1998, 1999, 2000) and Hailu and Veeman (2001*a*, 2001*b*), summarized in Table 2.6. A trend developed in some of these studies was considering effects of environmental performance of firms in their efficiency. Brannlund et al. (1995) compared the profit efficiency of Swedish pulp and paper firms with and without considering environmental regulations. The regulations were represented by constraining undesirable outputs. Hailu and Veeman (2001*a*) proposed a model to incorporate undesirable outputs in the DEA models and further discussed lower and upper bounds for intertemporal efficiency. The conventional efficiency measures, which ignore undesirable outputs, were found to underestimate the efficiency growth along time.

Table 2.5 - Summary of parametric efficiency studies of pulp and paper sector

Study	Industry	Region	Time Period	Method	Other Attributes or Findings
Sherif, 1983	Pulp and paper mills	Canada	1958-1977	Parametric-Translog total cost function	Observed negative technical change (efficiency decline) but slightly increasing total productivity.
Rao and Preston, 1984	Wood Industry, Pulp and paper	Canada	1957-1979	Parametric-Translog total cost function	Input quality, capacity utilization and management abilities affected technological progress.
Martinello, 1985	Logging, Sawmills, Pulp & paper mills	Canada	1963-1982	Parametric-Translog total cost function	Found large increasing returns to scale and negative technical change in pulp and paper sector.
Nautiyal and Singh, 1986	Pulp and paper	Canada	1956-1982	Parametric-Translog cost function	Labour productivity grew; input misallocation led to cost inefficiency.
Frank et al., 1990	Pulp and paper	Canada	1963-1984	Parametric-Translog total cost function	The total factor productivity was raised, largely due to the increased scale of the industry.
Oum et al., 1991	Pulp and paper	Canada, U.S., Sweden	1970-1980	Parametric-Translog total cost function	U.S. had higher total productivity growth.

Study	Industry	Region	Time Period	Method	Other Attributes or Findings
Hailu and Veeman,2000*a*	Pulp and Paper	Canada	1959-1994	Parametric-Input distance function	Productivity growth has mostly happened due to scale effects.
Hailu and Veeman,2000*b*	Pulp and Paper	Canada	1959-1994	Parametric-Input distance function	Traditional methods underestimated growth of productivity, due to ignoring undesirable outputs.
Hailu, 2003	Pulp and Paper	Atlantic and Prairies, ON,QC,BC,	1970-1993	Parametric-Input distance function	Included desirable and undesirable outputs to estimate efficiency.

Table 2.6 - Summary of non-parametric efficiency studies of pulp and paper sector

Study	Industry	Region	Time Period	Method	Other Attributes	Findings
Hsue and Buongiorno,1994	Pulp and Paper	Canada	1961-1984	Non-parametric distance function	6 inputs, 1 output	The two countries experienced similar productivity growth rates.
		U.S.	1959-1987			
Brannlund et al., 1995	Pulp and paper	Sweden	1989-1990	DEA-CCR (output oriented)	41 DMUs, 4 inputs, 4 outputs	Evaluated the effects of environmental regulations on firms' profit.
Yin, 1998	Linerboard	U.S.	n/a	DEA- CCR, BCC (input oriented)	44 DMUs, 7 inputs, 1 output	Observed constant returns to scale and high technical efficiency.
Yin, 1999	Pulpmills	Pacific Rim	1994	DEA- CCR, BCC (input oriented)	70 DMUs, 6 inputs, 1 output	BC was the most cost efficient and Asia and Oceania the lowest.
Yin, 2000	Pulpmills	Worldwide	1996	DEA-BCC (input oriented); SFA	102 DMUs, 4 inputs, 1 output	SFA scores were higher than their DEA counterparts.
Hailu and Veeman, 2001*a*	Pulp and paper	Canada	1959-1994	DEA-BCC (input oriented)	36 DMUs, 4 inputs, 6 outputs	Productivity increased in 1960's but remained stable in 1970's.
Hailu and Veeman, 2001*b*	Pulp and paper	Canada	1959-1994	DEA-BCC (input orientated); Parametric analysis; Index numbers	36 DMUs, 7 inputs, 4 desirable outputs, 2 undesirable outputs	Compared the methods in environmental efficiency assessment.

2.5 Discussion

Studies that used parametric methods to evaluate the efficiency of forest related companies mainly occur in the category of applied production analysis. They discuss production specifications such as scale efficiency, technology change, substitution factors and elasticity of input factors. Forest industries, in Canada or elsewhere, have been studied by such methods employing production or cost functions. A plausible aspect of these studies is the parameters included in the production (or cost) function. Parameters such as quality of raw material, skill level of labour, capacity utilization etc. may well add to the accuracy of the results and enable better analyses.

Another parametric method of efficiency assessment is analysis of stochastic production frontiers. This method incorporates more details into analyses and is particularly helpful in situations where two different systems, e.g. manufacturing, economic or managerial, have been in place and it is desired to investigate their effects. This method has been used in studying the harvesting and logging sectors in the U.S. and Europe, but not in Canada. Given the advantages of this method, it may be examined with respect to its applications to evaluating the efficiency of Canadian forest sector; it is for example well suited to studying this sector before and after changes in different regulations or strategies, like forest ownership, Annual Allowable Cut, international trade policies, etc.

DEA, with a non-parametric approach to efficiency measurement, has been used in evaluating the efficiency of forest industries only in the recent years. Logging companies in the U.S. and Brazil have been studied by LeBel and Stuart (1998) and Otsuki et al. (2002) respectively, while Hailu and Veeman (2003) assessed the boreal logging sector across provinces in Canada.

The Sawmilling sector has been assessed in terms of its efficiency in a number of DEA studies in Russia, Greece and Norway. Aside from benchmarking the underlying companies based on their efficiency, important policy implications were outcomes of these studies, such as how development programs, scale of operation and market strategies would affect companies' efficiencies.

The use and potential benefits of Data Envelopment Analysis is yet to be fully explored in the Canadian wood industry. DEA can be used to meet the need of the Canadian wood industry for performance assessment under the changing and challenging business environment, as it has been successfully used in efficiency analyses of various other manufacturing sectors. These applications cover a wide range of industries such as aviation, communication and computer hardware, beverage and brewing industry, farming, coal mining, logging and pulp and allied industries as well as wood industry in other regions (Charnes et al., 1994). The applications of DEA in evaluating manufacturing sectors suggest that this method can consider the relevant general characteristics of this type of sectors and accommodate their multiple performance dimensions. Moreover, successful applications of DEA to different regional wood products sectors, as discussed in section 2.3.2, imply that the method is potentially applicable to this sector as well.

In particular, DEA studies can be used to provide inclusive efficiency measures, to benchmark underlying units and to develop more realistic improvement policies for the Canadian wood industry. Such tools have applications for individual competing companies in the industry, and for related higher levels of decision-making units such as local, provincial or federal managerial and supervisory bodies.

The DEA models may also be extended to incorporate factors and aspects specific to wood industry (and the Canadian wood industry), for instance wood quality, seasonal effects of market and export regulations. Comparative analyses among the Canadian and other regional wood sectors are also important in studying their relative competitiveness and in identifying improvement opportunities.

Another area for further research with the DEA method is the value-added wood products sector in Canada. This sector has not yet been explored by DEA, while it can use such analyses to develop strategies and set reliable targets as it goes through expansion.

DEA can also be used to provide environmentally sensitive efficiency measures of wood products companies. There are successful examples of such efforts in the Canadian pulp and paper sector. In these studies, both desirable outputs and undesirable outputs of production process were incorporated in the efficiency measure. Using this method, a ranking for companies with respect to environmental policies can also be developed. Environmental efficiency measurement and environmental ranking suggest a vast area for further research.

In choosing a method for a particular study, one should be aware of limitations and advantages of each method. A general comparison of different methods for efficiency measurement reveals that partial efficiency measures, ratio analysis, are helpful for analyzing the effect of one factor on another factor, or in two different systems. This method cannot accommodate multiple performance factors, nor does it provide an overall efficiency measure.

Efficiency measurement methods with a parametric approach remove the limit of the ratio analysis method regarding the number of performance factors in the analysis; these methods allow incorporating one output and several inputs, or one input and several outputs. However, these methods require strict assumptions on the behaviour of the units under study, on the specifications of performance factors included in the model, and on the error distribution of the parameters of the functional form (Charnes et al., 1994). Such requirements decrease the practicality and reliability of these methods especially for assessing multi-dimensional performance or overall performance measures.

The DEA method relaxes assumptions of the methods with a parametric approach by taking a non-parametric approach to efficiency measurement. DEA does not require a definition for the functional form of the units under study. It can also integrate several inputs and outputs in the efficiency measure even with different measurement units. DEA provides efficient targets for inefficient units based on actual peer units. This attribute increases the credibility and acceptability of these targets to practitioners. However, there are some limitations for the DEA method. For instance, in order for a DEA model to well discriminate DMUs, the number of DMUs should be greater than twice the total number of inputs and outputs (Cooper et al., 2000). This requirement limits the applicability of DEA in some cases. In addition, DEA may assign weights to inputs/outputs that are not meaningful in practice. It also cannot identify any improvements for efficient units.

In employing any of these methods, especially methods with a parametric approach and DEA, one should pay attention to extensive data required for such analyses and insure the quality and consistency of data, as desired in any quantitative study.

2.6 Summary

Different methods have been used in the literature for measuring and analyzing efficiencies in the wood industry. These methods take either a parametric or a non-parametric approach to efficiency measurement. There are also some production ratios that have been used to calculate partial efficiency measures such as labour productivity, lumber recovery factor and waste index.

Efficiency measurement methods with a parametric or non-parametric approach have been employed in more complex studies of efficiency. Many applied production analyses used parametric methods and provided different production factors, e.g. scale economies, technical change and input substitutability. Still, the application of modified parametric methods, such as input distance function, can be further explored in the Canadian wood industry. These methods enable to incorporate detailed data into a model, and thereby provide more concrete measures of efficiency and other production factors.

The DEA method with a non-parametric approach to efficiency measurement has been used when several production outputs were to be analyzed in the Canadian logging and pulp and paper industries. However, the application of DEA has yet to be explored in the Canadian wood sector. DEA may be useful in a number of directions. One is in providing comprehensive efficiency measures of wood products companies, considering multiple inputs and multiple outputs. Another one is in benchmarking companies based on their efficiency and competitiveness. DEA may be used for setting reasonable targets and developing improvement policies for inefficient units. It can also be used to perform comparative efficiency analyses between regions in Canada, and between Canada and other competing countries. DEA can be employed for developing environmentally sensitive efficiency measures and ranking. Extending the theory of DEA is also another direction that would help to integrate aspects specific to wood industry.

Efficiency analyses, using these complex methods or a hybrid of them, would help the Canadian wood industry to acquire a better picture of its operational efficiency and competitiveness, in the level of its internal units and in the world. The analyses could also provide a tool for developing competing strategies for improvement, and taking better informed decisions in restructuring and leading the industry into the future.

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Chapter 3

Static DEA Analysis of Primary Wood Producers in British Columbia*

3.1 Background

Forestry is the largest single contributor to Canada's economy. It contributed $29.9 billion to Canada's gross domestic product (GDP) in 2002 (Natural Resources Canada, 2002) which accounts for more than 3% of the total GDP, $991.9 billion, in that year (Statistics Canada, 2004). Among forest industries, wood products manufacturing is the second largest sector, after pulp and paper, producing more than 38% of the annual total production value of forest industries since 1990. Sawmilling is the largest sub-sector of wood products manufacturing, providing more than 55% of the sector's annual manufacturing value in the same period (Natural Resources Canada, 2003).

Canadian sawmilling industry is to a large degree concentrated in the province of British Columbia (BC). As such, about half of the Canada's sawmilling value is produced in BC every year (Natural Resources Canada, 2003). In 2002, more than 200 sawmills operated in BC and produced 14,706 million board feet of lumber. BC sawmills vary in operational scale with the number of employees from 5 to 415 persons, the volume of log consumption from 20,000 m^3 to more than 1,700,000 m^3 and an annual production from 5 million to 500 million

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board-feet lumber[1]. They use a variety of logs as their raw material from high-grade to lower quality logs of species such as spruce – pine – fir[2], hem – fir[3], and Douglas-fir – larch[4] groups or cedar[5] in softwood mills and aspen and poplar[6] in hardwood mills (Forintek Canada, Corp., 2003*a*; 2003*b*).

Given the size and the manufacturing value of BC sawmilling sector, it plays a significant role in the economy of BC and Canada. Thus, it is important to evaluate the performance of BC sawmills and ensure a high efficiency and competitiveness in their production and continual improvements in their performance. However, the performance of BC sawmills has not been explored in the academic literature and business practices in the recent years.

This research was conducted to determine the operational efficiency of primary wood producers in BC. A non-parametric method, Data Envelopment Analysis, was employed for this purpose. This is the first study of this kind on this sector known to the author. Besides, rather than aggregate data of the sector, as used in DEA studies on the other Canadian forest sectors, mill-level data were incorporated in this study to evaluate the relative efficiency scores of each individual sawmill. These results were further analysed to find the major causes of inefficiency and how the efficiency level of sawmills were affected by forest regions and the number of operating days. Two non-parametric statistical tests, Median Quartile and Kruskal-Wallis *H*-test, were applied for this purpose.

The remainder of this chapter is organized as follows. An overview on DEA and efficiency studies in forestry using DEA is presented in section 3.2.1. The non-parametric tests and their previous applications in DEA studies are summarized in section 3.2.2. Section 3.3 presents the dataset, analyses and results. Finally, a summary and suggestions for future research are drawn in section 3.4.

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[1] These statistics are based on a dataset provided by the BC Ministry of Forests. Descriptive statistics of this dataset are given in section 3.3.1.
[2] Picea species- Pinus species-Abies species.
[3] Tsuga speices-Abies species.
[4] Pseudotsuga menziesii-Larix species.
[5] Cedrus specie.
[6] Populus species.

3.2 Literature Review

3.2.1 Efficiency Studies in Wood Industry

There are two groups of studies in the context of wood products manufacturing, that have discussed organizational efficiency.

The first group has used a parametric approach to evaluate efficiency. Some of these studies used cost functions to assess the productivity growth (see for example Banskota et al., 1985; Martinello, 1987; Meil et al., 1988; Puttock and Prescott, 1992), and some used profit functions (Constantino and Haley 1988, 1989). An important aspect of Constantino and Haley's study (1988) was developing a wood quality index and incorporating that as an input factor in their efficiency models. There were also studies focused on total factor productivity growth which used aggregate input and output indices (Abt et al., 1994), while some others used stochastic production frontiers (Grebner and Amacher, 2000; Siry and Newman, 2001).

The second group of efficiency studies on wood products companies has applied DEA, a non-parametric method, for measuring the efficiency (see for example Fotiou, 2000; Hernandez-Sancho et al., 2000; Nyrud and Bergseng, 2002; Nyrud and Baardsen, 2003). Fotiou (2000) investigated the effects of purchase markets and material handling systems on the efficiency of Greek sawmills. Mills which purchased lumber from both local and foreign markets, and/or had automated material handling systems received higher efficiency scores. Hernandez-Sancho et al. (2000) looked at the effect of environmental regulations on the efficiency of wooden goods and furnishing industry in Spain. They found that when waste reduction regulations were in effect, the efficiency of firms decreased due to reallocation of inputs. However, those firms associated with a technological institute or located at industrial districts were less affected. Nyrud and Bergseng (2002) studied the efficiency of Norwegian sawmilling sector and its relation to the size of mills. Smaller mills were less efficient than the larger mills.

Although there are some studies on the efficiency of the Canadian wood industry using parametric methods, Banskota et al. (1985), Meil et al. (1988), Puttock and Prescott (1992) and Abt et al. (1994) to name a few, a non-parametric efficiency method, i.e. DEA, has not been used to evaluate this sector. There are, however, a few DEA studies on the other

Canadian forest industries, namely logging, and pulp and paper industries. Hailu and Veeman (2003) studied the Canadian boreal logging industries from 1977 to 1995. They found positive effects of forest density and the proportion of hardwood production on efficiency and also a significant positive scale effect. In studying pulp and paper industry, Hsue and Buongiorno (1994) compared the productivity of the firms in the U.S and Canada. Hailu and Veeman (2001*a*, 2001*b*) proposed a DEA model incorporating undesirable outputs to evaluate Canadian pulp and paper industry during 1959-1994. They further discussed lower and upper bounds for inter-temporal efficiency. The conventional efficiency measures ignoring the undesirable outputs were found to underestimate the efficiency growth along time.

This study focused on assessing the performance of primary wood producers in BC, which has not been addressed in the literature. For this purpose, Data Envelopment Analysis (DEA) was chosen. There were several reasons for this choice. Firstly, DEA has a non-parametric approach to measuring efficiency that allows taking multiple inputs and multiple outputs of sawmilling industry into consideration. This would not be possible should a parametric method be undertaken. In addition, DEA does not simplify production technology with mathematical functions, nor does it force any assumptions on individual mills in terms of behaving with an interest in cost minimization or profit maximization. If a parametric method were to be employed in this study, such assumptions and requirements would limit the credibility of results. The DEA method also facilitates efficiency evaluation by enabling the incorporation of performance factors with different dimensions, yet not necessitating cost or price data. This is most often a problem in parametric efficiency assessment since parametric methods require all the included factors to be of the same dimension, or require to incorporate the equivalent of all the desired factors in terms of a single dimension, for example cost. More over, DEA provides a single efficiency score that can be well used for benchmarking sawmills. It also suggests target improvements for inefficient mills.

The difference of this study with DEA studies on other Canadian forest sectors is that mill-level data were used here to analyze the efficiency of each individual mill while Hailu and Veeman (2001*a*, 2001*b*, 2003) used aggregate regional or temporal data. Besides, this study applied a combination of DEA efficiency scores and non-parametric statistical tests to further analyze the results.

3.2.2 Application of Non-parametric Statistical Tests in DEA Efficiency Studies

To statistically analyze the DEA results for groups of DMUs, there are two types of tests: parametric and non-parametric. Parametric tests require a priori knowledge or an assumption on the population distribution function, mean, variance and sample size. Non-parametric tests, on the other hand, relax such assumptions and are therefore, usually, called distribution-free statistics. Although non-parametric tests need fewer assumptions than comparable parametric tests, they exhibit quite high asymptotic efficiency. Besides, they need relatively less calculations and are easy to use and interpret (see for example Sachs, 1984; Neter et al., 1993).

Non-parametric statistical tests were considered suitable for the post-hoc efficiency analysis in this research. The reason was that non-parametric tests were the only type of statistical tests that could accommodate having no knowledge or presumption on the distribution function of the efficiency scores, which was the case in this study. Besides, such tests have previously been used in some DEA studies (Brockett and Golany, 1996; Schaffnit et al., 1997; Nyrud and Bergseng, 2002). Brockett and Golany (1996) used Wilcoxon-Mann-Whitney (W-M-W) rank statistic to compare the efficiency of two groups of schools that differed in providing educational programs. Schaffnit et al. (1997) analyzed the performance of some Ontario-based bank branches using DEA; then, they employed W-M-W and also Kruskal-Wallis (K-W) tests to investigate the causes and effects of efficiency. Nyrud and Bergseng (2002) analyzed the effect of mill size on its efficiency using K-W and also Mood tests.

In this research, two non-parametric tests, Median Quartile (MQ) and K-W, were used. The MQ test was employed to determine whether the distribution function of different groups of sawmills were the same. The K-W test was applied to those groups of sawmills that proved to have the same efficiency distribution in order to inspect whether their mean efficiency was also the same. These two tests were chosen for these analyses because they could accommodate the purpose of the analyses. In addition, the assumptions of the tests were observed in the study. These tests have also been used in other DEA studies as mentioned above.

3.3 Methods

3.3.1 Data Envelopment Analysis

The performance of BC sawmills was measured by applying an output oriented CCR model (2.8) and a BCC model (2.8, 2.9). Their scale efficiency was then calculated using equation (2.10). The resulting technical and aggregate efficiencies, and also the suggested efficient targets were further inspected to explore inefficiency sources in 2002.

The DEA models used were chosen to be output oriented since the general interest in industry is to increase production. However, individual sawmills may operate with other objectives. This was not considered in this study since such data was not available.

3.3.2 Median Quartile Test

The Median Quartile test was used to determine whether the distribution function of different groups is the same. It is an extension to the *U*-test of Wilcoxon, Mann and Whitney. W-M-W required the assumption of having the same distribution function in order to examine the equality of means of two groups (Sachs, 1984; Neter et al., 1993). This assumption is relaxed in the MQ test. The assumptions of the MQ test are as follows:

(1) The populations of the underlying groups are continuous. This assumption may seem hardly fulfilled in practice, since all the measurement results (observation values) are rounded off numbers. However, this evidence has little effect on the validity of the continuity assumption, emphasizing rather the inaccuracy of the method of measurement (Sachs, 1984; Neter et al., 1993).

(2) The study is based on an independent sampling design or on a completely randomized design (Neter et al., 1993).

The MQ test states the problem as examining whether there is any significant difference among the population distribution functions of the concerning groups. Therefore, the null hypothesis stands as:

H_0 = All the groups have the same population distribution.

Against the alternate hypothesis of:

H_1 = At least one group has a different population distribution.

The procedure of applying the MQ test consists of these steps:

(1) The observations from all the groups are sorted in an ascending order. A ranking number, starting from 1 for the least value, is assigned to each observation.

(2) Considering n as the highest rank order, i.e. the total number of observations in the set, the quartiles of the set are defined as (3.1).

$$\begin{aligned} Q_1 &= \text{The value of the observation ranked } \lceil n/4 \rceil \\ Q_2 &= \text{The value of the observation ranked } \lceil 2n/4 \rceil \\ Q_3 &= \text{The value of the observation ranked } \lceil 3n/4 \rceil \end{aligned} \tag{3.1}$$

(3) The number of observations from each group which has a value in each of the quartiles is recorded in a $k \times 4$ matrix; k represents the number of groups that are to be compared and 4 shows the 4 quartiles of the whole sample set (Table 3.1). The matrix must be checked to be sufficiently occupied, i.e. all the matrix entries must be greater than 1; otherwise, the rows or columns that include the under-occupied cells must be grouped with their adjacent ones (Sachs, 1984). This will form a final matrix of the dimension $r \times c$, where r is the number of rows ($r \le k$) and c is the number of columns ($c \le 4$).

Table 3.1 - The MQ matrix

	Observations range			
Group	$Q \le Q_1$	$Q_1 < Q \le Q_2$	$Q_2 < Q \le Q_3$	$Q > Q_3$
1				
...				
k				

(4) The required statistic is calculated as (3.2) (Sachs, 1984), where n is the total number of observations, n_{ij} ($i = 1,...,r$ and $j = 1,...,c$) the cell entry in the ith row and jth column, n_i ($i = 1,...,r$) the sum of cell entries of the ith row and n_j ($j = 1,...,c$) the sum of cells of the jth column.

$$\hat{\chi}^2 = n\left[\sum_{i=1}^{r}\sum_{j=1}^{c}\frac{n_{ij}^{\ 2}}{n_i n_j} - 1\right] \quad (3.2)$$

$\hat{\chi}^2$ has an approximate distribution of $\hat{\chi}^2$ with an *(r-1)(c-1)* degree of freedom.

(5) If $\hat{\chi}^2 \geq \chi^2_{(r-1)(c-1);\alpha}$, then the null hypothesis, H_o, is rejected. This means that at least one group in the sample set did not have the same population distribution as the others at an α significance level.

3.3.3 Kruskal-Wallis *H*-Test

The *H*-test of Kruskal and Wallis was applied to explore whether the observations in any one group from the set are higher than those in the other groups. The K-W test is a generalization of W-M-W test to accommodate several groups (Conover, 1980). It requires a number of assumptions:

(1) All groups are random samples from their respective population.

(2) The groups are mutually independent.

(3) The measurement scale is ordinal.

(4) The population distributions of the groups are identical, or else they only differ in their mean values (Conover, 1980). The statistical hypothesis of this test indicates:

H_0 = The group populations have an identical mean.

Challenging the alternate hypothesis of:

H_1 = At least one of the populations tends to yield larger observations than at least one another population.

The alternative hypothesis can also be stated as:

H_1 = The populations do not all have identical means.

The implementation procedure of the H-test of K-W can be outlined as follows:

(1) All the observations from all the groups are sorted in an ascending order, and then are assigned a rank, starting at 1 for the least value. In case of tied observation values, the average of the ranks of the underlying observations is assigned to each of them.

(2) The statistic T is calculated as follows (3.3):

$$
\begin{aligned}
n &= \sum_{i=1}^{k} n_i \\
R_i &= \sum_{j=1}^{n_i} R(x_{ij}) \quad i = 1,2,\ldots,k \\
S^2 &= \frac{1}{n-1}\Big(\sum_{All\ ranks} R(x_{ij})^2 - \frac{n(n+1)^2}{4}\Big) \\
T &= \frac{1}{S^2}\Big(\sum_{i-1}^{k} \frac{R_i^2}{n_i} - \frac{n(n+1)^2}{4}\Big)
\end{aligned}
\tag{3.3}
$$

Considering k groups in the sample set, each of size n_i ($i = 1,\ldots,k$), n in (3.3) gives the total size of the set. R_i ($i = 1,\ldots,k$) is the sum of the ranks of the observations in each group. S is the correction parameter for the tied ranks. Statistic T has approximately a $\hat{\chi}^2$ distribution with a $(k\text{-}1)$ degree of freedom.

(3) If $T \geq \chi^2_{(k-1);\alpha}$, then H_o is rejected at a significance level of α (Conover, 1980). This means that statistically there is a significant difference among the population means of the sample groups.

Having rejected the null hypothesis, one may proceed to determine which pairs of the groups tend to differ; group i and j are said to be different if the following inequality stands true (3.4):

$$
\left|\frac{R_i}{n_i} - \frac{R_j}{n_j}\right| > t_{1-\alpha/2}\left(S^2\,\frac{n-1-T}{n-k}\right)^{1/2}\left(\frac{1}{n_i}+\frac{1}{n_j}\right)^{1/2} \tag{3.4}
$$

In this formula, $t_{1\text{-}\alpha/2}$ denotes the (1-α/2) quantile of the t distribution with an $(n\text{-}k)$ degree of freedom.

3.4 Analyses and Results

3.4.1 Dataset

To investigate the performance of BC sawmills, a database of sawmills operating in BC, 2002, was acquired from the BC Ministry of Forests. After dropping the records with missed or invalid values, a total of 82 sawmills were used in the analyses.

The data elements for each mill include a mill identifier, its associated forest region, lumber production volume in million board feet (mbf), chip production volume in '000 bone dry units[7] ('000 BDU), log consumption in '000 cubic meters ('000 m^3), number of employees and number of operating days.

A sawmill processes different types of logs that are converted to lumber, the main product, and chips, as side product. The produced lumber may be custom made or for standard sizes requested in the market (Forintek Canada, Corp., 2003*a*; 2003*b*). Data on log sizes and species used by each sawmill as well as variations in lumber types and values were not provided in this dataset; only aggregate measures of log consumption and lumber production were available. Machinery, energy and labour are other resources that a sawmill uses in its production process. As such, the production technology of a sawmill can be well represented by the traditional production factors, namely raw materials, labour, capital and products. In this study, all these factors are included except energy and capital; this is first because the latter were not available from the primary source of data used for the study. Second, it was preferred to avoid inconsistency in the data by adding these factors extracted from other sources. Third, these two factors are expected to have inconsiderable effects on the results. Energy, for example, constitutes less than 4% of the total annual manufacturing cost in the Canadian sawmilling sector (Industry Canada, 2004). Exclusion of capital, on the other hand, could also be justified considering the focus of the paper, which is studying the operational efficiency of sawmills as opposed to cost.

[7] Bone Dry Units (BDU) is a quantity of wood residue that weighs 2,400 pounds at zero percent moisture content (Oregon Department of Energy, 2004).

In the DEA models, the amount of processed logs and number of employees were considered as the resources (inputs) that each mill had used to produce lumber and chips as its desired products (outputs). The correlation test was done for inputs and outputs. No significant correlation was observed, implying that no duplicative representation of performance factors was occurred. Therefore, all the four factors were included in the analyses. The descriptive statistics of the data elements are given in Table 3.2.

Table 3.2 - Statistics of data elements

	Factor	Minimum	Average	Maximum
Input	Log ('000 m^3)	23	540.4	1 742
	Employee (no. of people)	7	181.5	415
Output	Lumber (mbf)	5	145	466
	Chips ('000 BDU)	0	71.9	232
Other	Operating days (no. of days)	71	231.1	364

3.4.2 DEA Analyses

The technical efficiency of BC sawmills was measured using equations (2.8) and (2.9). The aggregate efficiency of BC sawmills was also obtained based on model (2.8). The scale efficiency of each mill was then calculated by means of equation (2.10). These results were compared to further explore the returns to scale specification of the sector.

Technical efficiency for a sawmill shows how well and efficiently the sawmill is able to use its resources, logs and labour in this case, to produce its desired products, lumber and chips. The scale efficiency, on the other hand, indicates the degree to which a sawmill has exploited scale economies. A sawmill which is aggregately efficient is one that is both technically and scale efficient.

Only 11 sawmills out of a total of 82, i.e. 13% of BC sawmills, were technically efficient. The average technical efficiency of all the mills was 83%. Their aggregate efficiency averaged at 80%, with 6 out of 82 mills (about 7%) being aggregately efficient.

These results ended in an average scale efficiency of 97%. In fact, 21 out of 82 mills (26%) were 100% scale efficient (Table 3.3). The distributions of BC sawmills' efficiencies are illustrated in Figure 3.1.

Table 3.3 - Summary results of efficiency analyses of BC sawmills in 2002

Efficiency type	Technical	Aggregate	Scale
No. of efficient sawmills	11	6	21
Average efficiency (%)	83	80	97
Standard deviation	0.12	0.11	0.03
Minimum efficiency (%)	51	45	86

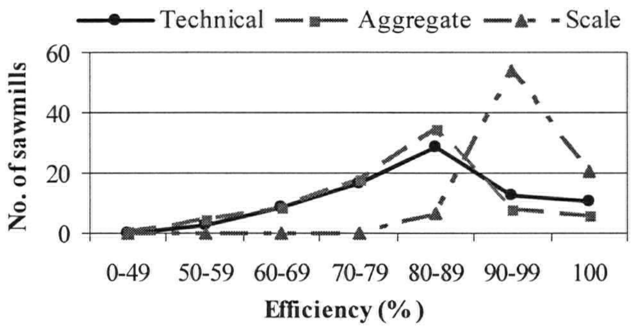

Figure 3.1 - Efficiency distribution of BC sawmills

Figure 3.1 demonstrates that the majority of BC sawmills enjoyed considerably high scale efficiency between 90% and 100%. But the greater part of the mills had a technical and aggregate efficiency between 80% and 90% with a larger variation than that of the scale efficiency. Detailed efficiency scores of all the mills are given in Appendix 1.

The high scale efficiency of the BC sawmills suggests that there is little scale economy unexploited. Therefore, the major inefficiency reason for BC sawmills is their technical inefficiency, as compared to their scale of operations. Accordingly, the analyses focused on the technical inefficiency.

In order to find the main technical factors of inefficiency, the efficient targets and suggested improvements by the technical efficiency analysis were studied. Out of 82 sawmills, 71 (about 86%) were performing inefficiently. To become as efficient as their best peers, they need to increase their production, including both lumber and chip, by 27% on average. This increase should be realized while using the same amount of inputs.

An additional source of efficiency improvement was revealed by examining the slacks. Over half of the inefficient mills, 36 out of 71, could even reduce their labour when achieving the improved production level. The labour saving averaged at 28%. No decrease was suggested in the log consumption. This implies that log utilization is at its best possible efficiency. Details of suggested output increase and labour saving for individual mills are presented in Appendix 2.

Such high production increase and labour reduction rates may seem unfeasible. Nevertheless, DEA specifies real units that are performing with those input and output levels, and efficiency degrees. Thus, in order to develop their own improved policies, the inefficient units can not only thoroughly explore their own operations, but also closely look into the practice of their reference units. The reference units of each inefficient DMU are members of the efficient frontier. In this case, DMUs 14, 21, 24, 32, 33, 35, 37, 63, 67, 72 and 81 form the entire technical frontier. The exact reference set for each individual sawmill is given in Appendix 2.

Analysis on the returns to scale (RTS) of sawmills showed that among efficient units, only 1 was in the region of increasing returns to scale (IRS), 6 were in the CRS region and 4 were in the decreasing returns to scale (DRS) region. Among inefficient units, 37 were in the IRS and the remaining 34 were in the DRS regions. This implies that the BC sawmills have in general a VRS production frontier. This result was also reported by Martinello (1987) for BC coast sawmills and Meil et al. (1988) for BC interior sawmills. Only Martinello (1987) had observed a CRS technology for the BC interior sawmills.

3.4.3 Statistical Inferences

There were two series of group comparisons in this study. The first one was to compare the technical efficiency of the 6 forest regions in BC. These regions are Cariboo, Kamloops, Nelson, Prince George, Prince Rupert and Vancouver. The second comparison analysis was to investigate the effect of the number of operating days on the efficiency measures. For this purpose, BC sawmills were grouped into 4 classes as: those who ran 0-3, 4-6, 7-9 and 10-12 months.

For each of these analyses, first the MQ test was used to check the distribution similarity (variations) among the groups. Then, for the groups, which had the same distribution function, the K-W test was employed to inspect the mean similarity.

3.4.3.1 Statistical Comparison of the Efficiency of Sawmills across BC Forest Regions

To compare the efficiency of sawmills among the six regions of BC forests, it was initially necessary to check if the MQ test assumptions held. These assumptions were continuity of the group populations and the observation independency. It was reasonable to assume a continuous population for efficiency of DMUs. The sample design was also independent. This was because the original dataset had covered the whole population of BC sawmills and the process of cleaning the dataset, i.e. selecting the observations, was regardless of the forest regions and the operating days.

To implement the MQ test, for inspecting the similarity of efficiency populations of forest regions, the hypotheses were formed as:

H_0 = All the 6 BC forest regions have the same efficiency population.

Against the alternate hypothesis of:

H_1 = At least one of the BC forest regions has a different efficiency population.

The technical efficiency scores of all the BC sawmills, operating in any of the six forest regions, were used as observation values. The efficiency distribution in each forest region was then tabulated, having each forest region in a row and the efficiency range in columns (Table 3.4). The MQ statistic was calculated based on (3.2), where n is the total number of efficiency observations, n_{ij} $(i=1,...,6$ and $j=1,2)$ the cell entry in the ith row and jth column of Table 3, n_i $(i=1,...,6)$ the sum of cell entries of the ith row, i.e. ith forest region, and n_j $(j=1,...,c)$ the sum of cells of the jth column, i.e. efficiency range. The classes for the efficiency range were decreased to two, from the initial four classes, due to under occupation of some cells.

Table 3.4 - Efficiency distribution in BC forest regions

	Efficient Range		
Forest Region	$Q \leq 84\%$	$Q > 84\%$	Row Total
Cariboo	2	8	10
Kamloops	9	8	17
Nelson	7	3	10
Prince George	8	13	21
Prince Rupert	3	3	6
Vancouver	13	5	18
Column Total	42	40	82

$$\hat{\chi}^2 = 9.961\,958\,6; \qquad \chi^2_{5;0.05} = 11.07 \qquad \Rightarrow \quad \hat{\chi}^2 \leq \chi^2_{5;0.05} \Rightarrow H_0 \text{ is accepted.} \qquad (3.5)$$

According to the calculations (3.5), the null hypothesis was not rejected at a 5% significance level. Therefore, it could be accepted that the efficiency populations were the same for all the forest regions with a 95% level of confidence. Hence, the equality of the efficiency means of the BC forest regions were examined using the K-W test (Figure 3.2).

Figure 3.2 - BC forest regions and their mean efficiency in 2002

The null hypothesis was stated as:

H_0 = All the forest regions have an identical mean efficiency.

Challenging the alternate hypothesis of:

H_1 = At least one of the forest regions tends to yield higher efficiency than at least one another forest region.

The K-W statistic, T, was then calculated based on (3.3).

$$T = 15.53 \text{ given } S^2 = 565.1; \quad \chi^2_{5;0.05} = 11.07 \quad \Rightarrow \quad T \geq \chi^2_{5;0.05} \Rightarrow H_0 \text{ is rejected.} \tag{3.6}$$

The K-W test rejected the null hypothesis, meaning that the means of efficiency scores were different among the six forest regions at a 5% significance level. To find out which of the regions differed in their efficiency, the pair K-W test (3.4) was applied. Table 3.5 displays the results. A significance level of 5% was used for this test.

The results suggested that sawmills in Cariboo and then Prince George forest regions tended to have greater efficiency than the others. The next most efficient forest regions were Prince Rupert and Kamloops with moderate efficiency results. Nelson and Vancouver forest regions showed the lowest scores among all (Table 3.6).

This analysis was based on efficiency measures that took into account only log and labour consumption, and lumber and chip production. Should other factors such as log species and sizes, lumber types and values, equipment and manufacturing process differences be considered in the analysis, the efficiency measures of mills across different forest regions, and consequently the rank for each forest region might change.

Table 3.5 - Kruskal-Wallis *H*-test results for pair comparisons among forest regions

Forest regions	$\left\lvert \frac{R_i}{n_i} - \frac{R_j}{n_j} \right\rvert$	$t_{1-\alpha/2}\left(S^2 \frac{n-1-T}{n-k}\right)^{1/2}\left(\frac{1}{n_i}+\frac{1}{n_j}\right)^{1/2}$	Decision on means equality
Cariboo vs. Kamloops	21.17	17.95	Reject
Cariboo vs. Nelson	29	20.14	Reject
Cariboo vs. Prince George	8.81	17.30	Accept
Cariboo vs. Prince Rupert	8.71	23.25	Accept
Cariboo vs. Vancouver	28.38	17.76	Reject
Kamloops vs. Nelson	7.83	17.95	Accept
Kamloops vs. Prince George	12.36	14.69	Accept
Kamloops vs. Prince Rupert	12.45	21.38	Accept
Kamloops vs. Vancouver	7.22	15.23	Accept
Nelson vs. Prince George	20.19	17.30	Reject
Nelson vs. Prince Rupert	20.28	23.25	Accept
Nelson vs. Vancouver	0.62	17.76	Accept
Prince George vs. Prince Rupert	0.1	20.85	Accept
Prince George vs. Vancouver	19.57	14.46	Reject
Prince Rupert vs. Vancouver	19.67	21.23	Accept

Table 3.6 - Competitiveness of BC forest regions in efficient performance

Forest regions	Cariboo	Kamloops	Nelson	Prince George	Prince Rupert	Vancouver
Cariboo	=	>	>	=	=	>
Kamloops	<	=	=	=	=	=
Nelson	<	=	=	<	=	=
Prince George	=	=	>	=	=	>
Prince Rupert	=	=	=	=	=	=
Vancouver	<	=	=	<	=	=

3.4.3.2 Statistical Comparison of the Efficiency of Sawmills with Different Number of Operating Days in a Year

In checking possible impacts of the number of operating days on efficiency, the MQ test (3.2) did not recognize any significant difference in the efficiency distribution among designated groups at a 5% significance level (3.7) (Table 3.7).

Table 3.7 - Efficiency distribution based on the number of operating days

Annual operating duration	Efficiency Range		Row Total
	Q ≤84%	Q >84%	
Up to 6 months	4	4	8
More than 6 months	17	57	74
Column Total	21	61	82

$$\hat{\chi}^2 = 2.76811; \qquad \chi^2_{1;0.05} = 3.84 \qquad \Rightarrow \quad \hat{\chi}^2 \le \chi^2_{1;0.05} \Rightarrow H_0 \text{ is accepted.} \qquad (3.7)$$

Since the efficiency functions were identified alike, the hypothesis of having the same mean was also checked with K-W test (3.3). It was accepted that the mean of efficiency scores were the same among the 4 classes of number of operating days with a 95% confidence level (3.8). This outcome, accepting H_o, states that the capability of a sawmill to perform efficiently is not significantly affected by the time length it keeps its plant running in a year.

$$T = 6.67 \text{ given } S^2 = 565.1; \quad \chi^2_{3;0.05} = 7.81 \quad \Rightarrow \quad T \le \chi^2_{3;0.05} \Rightarrow H_0 \text{ is accepted.} \qquad (3.8)$$

3.5 Summary

In this research, the performance of primary wood producers in BC was studied from different aspects. DEA, a non-parametric method to efficiency measurement, was used for this purpose to provide more holistic efficiency measures. Mill-level data were incorporated in BCC and CCR models to capture technical, aggregate and scale efficiencies of each mill.

The DEA efficiency measures revealed that although the majority of BC sawmills enjoyed high scale efficiency in 2002, due to technical performance deficiencies their aggregate efficiency remained lower. There was also a large variation observed in the technical and aggregate efficiency measures. This highlights that a focus on technical efficiency improvement policies could greatly reward the performance of the whole sector and also individual mills. In particular, substantial increase in production and decrease in labour use was suggested by the data envelopment analysis to enhance the technical efficiency.

The efficiency measures were further analyzed to see whether the forest regions and the number of operating days had effects on the mills' technical efficiency. The statistical analyses indicated that the efficiency of BC forest regions was significantly different at a 5% significance level; central and interior forest regions (Cariboo, Prince George, and Prince Rupert) showed the highest efficiency level. Southern forest regions (Kamloops, and Nelson) had a mediocre efficiency while the Coast region, Vancouver, had the lowest efficiency level. This comparison used efficiency measures that were solely based on log and labour consumption, and lumber and chip production. The analysis did not take into account product values, log size differences or different technologies that such logs would require to be processed. The number of operating days, on the other hand, was found to have little influence on the technical efficiency of sawmills. This implied that the capability of a mill in transforming its resources to products was not affected by the duration the mill ran in the year.

If data on other performance factors were available, this study could take them into account as well. Hence, future work can be built based on this research. Incorporating additional performance factors, such as the raw material suppliers and final product markets, into the study would help to better capture the sawmills' efficiency measure. Also, taking cost and price information into models would allow for other types of efficiency analyses such as allocative, cost and profit efficiency analyses.

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Chapter 4

Dynamic DEA Analysis of Primary Wood Producers in British Columbia*

4.1 Background

Primary Wood Manufacturing is a key sector in the Canadian wood industry. It has annually contributed between 8 and 19 billion CDN$ (about 60%) to the total manufacturing value of the wood industry since 1990. Among the Canadian provinces, British Columbia has the largest share in the primary wood manufacturing with an annual production value of 5.5 to 9.5 billion CDN$. This value accounts for more than 50% of that of the Canadian sector (Figure 4.1).

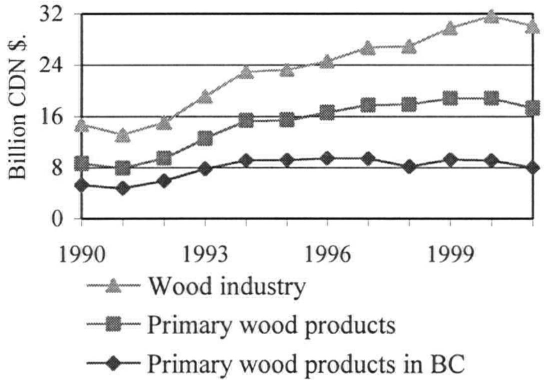

Figure 4.1 - Manufacturing value of the primary wood products in BC and Canada. Source: Natural Resources Canada, 2004.

* A version of this chapter has been submitted for publication. Salehirad, N. and Sowlati, T. (2004) Dynamic efficiency analysis of primary wood producers in British Columbia from 1990 to 2002. Canadian Journal of Forest Research.

Primary Wood Manufacturing mainly refers to sawmilling, of which the end products are lumber, its variants and chips. The sawmilling sector in western Canada, including BC, expanded strategic planning to increase revenue since 1980's. Their initial strategy was to increase production capacity, which later shifted to minimizing labour costs. Consequently, they directed their strategies towards automation and speeding up manufacturing processes. However, more recently they have focused on increasing machinery productivity and lumber recovery factor by improving technology and installing optimization manufacturing systems (Forintek Canada, Corp., 2003*a*). In doing so, the sawmilling sector has experienced significant technological advancements particularly over the last decade. At the same time, the sector has been influenced by other factors such as supporting policies for the expansion of value-added wood products, the lumber trade dispute with the U.S., and general changes in the Canada's economy (Forintek Canada, Corp., 2003*b*). The sector has also faced a continuing decline in the number of sawmills; the number of BC sawmills has decreased by 22% since 1990. During the same period lumber production has expanded by 1.8% in volume (Figure 4.2).

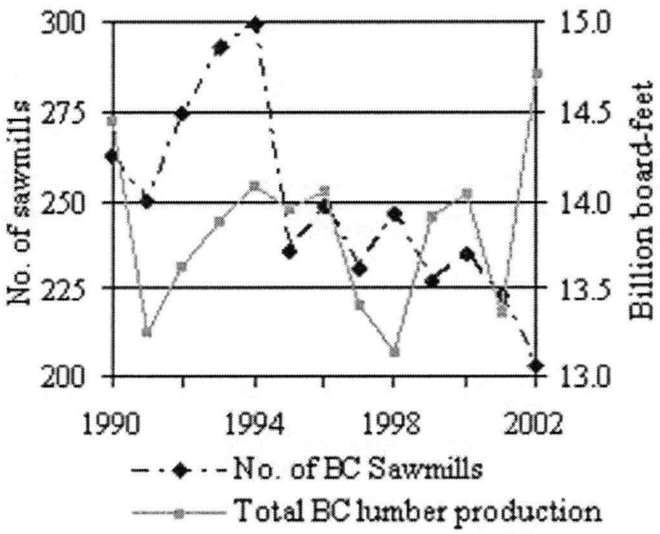

Figure 4.2 - Number of BC sawmills and their total lumber production volume[1].

[1] These statistics are based on a dataset provided by the BC Ministry of Forests. Descriptive statistics of this dataset are given in section 4.4.1.

This rapidly changing environment has indeed affected the industry's performance. However, to the best knowledge of the author, there has been no study to explore such effects. This research was therefore designed to this end.

This study aimed to analyze the efficiency of sawmills in BC for the period from 1990 to 2002. The Data Envelopment Analysis (DEA) method along with a number of analysis approaches were utilized to capture different performance characteristics of the BC sawmills over this period. First, a contemporaneous analysis was conducted to provide a picture of their performance in each year individually. The BCC and CCR models were used in this stage to measure technical, aggregate and scale efficiencies. To obtain an estimation of the relative performance of units in the years 1990-2002, two analyses, an intertemporal analysis and a Window Analysis (WA), were conducted. In respect to the technological advancements in the underlying study period that could affect the productivity of the sawmills, a Malmquist productivity index was also calculated. This index provided a quantified measure of different factors that mark the productivity changes between periods. In addition, a separate analysis was performed on the BC mills that were shut down in 2002, to examine whether they had suffered from a poor performance.

The rest of this chapter is organized as follows: an explanation and a literature review of the alternative efficiency analysis methods used in this study are presented in section 4.2 and 4.3, respectively. The dataset, analyses and results are discussed in section 4.4. Finally, section 4.5 concludes the chapter with study remarks and suggestions for future research.

4.2 Methods

A part of the performance assessment literature using DEA is related to the studies of efficiency over time. These studies have exercised DEA on time series and panel performance data[2] with various analysis approaches.

[2] "Performance time series data" refers to a set of performance data of a specific unit, observed over a period of time. "Panel performance data" refers to a set of time series data for a number of units.

4.2.1 Contemporaneous Analysis

In some studies on performance data over time, the performance of each unit is evaluated by comparing it to other units in the same period, independent from other periods. That is, given a performance time series or panel data for T periods ($t = 1,...,T$) with an equal or different numbers of DMU in each year (respectively called balanced and unbalanced panel data), DEA models are run for the set of DMUs in each period separately, for a total of T periods. Such an analysis approach is called contemporaneous analysis (Tulkens and Vanden Eeckaut, 1995).

The efficiency measures from a DEA contemporaneous analysis do not reflect a relative efficiency from year to year, but rather within the same year. Therefore, these measures are suitable for an assessment of units in individual years. However, they cannot explain the trend of efficiency from year to year.

4.2.2 Intertemporal Analysis

To analyze the efficiency trends from another perspective, all DMUs from all periods may be put together in a pool and thereby be evaluated against each other. Accordingly, for a set of performance data spread over a T period time span, with n_t units in each period t ($t = 1,...,T$), DEA models are run a total of n times ($n = \sum_{t=1}^{T} n_t$) with the inclusion of all the n units in the underlying constraints. This analysis approach is called intertemporal analysis (Tulkens and Vanden Eeckaut, 1995).

An intertemporal analysis provides a better basis if the efficiency measures are meant to be compared among the years. However, applications of this method would be appropriate for cases in which changes in the production technology along time are negligible. This validates the evaluation of DMUs in the earlier periods when compared to units in the later periods.

4.2.3 Window Analysis

WA introduced by Charnes et al. (1985) is a more recent method for efficiency trend analysis. This method helps to study efficiency over time considering that production technology may also change along time. There are other applications for WA as well. One is to examine the stability of performance (efficiency) over time. Another application is to increase the number of DMUs to a sufficient level, when compared to the total number of inputs and outputs. For such a purpose, WA is applicable if the number of units under study is limited but a time series of their performance data is available.

DEA-WA extends the comparison set for a particular DMU, from DMUs in that single year to include DMUs from the neighbouring years. In doing so, WA treats an identical unit in different time periods as different DMUs (Charnes et al., 1985). In a WA for a series of T periods and with a window size of l ($l \leq T$), a DEA model is run for all DMUs in the first l periods. Then the window is moved one period by period, and the DEA model is run for each window separately. This continues until the last window which covers the last l periods in the time span.

In WA, the performance trend of each DMU over time can be analyzed in several ways. One way is to inspect the efficiency scores of a DMU across one specific window, referred to as row analysis. Another way is to study a DMU's efficiency scores for each period in different windows, referred to as column analysis. The average efficiency measure of a DMU in each window and its trend along the sequential windows can also be examined. This would be a case of studying moving averages, since the window average moves over the whole time span with a one period time step as the window moves. WA also enables an investigation of the stability of the efficient frontier over time by examining the durability of a DMU's appearance on the frontier of different windows. The stability of the reference set of individual DMUs can also be inspected (Cooper et al., 2000).

WA entails weaknesses in efficiency trend analysis as well. One problem is choosing the width for a window, which is currently determined by trial and error. Such a choice should take into account the sensitivity of DEA solutions to window width. Besides, a window is to cover a time interval with negligible technological changes. This factor itself introduces another challenge that concerns how to define technology and measure it, and what limit to set for negligible technological changes. To address this issue, Sueyoshi and Aoki (2001) proposed an altered WA approach. They first ran a statistical test to identify the periods in which a technological change had occurred. Then, they formed windows with no technological change, and accordingly obtained the efficiency scores within each window. Although this approach attends to having windows with negligible technological changes, it loses some of the WA advantages being a quasi-WA approach.

Another deficiency of WA is that it does not test the DMUs in the beginning and ending periods as frequently as the others. To address this problem, Sueyoshi (1992) introduced a "round robin" procedure that proceeds as follows: first, each period is examined independently. This is followed by a two-period analysis after which a three-period analysis is used, and so on. However, this analysis becomes unwieldy since the number of combinations grows exponentially with the number of periods in the study horizon.

4.2.4 Malmquist Index

To measure the productivity change between two periods in a DEA dynamic analysis, the Malmquist total factor productivity (TFP) index can be used. The Malmquist index is calculated either directly between two adjacent periods (Fare et al., 1994), or by means of auxiliary measures using a base period (Berg et al., 1992). This index can further be decomposed into two effects: technology shift and efficiency change[3]. Each of these indices would indicate a progress if the index is greater than 1, no change if equal to 1, and a regress if less than 1.

The origin of TFP was an early work by Malmquist (1953) in which he introduced a quantity index number, based on output or input distance functions. Later, Caves et al. (1982) developed that measure to a TFP growth index. Fare et al. (1994) illustrated how the distance functions in Malmquist TFP index could be estimated using DEA-like methods. They

[3] There are other versions of Malmquist TFP index which can be decomposed into three components: technology shift, technical efficiency change and scale change. These indices, usually called Generalized Malmquist Index, were not used in this study, and are not discussed here.

formulated the index, here denoted by M (4.1), using aggregate efficiency scores resulted from a CRS model, i.e. a CCR model (2.8).

$$M_O = \left(\frac{\Phi_{ba}\,\Phi_{bb}}{\Phi_{aa}\,\Phi_{ab}} \right)^{1/2} \tag{4.1}$$

This index, M_o, measures the total productivity change for DMU$_o$ between periods a and b. Φ_{ba} indicates the DEA efficiency of DMU$_o$ in period b when it is evaluated against the frontier of period a, i.e. compared to units in period a. Whereas Φ_{bb} is the efficiency estimation of DMU$_o$ in period b when projected to the frontier of period b. The other factors, Φ_{aa} and Φ_{ab}, are defined in a similar way.

In order to decompose the Malmquist TFP index into its two components, technical efficiency change (EC) and technology change (TC), the following formulae are respectively applied (4.2, 4.3). While the EC measures how the position of the unit has changed relative to its frontiers of the two periods, the TC measures the shift in the position of the frontier from one period to another.

$$EC_O = \frac{\Phi_{bb}}{\Phi_{aa}} \tag{4.2}$$

$$TC_O = \left(\frac{\Phi_{ba}\,\Phi_{aa}}{\Phi_{bb}\,\Phi_{ab}} \right)^{1/2} \tag{4.3}$$

The Malmquist TFP index is helpful since it provides an overall relative measure of the performance changes of units, which combines both changes in their efficiency and changes in technology available to that group of units. The Malmquist index also provides a base to assess efficiency and technology separately. It measures the efficiency of a unit as its level of utilization of the current technology. The technology is identified as the best practice in each period. By doing so, this method brings a possibility for improvement into view that is not apparent in customary productivity indices that do not distinguish between productivity increases resulting from 1) improvements in technology and 2) improvements in performance with existing technologies (Charnes et al., 1994).

4.3 Literature Review

Contemporaneous analysis has been widely used in service industries: in finance services Grifell-Tatje and Lovell (1997) and Worthington (2001), in the hospitality industry Johns et al. (1997), and in health care sector Rosko (2001) and Harper et al. (2001). Worthington's (2001) study was on Australian credit unions that had acquired or had been acquired by other institutes to explore their behaviour in the pre and post-merging periods. Rosko (2001) used stochastic DEA in a contemporaneous analysis. Harper et al. (2001) compared DEA and an econometric method in their resultant contemporaneous efficiency measures.

Efficiency studies on industrial sectors have also employed contemporaneous analysis. For example, Clarke (1992) studied vehicle maintenance in U.S. Air Force, Fraser and Hone (2001) analyzed the efficiency of wool producers, and Hailu and Veeman (2003) measured the contemporaneous efficiency of logging industry in 6 regions in Canada.

Contemporaneous analysis was also used to compare industrial countries based on aggregate data. Zofio and Prieto (2001) studied the effect of CO_2 emissions on environmental efficiency of 14 industrial countries. Serrao (2003) used contemporaneous efficiency of 18 European countries to further analyze their productivity changes over 1981-1998.

Intertemporal efficiency analysis has been used in service sectors. In professional sports sector, Fizel and D'Itri (1997) estimated the managerial efficiency of basketball team coaches. They tried to relate that measure to the organizational performance, the winning probability and the managerial succession in a team. In finance sector, Asmild et al. (2004) overviewed the development of Canadian bank institutes over a 20 year period.

Some DEA applications in manufacturing industries have also used intertemporal analysis. Golany et al. (1994) evaluated the performance of power plants in Israel. Feroz et al. (2001) investigated the intertemporal revenue efficiency of some textile companies.

There are a number of applications of intertemporal analysis in forest industries: in the pulp and paper sector Brannlund et al. (1995) and Hailu and Veeman (2001), in the logging sector LeBel and Stuart (1998), and in sawmilling Nyrud and Bergseng (2002). Brannlund et al. (1995) compared the profit efficiency of Swedish pulp and paper firms with and without considering environmental regulations. The regulations were represented by constraining undesirable outputs. Hailu and Veeman (2001) discussed lower and upper bounds for intertemporal efficiency.

The initial applications of WA were in the U.S. air force, where Charnes et al. (1985) analyzed the efficiency stability of their maintenance units and Bowlin (1987) assessed their seasonal efficiency of property maintenance. Duygun Fethi (1999) used WA in commercial aviation industry to evaluate the relative competency of European airlines in taking full advantage of market liberation policies.

WA was also applied in finance industries. Hartman and Storbeck (1996) examined the efficiency of Swedish banking. They used a quasi-window analysis, in that they had non-overlapping windows each of length 3. Asmild et al. (2004) analyzed the performance of the Canadian banking industry in the last two decades.

Nonetheless, the main studies with WA have been in technology-based industries. For instance, Thore et al. (1996) calculated the efficiency of computer technology manufacturers performing a WA with a window length of 2 years. They then suggested a model to use the acquired efficiency for policy implications in product cycle management. For process improvement in cellular manufacturing, Talluri et al. (1997) suggested a modified version of WA. Their method entailed omitting the period with the least cross-efficiency from the window while moving the window along time.

There are productivity studies using DEA-based Malmquist indices in service industry at large: Grifell-Tatje and Lovell (1997) and Asmild et al. (2004) in Banking, Duygun Fethi (1999) in Aviation, Sueyoshi and Aoki (2001) in postal services and Sommersguter-Reichmann (2003) in Health Care. Grifell-Tatje and Lovell (1997) used a generalized Malmquist index which accounted for scale effects on productivity changes as well. They also introduced two concepts for the productivity index, the regular TFP index which was evaluated for each group of banks separately, and the potential productivity change index, measured when merging all the bank groups together. The merging procedure involved the elimination of managerial inefficiency within each group. This enabled distinguishing between the managerial and the institutional inefficiencies of each bank group. Sueyoshi and Aoki (2001) suggested a computation procedure for a base year Malmquist index using efficiency measures from a quasi-WA. They first ran a statistical test to identify the years in which a technological change had occurred. Then, they formed windows with no technological change. According to the proposed windows, they obtained the efficiency scores and thereby computed the index. Asmild et al. (2004) discussed the definition of own period frontier when measuring Malmquist index with WA efficiency scores. They argued that Malmquist index based on WA efficiency would generate incorrect results.

There are also applications of Malmquist index estimated based on DEA scores in manufacturing sectors, agriculture and forestry. In manufacturing, Fraser and Hone (2001) evaluated the operational efficiency and productivity growth of wool producers. Mahadevan (2002) also studied manufacturing sectors of Malaysia using generalized Malmquist index. This helped to capture the scale effect on productivity as well. For a sensitivity analysis, she compared her indices, based on contemporaneous CRS efficiency, to the same indices calculated from WA efficiency scores.

The studies in agriculture include Aldaz and Millan (2003), Bayarsaihan and Coelli (2003) and Serrao (2003), and in forestry Hailu and Veeman (2003) and Nyrud and Baardsen (2003). Aldaz and Millan (2003) proposed a model which by using TFP indices provided lower and upper bounds for the annual technical efficiency. Bayarsaihan and Coelli (2003) compared the Malmquist indices computed from DEA efficiency of deterministic and stochastic frontier approaches.

4.4 Data and Analyses

4.4.1. Dataset

To investigate the dynamics of the efficiency of BC sawmills, a dataset of sawmills located in BC was acquired from the BC Ministry of Forests. The dataset included a number of performance data from 1990 to 2002. After dropping the records with missed or invalid values, a balanced panel data with a total of 82 sawmills in each year was created for the analyses.

The dataset provided four performance factors for each sawmill in each year, besides an identifier number for mills. The factors were lumber production volume in million board feet (mbf), chip production volume in '000 bone dry units ('000 BDU), log consumption in '000 cubic meters ('000 m^3) and number of employees. The descriptive statistics of these data are given in Table 4.1.

Table 4.1 - Descriptive statistics of data elements.

Year	INPUT				OUTPUT			
	Log ('000 m^3)		Employee (no. of persons)		Lumber (mbf)		Chips ('000 BDUS)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1990	481.8	260.7	179.6	101.6	109.8	63.3	68.1	49.7
1991	460.3	261.6	172.5	89.7	105.3	65.4	69.4	47.4
1992	482.6	268.8	170.5	85.6	113.5	66.9	72.1	47.5
1993	486.8	264.9	177.1	89.0	117.2	68.8	70.8	40.9
1994	484.7	251.7	181.6	89.6	117.1	67.6	70.4	37.0
1995	478.9	254.2	185.9	92.1	116.1	68.1	68.5	34.7
1996	481.6	251.6	186.9	91.7	117.7	68.5	68.6	36.4
1997	464.8	244.9	187.1	90.9	114.9	68.6	71.1	48.5
1998	446.7	251.4	180.1	82.9	114.7	71.7	61.9	35.7
1999	482.8	266.9	181.1	85.6	125.7	76.1	68.5	37.5
2000	492.9	271.4	177.7	82.7	128.1	79.0	70.9	42.1
2001	467.6	272.6	176.6	82.2	123.2	78.7	61.7	37.9
2002	540.4	337.3	181.5	84.6	145	98.8	71.9	47.1

Based on the available data, a DEA model was developed with two inputs and two outputs: log consumption and number of employees as inputs and lumber and chip production as outputs. The correlation test conducted on the inputs and the outputs reported no duplicative representation of performance factors. Therefore, all the four factors were used in the analyses.

4.4.2 Analyses and Results

4.4.2.1 Contemporaneous DEA

To provide a preliminary picture of the BC sawmills' efficiency in each year of the study time span, contemporaneous analyses were performed using different DEA models. A CCR output-oriented model (2.8) was ran to measure the aggregate efficiency of BC sawmills. The orientation of the model was chosen as output-oriented according to the strategic interest of the sector in production increase (refer to section 4.1) and also in considering provincial support policies for production increase and job creation (Forintek Canada, Corp., 2003*c*). A BCC output-oriented model (2.8, 2.9) was then applied to estimate the technical efficiency of BC sawmills. Consequently, the scale efficiency of mills was obtained based on (2.10). The results are summarized in Table 4.2.

Table 4.2 - Summary results of contemporaneous efficiency analyses.

Year	Aggregate efficiency			Technical efficiency			Scale efficiency		
	% Efficient mills	Mean	Min	% Efficient mills	Mean	Min	% Efficient mills	Mean	Min
1990	6.1	0.81	0.51	12.1	0.85	0.58	12.1	0.95	0.51
1991	6.1	0.81	0.49	12.1	0.84	0.57	23.2	0.96	0.80
1992	6.1	0.81	0.48	15.8	0.85	0.55	14.6	0.95	0.68
1993	8.5	0.84	0.59	14.6	0.87	0.62	29.3	0.96	0.72
1994	6.1	0.80	0.49	14.6	0.85	0.57	26.8	0.94	0.59
1995	3.6	0.79	0.51	13.4	0.86	0.59	6.1	0.92	0.60
1996	7.3	0.84	0.50	15.8	0.87	0.55	41.5	0.97	0.63
1997	7.3	0.79	0.49	15.8	0.84	0.57	18.3	0.96	0.57
1998	4.9	0.81	0.52	12.1	0.86	0.62	14.6	0.94	0.58
1999	7.3	0.81	0.52	14.6	0.86	0.64	24.3	0.95	0.57
2000	4.9	0.80	0.51	9.7	0.84	0.58	21.9	0.96	0.56
2001	8.5	0.87	0.52	14.6	0.88	0.52	48.8	0.99	0.90
2002	7.3	0.80	0.45	13.4	0.83	0.46	25.5	0.97	0.86

It was observed that the mean aggregate efficiency of the whole BC sawmilling sector fluctuated about a rather constant average. The domain of the aggregate efficiency scores covered from 0.79 to 0.87, which was fairly overlying the technical efficiency range, 0.83 to 0.88. This suggested that the scale efficiency of BC sawmills was quite high which was evident in the scale efficiency scores. In fact, more than 23% of the mills were 100% scale efficient in each year on average (Figure 4.3).

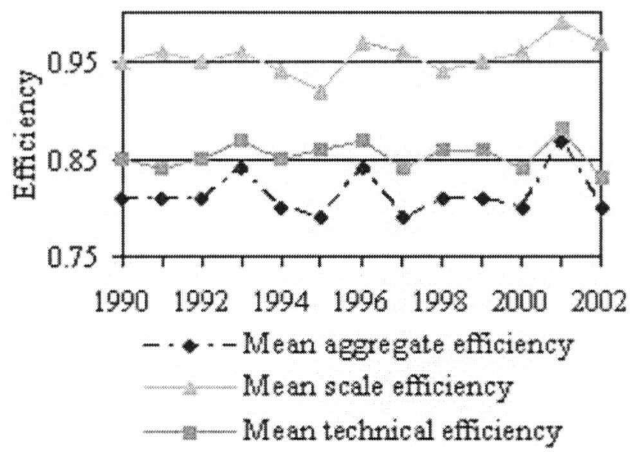

Figure 4.3 - Average efficiency of BC sawmills in contemporaneous analyses.

It must be noted that the contemporaneous efficiency measures were not calculated in comparison to a fixed frontier across the years; therefore, for instance, an efficiency increase from 0.79 in year 1997 to 0.86 in 2001 would not mean an exclusive efficiency growth of 0.07. Hence, these results were further inspected with other dynamic methods of studying efficiency (refer to sections 4.2.2, 4.2.3 and 4.2.4).

The percentage of best performers was also monitored over the years. This measure indicated what portion of sawmills were able to fully utilize the available technology. The percentage of aggregately best practitioners showed a fluctuating behaviour about a quite stable average of 6% (5 sawmills out of 82). The percentage of technically best performers also had a similar pattern with an average of 13% (11 sawmills out of 82). However, the percentage of mills that were scale efficient demonstrated more noticeable changes, following an increasing trend in general (Figure 4.4).

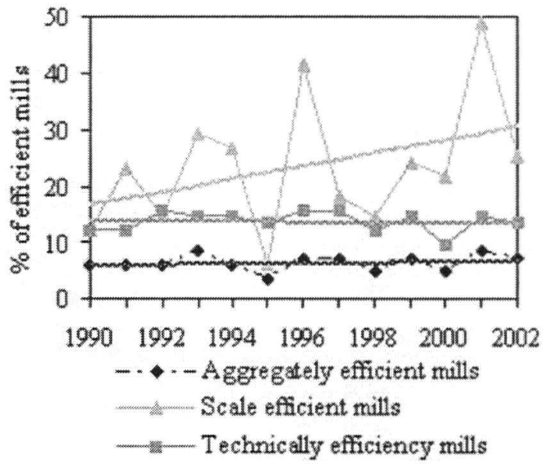

Figure 4.4 - Percentage of efficient mills in contemporaneous analyses.

An analysis of the years in which the mean efficiencies were highest and the years where the percentage of efficient mills faced significant changes would lead to the conclusion that the sawmilling sector in BC noticeably improved its performance in 1993, 1996 and in 2001. The sector also went through periods of poorer performance in 1995 and 1997.

4.4.2.2 Intertemporal DEA

As mentioned, the contemporaneous analyses were based upon each year independently and ignored the best performance practices in the whole time span in order to assign efficiency scores. To address this issue and providing more reliable comparisons between different periods, intertemporal analyses were exercised on the whole period of 1990 to 2002. Intertemporal aggregate, technical and scale efficiency measures of BC sawmills were obtained using CCR model (2.8), BCC model (2.8, 2.9) and (2.10). The results are shown in Table 4.3.

Table 4.3 - Summary results of intertemporal analyses.

Year	Aggregate efficiency			Technical efficiency			Scale efficiency		
	% Efficient mills	Mean	Min	% Efficient mills	Mean	Min	% Efficient Mills	Mean	Min
1990	1.2	0.65	0.39	1.2	0.68	0.50	23.1	0.95	0.65
1991	0	0.64	0.34	1.2	0.67	0.35	26.8	0.95	0.67
1992	0	0.67	0.41	0	0.70	0.44	19.5	0.95	0.68
1993	0	0.67	0.36	0	0.70	0.38	18.2	0.96	0.75
1994	1.2	0.67	0.38	1.2	0.69	0.39	19.5	0.96	0.77
1995	0	0.66	0.36	0	0.69	0.37	15.8	0.96	0.77
1996	0	0.67	0.34	0	0.69	0.35	20.7	0.96	0.77
1997	0	0.68	0.40	1.2	0.70	0.42	24.4	0.96	0.75
1998	0	0.69	0.42	0	0.71	0.45	19.5	0.97	0.77
1999	0	0.71	0.41	0	0.73	0.45	18.3	0.97	0.77
2000	0	0.71	0.43	2.4	0.73	0.45	25.6	0.97	0.77
2001	0	0.71	0.42	1.2	0.74	0.42	30.5	0.97	0.70
2002	2.4	0.73	0.39	6.1	0.77	0.42	20.7	0.96	0.69

Not surprisingly, the efficiency scores were distinctly lower than those obtained in the contemporaneous analyses. This was due to comparing each unit to a wider sample. The average efficiency scores resulted from intertemporal analyses are displayed in Figure 4.5. In general, BC sawmills improved their aggregate efficiency over the study period with the exception of years 1991 and 1995. The contemporaneous analysis had also recognized the performance deterioration in 1995. However, it was not able to reveal that in 1991.

Having decomposed the aggregate efficiency into scale and technical efficiencies, it was observed that their scale efficiency was stable and at a high level. However, their technical efficiency followed an increasing trend since 1996 (Figure 4.5). This behaviour is not compatible with that observed in the contemporaneous analysis. This can be explained by considering that an intertemporal DEA forms a single technology frontier for the whole study period. Thus, in case of facing changes in technology, the intertemporal technical efficiency not only includes the actual technical efficiency level but also the technology effects. The case of BC sawmilling introduced in section 4.1 suggests that there has been substantial technological advancement in the sector; this might be the reason for the mismatch between the intertemporal measures and the contemporaneous ones. Yet, this issue was better explored by WA and Malmquist index in sections 4.4.2.3 and 4.4.2.4.

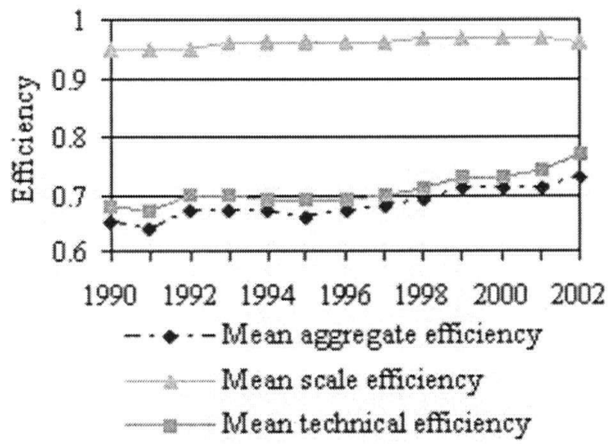

Figure 4.5 - Average efficiency of BC sawmills in intertemporal analyses.

The contribution of units in each year to the intertemporal frontiers is graphed in Figure 4.6. Sawmills from 2000 and 2002 largely constitute the frontier. This could be attributed to their opportunity to access more advanced technologies and not purely their more efficient performance (refer to sections 4.1).

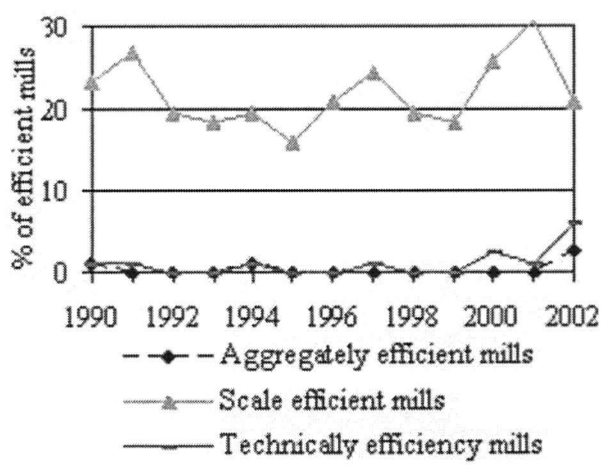

Figure 4.6 - Percentage of efficient mills in intertemporal analyses.

4.4.2.3 DEA Window Analyses

A WA was conducted in order to take the sector's technological changes into account when providing comparative efficiency measures between the years. The window size was chosen as 4 years. This was with respect to the production technology of primary wood manufacturing sector that could be assumed constant in such a length of time. The aggregate, technical and scale efficiencies, measured by iteratively running an output-oriented CCR model (2.8), BCC model (2.8, 2.9) and equation (2.10), are summarized in Table 4.4. The sector's average results within each window are presented in Appendix 3.

Table 4.4 - Mean annual efficiency scores in WA (*l* =4).

	No. of efficient sawmills			Average efficiency			Minimum efficiency		
Year	Technically	Scale	Overall	Technical	Scale	Overall	Technical	Scale	Overall
1990	4	13	1	0.78	0.94	0.73	0.58	0.45	0.45
1991	4	8	0	0.77	0.95	0.73	0.42	0.74	0.41
1992	4	2	0	0.81	0.95	0.76	0.50	0.67	0.47
1993	3	6	1	0.81	0.95	0.77	0.44	0.74	0.44
1994	2	3	2	0.81	0.95	0.77	0.48	0.65	0.47
1995	2	2	2	0.81	0.95	0.77	0.50	0.61	0.47
1996	3	1	1	0.81	0.95	0.77	0.47	0.57	0.44
1997	2	13	0	0.81	0.96	0.77	0.54	0.57	0.49
1998	1	13	0	0.81	0.96	0.78	0.54	0.62	0.50
1999	0	18	0	0.81	0.96	0.78	0.54	0.66	0.48
2000	4	26	2	0.79	0.97	0.77	0.52	0.71	0.50
2001	2	32	1	0.79	0.98	0.77	0.46	0.74	0.46
2002	7	23	2	0.78	0.97	0.75	0.43	0.72	0.43

The mean technical efficiency curves, moving with the windows, demonstrated a sharp decrease followed by a major increase in the 1990-92 period. The efficiency trends then were rather stable by 1996 when they started a constant progress overall (Figure 4.7). The mean aggregate efficiency curves also followed a similar pattern (Figure 4.8).

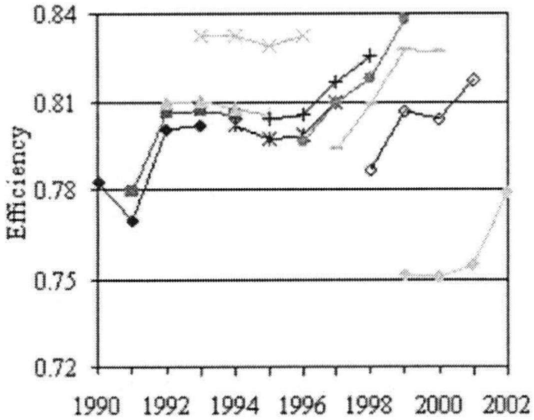

Figure 4.7 - Mean technical efficiency of BC sawmills across windows.

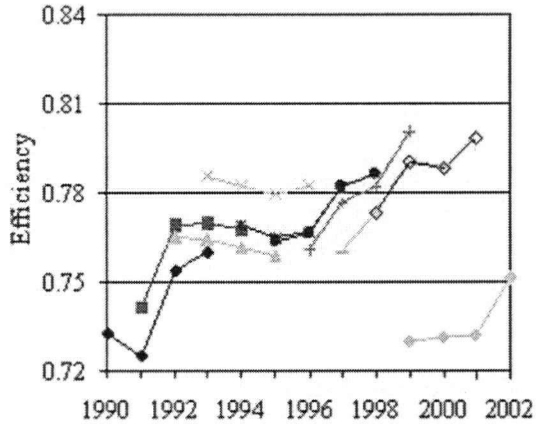

Figure 4.8 - Mean aggregate efficiency of BC sawmills across windows.

The WA results generally match those from the intertemporal analysis. However, the question of to what extent technology advancements played a role in the enhanced efficiency of the later years and to what extent it was due to actual performance improvements is not yet addressed. To do so, I looked at the Malmquist productivity indices of BC sawmills.

4.4.2.4 Malmquist Index

The Malmquist productivity index was calculated for the period of 1990 to 2002, with year 1990 as the base period (4.1). The composing elements of Malmquist index were also measured to separately identify the technology and efficiency changes (4.2, 4.3). These indices incorporated the contemporaneous aggregate efficiency scores (Table 4.5).

Table 4.5 - Malmquist TFP index.

Year	Malmquist index (M)	Efficiency change (EC)	Technology change (TC)
1990-91	0.991	1.006	0.984
1990-92	1.033	1.004	1.029
1990-93	1.032	1.048	0.991
1990-94	1.034	0.999	1.034
1990-95	1.017	0.985	1.031
1990-96	1.030	1.045	0.985
1990-97	1.045	0.988	1.055
1990-98	1.050	1.010	1.040
1990-99	1.083	1.012	1.070
1990-2000	1.108	0.994	1.113
1990-2001	1.102	1.090	1.012
1990-2002	1.112	1.003	1.111

The trend of productivity, efficiency and technology changes, all with a base of 1 in 1990, is presented in Figure 4.9. The productivity of BC sawmills improved over the whole period except in 1991 and 1995. These can be explained by the major technology decline in 1991 and the efficiency drop in 1995 displayed in Figure 4.9.

The efficiency change of BC sawmills appeared relatively stable about the same level as in 1990. However, a few sharp increases happened in 1993, 1996 and 2001. There were also noticeable decreases in 1995 and 1997. These implications agree with the earlier understanding from the contemporaneous efficiency analysis.

Technology rose and fell about an average level from 1990 to 1996. Consequently, it followed an upward direction, aside from 2001. This evidence clarifies that the technology advancement was the major reason for the growing pattern of efficiency in the intertemporal analysis and WA, not a progress in the own ability of mills.

Such behaviour in technology with significant ups and downs in subsequent years is rather unusual. However, it can be more understandable if one remembers that the term "technology" refers to not only the manufacturing technology and machinery, but also the policies, regulations, and business environment that affect the performance of a unit in one way or another. For instance, the challenges, strategies and policies related to sawmilling sector in Western Canada as well as manufacturing technology changes (refer to section 4.1) are all reflected in the technology measures obtained here.

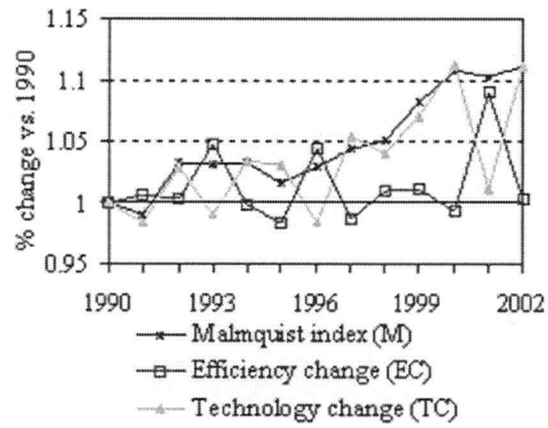

Figure 4.9 - Malmquist productivity index and its components.

Another interesting observation in this analysis was the simultaneous occurrence of significant efficiency improvement whereas technology weakening in 1993, 1996 and 2001. This confirms that a unit could enhance its technical performance even if accessing a relatively weaker technology.

4.4.2.5 Performance Analyses of Shut Down Sawmills

As discussed in section 4.1, one of the observations was that many sawmills in BC closed in the 1990-2002 period especially in the latest years. There were several reasons for this: (1) log shortage which made continuing the minimal production at large mills not worth the total cost (Mordant, 2003); (2) loosing the U.S market, which was due to heavy duties on the imported Canadian lumber, led many BC mills whose primary market was the U.S. to closure (Campbell, 2002); and (3) equipment investment that could provide multi-mill firms with huge increase in their production with less cost and hence rationalizing the closure of not modernized mills (CBC News British Columbia, 2003). However, no evidence was found to indicate whether these mills were actually performing inefficiently and being uncompetitive in the business. Therefore, it was decided to study the performance of the mills that had shut down to determine whether a clear pattern could be identified in their historical efficiency.

It was noted that six of the sawmills shut down in 2002– four in Vancouver, one in Prince George and one in Prince Rupert– have been in business since at least 1990. These mills were strong enough to remain in the competitive market for more than a decade. To determine if the closure of these mills could be attributed to an inadequacy in performance, their operating efficiency in the earlier years, i.e. 1990 to 2001, was compared to that of their competitors in the province. In doing so, these mills, referred to as mill 1 to 6, were added to the 82 sawmills in the previous analyses. Thus, 88 sawmills were included in a contemporaneous analysis for 1990-2001. The output-oriented CCR model (2.8), BCC model (2.8, 2.9) and equation (2.10) were used to obtain their relative aggregate, technical and scale efficiencies (Table 4.6).

Table 4.6 - Analyses of shut down sawmills.

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Mill 1	AE	0.61	0.94	0.71	0.72	0.76	0.75	0.80	0.74	0.74	0.73	0.73	0.74
	TE	0.72	0.94	0.78	0.75	0.77	0.79	0.80	0.75	0.74	0.74	0.74	0.77
	SE	0.84	1.00	0.91	0.96	0.98	0.95	1.00	1.00	1.00	1.00	0.99	0.97
Mill 2	AE	1.00	0.71	0.80	0.74	0.43	0.67	1.00	0.66	0.68	0.66	0.67	0.66
	TE	1.00	0.71	0.93	0.79	0.55	0.72	1.00	0.66	0.68	0.66	0.68	0.68
	SE	1.00	0.99	0.86	0.93	0.77	0.94	1.00	1.00	1.00	1.00	1.00	0.97
Mill 3	AE	0.85	0.86	0.87	0.82	0.70	0.70	0.82	0.78	0.82	0.83	0.81	0.90
	TE	0.89	0.90	0.88	0.88	0.72	0.73	0.84	0.79	0.86	0.85	0.81	0.90
	SE	0.96	0.96	0.99	0.94	0.97	0.96	0.99	0.99	0.95	0.97	1.00	1.00
Mill 4	AE	0.29	0.58	0.48	0.68	0.58	0.64	0.58	0.46	0.50	0.50	1.00	1.00
	TE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	SE	0.29	0.58	0.48	0.68	0.58	0.64	0.58	0.46	0.50	0.50	1.00	1.00
Mill 5	AE	0.80	0.77	0.57	0.63	0.66	0.75	0.69	0.60	0.61	0.61	0.58	1.00
	TE	0.83	0.84	0.57	0.65	0.67	0.75	0.69	0.61	0.61	0.61	0.59	1.00
	SE	0.97	0.92	0.99	0.97	0.99	1.00	0.99	0.99	0.99	0.99	1.00	1.00
Mill 6	AE	0.71	0.76	0.70	0.68	0.70	0.68	0.72	0.67	0.67	0.66	0.66	0.66
	TE	0.74	0.87	0.77	0.72	0.71	0.73	0.72	0.67	0.67	0.66	0.67	0.67
	SE	0.96	0.88	0.90	0.95	0.98	0.93	0.99	1.00	1.00	1.00	1.00	0.98
Average in BC sawmills	AE	0.76	0.81	0.80	0.83	0.80	0.78	0.82	0.78	0.80	0.80	0.79	0.87
	TE	0.80	0.84	0.84	0.86	0.83	0.84	0.84	0.80	0.83	0.82	0.80	0.88
	SE	0.95	0.96	0.95	0.97	0.96	0.93	0.98	0.98	0.96	0.98	0.99	0.99

Mills 1, 3, 5 and 6 operated with an aggregate efficiency equal to or lower than the BC average level in most years of the study period (Figure 4.10). The reason for this was observed to be their technical efficiency that was enveloped by the provincial average in the most years (Figure 4.11).

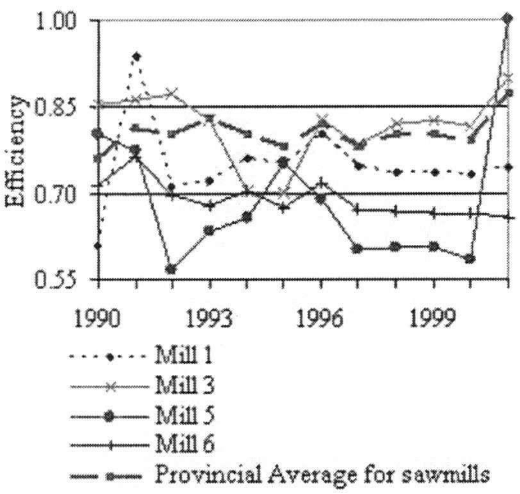

Figure 4.10 - Aggregate efficiency scores of shut down mills vs. provincial average.

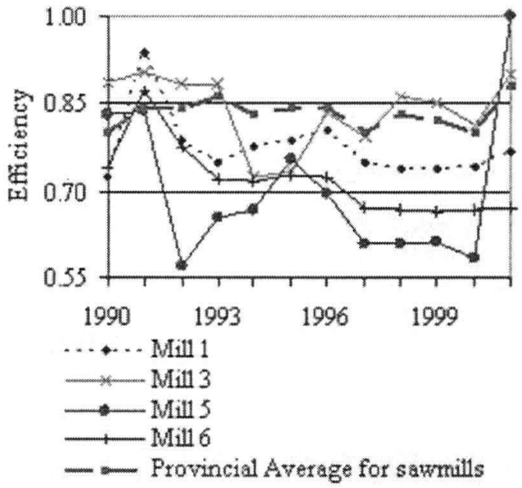

Figure 4.11 - Technical efficiency scores of shut down mills vs. provincial average.

Mill 2 and Mill 4 also displayed a lower than average aggregate efficiency in the province (Figure 4.12). However, their performance problem was with the scale of operation. They were more scale inefficient or just as inefficient as the provincial average since 1995 (Figure 4.13).

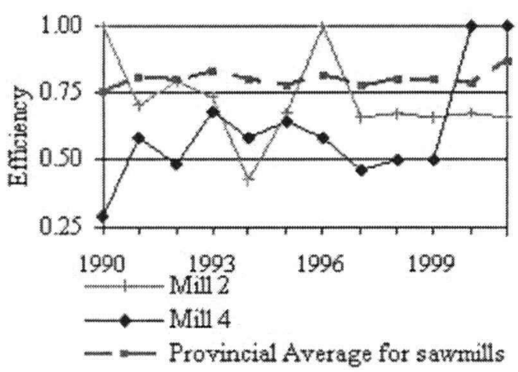

Figure 4.12 - Aggregate efficiency scores of shut down mills vs. provincial average.

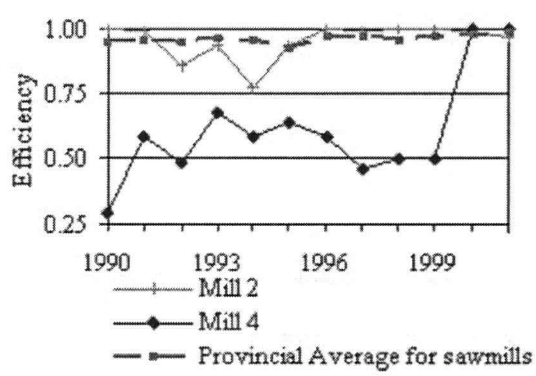

Figure 4.13 - Scale efficiency scores of shut down mills vs. provincial average.

The analyses of the 6 shut down mills revealed that all of them had operated poorly in the last years before their closure as compared to the average provincial competitors. This observation confirmed the decision to shut these mills down based on a performance criterion system.

4.4 Summary

DEA has been used in many efficiency trend studies of organizational units across manufacturing and service industries. In this study, DEA models were used to study the dynamic efficiency of BC sawmills. For this purpose, several analysis approaches were applied to a balanced panel performance data of BC sawmills during 1990-2002.

This research is unique in integrating all possible analysis approaches with DEA to provide a thorough analysis of an efficiency trend. The applied case has also significant importance because of the key role of primary wood manufacturing in Canada and BC's economy.

The contemporaneous efficiency measurements revealed that although BC sawmills enjoyed high scale efficiency, their aggregate efficiency remained lower due to deficiencies in technical performance. This verified that implementing policies to improve technical efficiency could greatly enhance the performance of the whole sector and the individual mills. This analysis also suggested a stable trend in the efficiency of sawmills.

The intertemporal analyses and WA presented an overview of the cross time comparative efficiency measures. WA differed from the intertemporal analysis in using moving frontiers over time to account for the technological differences of the units in the later years. Both of these analyses demonstrated that the BC sawmilling has had a stable trend in its aggregate efficiency followed by a period of efficiency increase since 1996.

Contemporaneous, intertemporal and window analyses could not reveal pure efficiency changes among the years. This made a case for measuring Malmquist index during time to better distinguish the efficiency changes from technology effects. The productivity index showed an increasing trend apart from the declines in 1991 and 1995. This was a combined measure of efficiency and technology, consistent with the results of intertemporal and window analyses.

The pure efficiency changes with some fluctuations were about the same average. This result validates what the contemporaneous analysis had implied. The meaning of this outcome is that policies such as learning, knowledge sharing, structural reforms, or alternative business approaches were not significantly used in the BC sawmilling in order to improve their abilities in performing better.

The index of technology has displayed an increasing trend since 1996. This explains the reason of increasing pattern of the efficiency measures which did not reflect only the efficiency changes but also the technology effects. These measures were the efficiency from intertemporal, window and productivity analyses.

This study did not investigate why efficiency decreased or increased in certain years. Different factors might have played a role in this respect, such as the general state of the economy in Canada, the Softwood Lumber Disputes with the U.S. and its consequences on the BC lumber market, etc. To examine such effects, further analyses is required.

The study of sawmills that were set close in 2002 confirmed the decision to shut them down based on their performance. These sawmills had performed less efficiently than the provincial average performers most of the times.

There are three outcomes of my analyses that can explain how the total production of the sector could stay stable (even increase by 1.8%) despite the significant reduction (about 22%) in the number of operating mills. These outcomes are: (1) the sawmilling technology advanced over 1990-2002; (2) the sector's efficiency improved slightly from 1990 to 2002; (3) sawmills that were closed down performed effectively under the provincial average in BC. Obviously, the mills, which stayed in the business, accessed enhancing technologies every year that provided them with the potential to increase production. They also increased their technical performance which enabled them to produce more using less resource. Besides, the mills which were closed were the most inefficient producers. In this manner, the two first factors created new capabilities for the mills such that they could maintain the total production, in spite of loosing some manufacturing capacity. Moreover, the lost capacity was not influential in the whole province due to their poor performance. Overall, technology advancement was the major cause in this scenario. The advancements can be tracked in such operation changes as automation, machinery productivity increase and applications of optimization manufacturing systems, which happened gradually in the 1990-2002 period as described in section 4.1.

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Chapter 5

Conclusion and Future Research

5.1 Conclusion

Canada operates one of the most extensive softwood forest industries in the world. Within the Canadian forest industry, the wood products sector is the second largest sector. The Canadian wood products sector has experienced several changes in recent years. These include increasing competition in the international market, changes in the macro practices of the industry at the provincial and national levels, restructuring of the industry towards value added wood products, and substantial advancement in production technology.

The changing business environment requires that the Canadian wood industry develop and implement flexible business policies to ensure an efficient and competitive performance in accordance with the business conditions. For this purpose, performance assessment of the industry is essential. Such studies help policy makers and managers to a) gain an insight into the competitiveness and effectiveness of the industry and individual companies, b) evaluate effects of alternative policies, and c) identify improvement opportunities.

To study the efficiency of organizational units in the Canadian wood industry, performance indicators such as two-factor ratios and different parametric methods have been used. Performance ratios provide partial efficiency measures of the underlying unit, whereas parametric methods present useful information regarding technical efficiency, economies of scale, factor substitution rates, etc. Nonetheless, parametric efficiency studies are inadequate for incorporating multiple performance factors of organizations; they can only incorporate multiple inputs and one output, or one input and multiple outputs. These methods are also limited by behavioural assumptions on units under study. Such limitations can be relaxed by employing the Data Envelopment Analysis method; yet, this method has received little attention in efficiency studies on the Canadian wood industry.

The Data Envelopment Analysis method is a recent method in efficiency assessment studies that can remove the limitations of parametric methods. DEA is the only method that takes a non-parametric approach to efficiency measurement, and hence able to accommodate multiple inputs and outputs in analyses. It does not impose any behavioural nor functional assumptions on the units under study. In addition, DEA has other advantages over previous efficiency measurement methods, such as proposing target efficient units for inefficient ones, and establishing a benchmark for the set of units under study. These attributes have promoted the application of DEA in many industrial and service sectors.

In this context, this research was designed to explore the application of DEA in efficiency assessment of the primary wood manufacturing sector in BC, Canada. The study had two objectives:

(1) To evaluate the efficiency of the BC primary wood sector in 2002, identify the inefficiency reasons, and analyze the effect of some external factors on efficiency.

(2) To examine the trend of the efficiency of the BC primary wood sector during the period of 1990 to 2002, measure the productivity of the sector and distinguish its determinant factors.

The first part of the research with a focus on the former objective evaluated the efficiency of sawmills in British Columbia in 2002. For this purpose, the DEA method was chosen; BCC and CCR models were employed to capture technical, aggregate and scale efficiencies. The DEA method helped to accommodate different production factors of sawmills individually, without presuming any optimizing behaviour. Such an assumption would be required by a parametric method if it were chosen. In addition, mill-level data were incorporated in the analyses as it provided a detailed view of the sawmilling performance in BC.

Only 7% of the BC mills were aggregately efficient implying that they were technically competitive and made the best use of scale economies. Such a low percentage of efficient mills is not a positive point, since it indicates that 93% of the sawmills in BC did not fully utilize the technology and their capabilities or did not benefit from scale efficiency.

A deeper look at the components of aggregate efficiency revealed that 13% of the BC sawmills were technically efficient. This demonstrated that these 11 mills took advantage of the available technologies to the best level. On the other hand, 26% of the mills showed high scale efficiency implying their superior use of economies of scale. The average scale efficiency was rather high at 0.97 whereas the average technical efficiency was lower at 0.83. The technical efficiency measures also exhibited a large variation. The analysis identified possible improvements for the inefficient mills by increasing production and labour productivity by an average of 27%.

These results are merely based on analyses of production factors. They do not involve any cost or price dimension and thus do not necessarily have implications with respect to profitability or cost efficiency.

To analyze the efficiency score of each mill with respect to its forest region and number of annual operating days, further statistical analyses were performed. Two non-parametric tests, Median Quartile and Kruskal-Wallis tests, were employed. It was observed that the efficiency of sawmills in different forest regions was significantly different. The central and northern interior sawmills were highly efficient. The southern interior mills retained a mediocre efficiency, while the coast sawmills had the lowest efficiency level. However, no significant effect of the number of operating days was observed on the sawmilling efficiency.

This analysis was based on efficiency measures that took into account only log and labour consumption, lumber and chip production. Should other factors be considered in the analysis, such as log species and sizes, lumber types and values, and differences in equipment and manufacturing process among forest regions, the efficiency measures and consequently the rank for forest regions might change.

The second part of the research addressed the latter objective and focused on evaluating the efficiency of BC sawmills over the period of 1990-2002. For this purpose, alternative methods based on Data Envelopment Analysis were used. This helped to capture the dynamics of their efficiency trend from a number of perspectives. Contemporaneous analysis helped to measure annual efficiencies. Intertemporal analysis observed the efficiency trend of BC sawmills over time. Window Analysis provided a more reliable picture of efficiency changes having considered technology changes. Finally, the Malmquist index separately measured the two factors that affect the sawmills' performance, i.e. efficiency changes and technology changes. The Malmquist index analysis also provided the combined effect of these factors on the sector, which is the productivity of BC sawmills.

The results of the contemporaneous and intertemporal analyses were consistent with the previous observations for year 2002, in that BC sawmills were highly scale efficient in most of the years and their major inefficiency cause was technical ability rather than scale of operations. This has implications for both managers at individual companies and for policy makers at higher levels. Managers at individual companies should recognize that there might be significant improvements to be gained using existing technologies. To identify such opportunities for each sawmill, the suggestions of this research regarding improvement directions for the individual mill can be well used. Further analyses may be carried out to develop implementation strategies for proposed improvement directions. On the other hand, policy makers at higher levels may use these results to identify successful patterns of performance in different dimensions, promote better use of current technologies, and determine which technology should be given priority to be developed.

The analyses based on Window Analysis and Malmquist productivity index demonstrated that the technical efficiency of the sawmills was generally stable during 1990-2002. However, a substantial technological advancement occurred in the industry during the same period. Given that these two factors constitute the productivity of the industry, they led to a small decline in the sector's productivity in 1991, compared to that in 1990, which was then followed by an increasing trend in the subsequent years. Nonetheless, the productivity growth was largely due to the technological advancement but not to an enhancement in abilities of BC sawmills in using technology.

This study did not investigate reasons for efficiency changes over time. There could be several reasons for such variations, including the general state of the economy in Canada and its resulting effects on the BC sawmilling sector, and the Softwood Lumber Disputes with the

U.S. and their consequences on the BC lumber market. Further study is required to examine such effects and those of other possible factors that could affect efficiency.

The use and potential benefits of DEA and its extended analyses for the Canadian wood industry warrant further study. This is concluded from the importance of assessing the performance of the Canadian wood industry, and significant developments that DEA has stimulated in the field of efficiency assessment in general. Given that DEA has proved successful in efficiency analyses and planning for many other industries, it may also be used in the Canadian wood industry for benchmarking companies, developing improvement strategies, and assessing the effect of prospective policies on efficiency. Such analyses could be very helpful for individual companies, and for the higher levels of decision-making units, such as the federal, provincial or local managerial or supervisory bodies.

5.2 Future Research

This study can be extended in several ways. For example, this study could take into account data, if available, on other conventional performance factors. Therefore, future work can be built on this research by incorporating performance factors such as capital, materials and supplies, fuel and energy consumption, log size distribution, lumber product mix/value, etc.

Other factors might also affect the efficiency of an organization, and thus may be incorporated in efficiency analyses to provide a more comprehensive measure of performance. These factors could be undesirable production factors, environmental factors, raw material supply methods, or final product markets. To carry out such analyses, it is first necessary to develop appropriate methodologies and models that could integrate the desired factors, and then to perform empirical studies.

In addition, other types of efficiency analyses such as allocative, cost and profit efficiency analyses can be performed by including cost and price data into models.

Regarding dynamic DEA analysis, future research may follow up on the choice of a window size, its effects on analyses and defining an optimum for that matter. It would also be interesting to look at the efficiency trend of the BC sawmilling sector or others in a qualitative manner. For instance, it may be examined how efficiency has behaved before and after the expiration of the Softwood Lumber Agreement in 2001. This was not possible in this study since not enough time has passed following the agreement expiration for such an examination to be feasible.

Reasons for efficiency changes over time can also be investigated. For example, it may be studied whether the general state of economy in BC (or Canada) has had an effect on sawmilling efficiency and if yes, by what means.

Furthermore, accounting for environmentally undesirable outputs of the sawmilling production and studying how the industry has traditionally dealt with these factors can provide an insight into the environmental efficiency of the sector. Such studies may lead to suggesting a practical framework for examining historically sustainable practices and appropriate policies to develop such operations.

Appendices

Appendix 1. Detailed efficiency scores of BC sawmills

Table A.1 - Detailed efficiency scores of BC sawmills

DMU#[a]	Aggregate efficiency	Technical efficiency	Scale efficiency	DMU#[a]	Aggregate efficiency	Technical efficiency	Scale efficiency
1	0.81	0.81	1.00	27	0.84	0.93	0.90
2	0.83	0.86	0.97	28	0.76	0.77	0.99
3	0.86	0.87	0.99	29	0.88	0.91	0.97
4	0.95	0.98	0.97	30	0.81	0.81	1.00
5	0.69	0.73	0.95	31	0.70	0.71	0.99
6	0.90	0.93	0.97	32	1.00	1.00	1.00
7	0.75	0.77	0.97	33	0.86	1.00	0.86
8	0.84	0.85	0.99	34	0.73	0.73	1.00
9	0.98	0.99	0.99	35	1.00	1.00	1.00
10	0.85	0.86	0.99	36	0.92	0.92	0.99
11	0.88	0.94	0.94	37	1.00	1.00	1.00
12	0.71	0.74	0.96	38	0.87	0.90	0.97
13	0.91	0.96	0.95	39	0.89	0.91	0.98
14	0.88	1.00	0.88	40	0.86	0.86	0.99
15	0.54	0.54	0.98	41	0.80	0.81	0.99
16	0.82	0.82	1.00	42	0.61	0.61	1.00
17	0.81	0.88	0.92	43	0.74	0.77	0.97
18	0.89	0.89	1.00	44	0.84	0.91	0.93
19	0.73	0.79	0.92	45	0.81	0.81	1.00
20	0.67	0.68	0.99	46	0.74	0.75	0.99
21	1.00	1.00	1.00	47	0.60	0.63	0.95
22	0.75	0.76	0.99	48	0.72	0.74	0.98
23	0.89	0.97	0.91	49	0.76	0.81	0.95
24	0.88	1.00	0.88	50	0.87	0.87	0.99

DMU#[a]	Aggregate efficiency	Technical efficiency	Scale efficiency	DMU#[a]	Aggregate efficiency	Technical efficiency	Scale efficiency
25	0.78	0.82	0.94	51	0.83	0.83	1.00
26	0.87	0.87	1.00	52	0.85	0.85	1.00
53	0.68	0.68	0.99	68	0.85	0.89	0.96
54	0.71	0.74	0.97	69	0.75	0.76	0.98
55	0.81	0.81	1.00	70	0.73	0.81	0.89
56	0.45	0.51	0.89	71	0.80	0.80	0.99
57	0.94	0.99	0.95	72	0.96	1.00	0.96
58	0.83	0.87	0.95	73	0.57	0.60	0.95
59	0.71	0.72	0.98	74	0.65	0.72	0.90
60	0.83	0.85	0.98	75	0.84	0.84	1.00
61	0.67	0.68	1.00	76	0.83	0.89	0.93
62	0.67	0.69	0.96	77	0.65	0.66	0.99
63	0.91	1.00	0.91	78	0.76	0.79	0.97
64	0.85	0.85	1.00	79	0.93	0.93	1.00
65	0.54	0.54	0.99	80	0.82	0.83	0.98
66	0.83	0.84	0.98	81	1.00	1.00	1.00
67	1.00	1.00	1.00	82	0.60	0.60	0.99
				Mean	0.80	0.83	0.97
				SD	0.11	0.12	0.35
				Min	0.45	0.51	0.86

[a] For confidentiality purpose, each sawmill is represented by a DMU#.

Appendix 2. Detailed results of BCC model on technical efficiency improvement for BC sawmills

Table A.2 - Detailed results of BCC model on technical efficiency improvement for BC sawmills

DMU#[a]	% Increase in outputs	% Decrease in labour	Reference set	DMU#[a]	% Increase in outputs	% Decrease in labour	Reference set
1	23.14	0	32 33 35 81	25	21.53	31.44	33 35 81
2	16.93	3.32	35 72 81	26	14.85	0	32 33 35 81
3	15.58	0	32 35 72 81	27	8.1	67.32	33 35 81
4	2.17	0	21 35 63 67	28	30.14	0	21 33 35 67
5	37.86	58.82	33 35 81	29	9.62	0	32 35 63 67
6	7.8	0	32 35 63 67	30	23.59	0	32 33 35 81
7	29.5	65	33 35 81	31	41.38	37.71	35 72 81
8	18.12	1.78	35 72 81	32	0	0	32
9	1	0	32 33 35 67	33	0	0	33
10	16.37	0	32 35 72 81	34	36.31	0	32 33 35 81
11	6.63	12.2	35 72 81	35	0	0	35
12	34.29	65.8	33 35 81	36	8.5	0	32 35 63 67
13	4.07	0	32 35 63 67	37	0	0	37
14	0	0	14	38	11.25	0	32 35 63 67
15	83.72	8.98	33 35 81	39	9.46	0	21 35 63 67
16	22.58	0	32 33 35 81	40	15.91	0	32 33 35 81
17	13.28	19.48	35 72 81	41	24.14	13	33 35 81
18	11.84	0	32 35 72 81	42	64.3	0	32 33 35 81
19	25.87	83.5	33 35 81	43	30.54	11.7	35 72 81
20	46.64	51.93	33 35 81	44	10.02	19.51	35 72 81
21	0	0	21	45	23.22	0	32 33 35 81
22	32.37	35.38	33 35 81	46	33.53	0	21 33 35 81

DMU#[a]	% Increase in outputs	% Decrease in labour	Reference set	DMU#[a]	% Increase in outputs	% Decrease in labour	Reference set
23	2.76	14.29	35 63 72	47	58.71	7.55	33 35 81
24	0	0	24	48	35.2	3.94	33 35 81
49	23.95	23.69	35 72 81	66	18.35	26.46	33 35 81
50	14.33	0	32 35 72 81	67	0	0	67
51	20.88	0	32 33 35 81	68	12.96	6.58	35 72 81
52	17.19	0	32 33 35 81	69	32.05	0	32 33 35 81
53	46.01	65.33	33 35 81	70	22.84	48.7	35 72 81
54	36.05	0.65	35 72 81	71	24.65	0	32 35 72 81
55	22.81	0	32 33 35 81	72	0	0	72
56	95.27	41.12	35 72 81	73	65.92	35.06	33 35 81
57	01.34	0	21 35 63 67	74	39.29	25.23	35 72 81
58	14.54	7.77	24 32 81	75	18.48	0	32 35 72 81
59	38.05	0	32 35 72 81	76	12.75	15.03	35 72 81
60	18.11	3.24	35 72 81	77	52.04	29.5	33 35 81
61	47.98	0	32 33 35 81	78	26.87	22.39	35 72 81
62	44.27	30.48	33 35 81	79	7.13	0	32 33 35 67
63	0	0	63	80	20.04	0	32 35 72 81
64	18.09	0	32 33 35 81	81	0	0	81
65	84.27	33.1	33 35 81	82	66.59	0	32 33 35 81
				Mean	27.13[b]	28.53[c]	-----
				SD	20.11[b]	22.27[c]	-----
				Max	95.27	83.5	-----

[a] For confidentiality purpose, each sawmill is represented by a DMU#.

[b] These statistics are the mean and SD of the percentage of output increase for inefficient units. The overall mean and SD, including efficient and inefficient units, would be 23.49 and 20.88 respectively.

[c] These statistics are the mean and SD of the percentage of labour decrease for those who actually were entailed to such saving. The overall mean and SD, including all the units, would be 12.52 and 20.43 respectively.

Appendix 3. Detailed results of WA

Table A.3 - Mean technical efficiency across windows (l =4).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
Technical efficiency of BC sawmills	0.78	0.77	0.80	0.80										0.79
		0.78	0.81	0.81	0.81									0.80
			0.81	0.81	0.81	0.81								0.81
				0.83	0.83	0.83	0.83							0.83
					0.80	0.80	0.80	0.81						0.80
						0.80	0.81	0.82	0.83					0.81
							0.80	0.81	0.82	0.84				0.82
								0.79	0.81	0.83	0.83			0.81
									0.79	0.81	0.80	0.82		0.80
										0.75	0.75	0.75	0.78	0.76
Mean	0.78	0.77	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.79	0.79	0.78	0.80

Table A.4 - Mean aggregate efficiency across windows (l =4).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
Aggregate efficiency of BC sawmills	0.73	0.73	0.75	0.76										0.74
		0.74	0.77	0.77	0.77									0.76
			0.76	0.76	0.76	0.76								0.76
				0.79	0.78	0.78	0.78							0.78
					0.77	0.77	0.77	0.78						0.77
						0.76	0.77	0.78	0.79					0.77
							0.76	0.78	0.78	0.80				0.78
								0.76	0.77	0.79	0.79			0.78
									0.77	0.79	0.79	0.80		0.79
										0.73	0.73	0.73	0.75	0.74
Mean	0.73	0.73	0.76	0.77	0.77	0.77	0.77	0.77	0.78	0.78	0.77	0.77	0.75	0.77