EFFICIENCY AND PRODUCTIVITY MEASUREMENT
OF THE CANADIAN MANUFACTURING SECTOR:
1994-2002

by

SABA VAHID

B.Sc., Sharif University of Technology, 2002

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Abstract

Performance assessment has been gaining increasing attention in different sectors, including the manufacturing industries. The need for assessing the performance of firms has increased as a result of growing competition and globalization. Information technology advances along with changes in political and economic conditions have promoted industrial globalization. While a global marketplace means more customers, at the same time, companies face intense competition when they produce and sell their products globally. Companies need to learn about foreign societies and understand foreign customers; they also need to have long term plans on how to remain competitive. Evaluating and monitoring the performance and increasing productivity and efficiency are important issues for competitive companies and their investors.

The Canadian manufacturing industries, which are important building blocks of our economy, face similar challenges since they are mainly export oriented. New countries, such as China or other South East Asian countries are currently exporting their manufactured products globally. These emerging exporters have greatly increased their market share in recent years, mainly because they have access to cheap resources and can
offer their products with lower prices compared to other industrialized countries. This has created a major challenge for Canadian manufacturers.

In Canada, forest industries contribute greatly to the economy by contributing to the country’s trade surplus and by creating jobs in rural areas. Wood products manufacturing is the second largest forest sector in Canada and is also classified under the manufacturing sector. The same issues faced by other manufacturing industries apply to wood industry as well. Considering the importance of manufacturing sector and the wood industry in particular, it would be useful to study their performance over time.

Therefore, the intent of this research was to evaluate the performance of the manufacturing sector in Canada and in the United States, Canada’s major trading partner. Productivity growth of the industries was studied separately for each country, using a non-parametric productivity measure, Malmquist Productivity Index. The results showed that both countries had an overall growth in Total Factor Productivity (TFP) during the study period. However, their growth was mainly due to the technological progress (frontier shift) rather than the efficiency improvements. In both countries, TFP of the wood products manufacturing was below the average for the sector and technical efficiency decreased over the study period.

In order to obtain a complete understanding of the wood products manufacturing sector’s performance, the efficiency changes of its sub-sectors were studied. These sub-sectors were sawmilling and wood preservation, veneer, plywood, and engineered wood products, and other wood products manufacturing. Data Envelopment Analysis, a non-parametric efficiency measurement method, was utilized for the analysis. Sawmilling and wood preservation showed the highest efficiency, on average, during the study period, while other wood products manufacturing was identified with the lowest efficiency.

The results of the study suggest that wood products manufacturing needs to direct its strategies mainly towards improving the technical efficiency of the whole industry as well as its sub-sectors. This includes better managerial knowledge, labour training, and investment in machinery and equipment among other things. The wood industry can follow examples of the best practices in the manufacturing sector and identify improvement possibilities for its performance.
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Glossary

Aggregate efficiency

The overall ability of the unit in transforming the inputs to outputs and includes both technical and scale efficiencies. It is calculated as the ratio of observed output to maximum output (minimum input to observed input), when the production frontier is constructed using the constant returns-to-scale technology.

BCC model

A DEA model that constructs the frontier based on the variable returns-to-scale assumption. Each unit is compared only with those within the same operating scale. Therefore, BCC efficiency scores take the scale variations into account and result in pure "technical" efficiency.
<table>
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<tr>
<td>Catch-up effect</td>
<td>If a unit improves its efficiency from one period to another, its distance to the frontier decreases; i.e. it catches up with the efficient units in the sample. This means that the unit is producing more output (using less input) for a given level of input (output); therefore, its productivity increases. Following the same logic, an efficiency decline can result in a lower productivity.</td>
</tr>
<tr>
<td>CCR model</td>
<td>A DEA model that calculates the efficiency scores based on a constant returns-to-scale frontier. CCR efficiency score do not account for differences in scale of operations among units in the sample; therefore, they are considered as &quot;aggregate&quot; efficiency scores.</td>
</tr>
<tr>
<td>Constant returns-to-scale (CRS)</td>
<td>Constant returns-to-scale exists when a proportional increase in the inputs results in the same proportional increase in the outputs.</td>
</tr>
<tr>
<td>Cost efficiency</td>
<td>The ability of a unit to produce a certain level of output with minimum cost. It is constructed as the ratio of minimum cost to the observed cost.</td>
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<tr>
<td>Cost function</td>
<td>Represents the minimum cost of producing a certain amount of output, given the input prices.</td>
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<td>Data Envelopment Analysis (DEA)</td>
<td>A non-parametric efficiency measurement method. It constructs a frontier using linear programming techniques and the best units in the sample and calculates the efficiency of all other units relative to this frontier. It also identifies efficient targets for inefficient units. DEA frontier can be constructed using constant returns-to-scale (CCR model) or variable returns-to-scale (BCC model) assumption.</td>
</tr>
<tr>
<td><strong>Economic efficiency</strong></td>
<td>See cost efficiency.</td>
</tr>
<tr>
<td>-------------------------</td>
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</tr>
<tr>
<td>Efficiency of an operating unit</td>
<td>A measure of how well a unit is performing relative to the best possible performance. It is calculated as the ratio of the observed output (minimum possible input) to maximum possible output (observed input). The maximum output (minimum input) is determined by the production frontier.</td>
</tr>
<tr>
<td>Efficient unit</td>
<td>A unit that is operating on the efficient frontier; it is performing at the best possible level (maximum output/minimum input/minimum cost).</td>
</tr>
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<td>Frontier shift</td>
<td>When all the units in the sample are performing better compared to previous time periods, the efficient frontier shifts upwards (in output-oriented case) and the productivity (ratio of output to input) increases. Downward frontier shift is also possible when the performance of all units becomes worse, for example because of economic downturns or changing regulations.</td>
</tr>
<tr>
<td>Malmquist Productivity Index (MPI)</td>
<td>A productivity index used for measuring Total Factor Productivity. It can be calculated using distance functions and can be decomposed into catch-up and frontier shift effect.</td>
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<td>Managerial efficiency</td>
<td>See technical efficiency.</td>
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<tr>
<td>Non-parametric frontier</td>
<td>A frontier that is constructed without requiring the functional relationship between inputs and outputs. Units can perform either on or below the frontier; any variation from the frontier is considered as inefficiency and statistical noise is not accounted for.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Parametric frontier</td>
<td>A frontier that is estimated using statistical estimation techniques. In order to estimate a parametric frontier, first a functional form (e.g. Translog) is selected and then the parameters of the function are estimated using the data on inputs and outputs (or prices). All the units are assumed to be operating on the frontier (except for stochastic frontiers) and any variations are attributed to the noise in the data.</td>
</tr>
<tr>
<td>Production frontier (function)</td>
<td>Represents the maximum output possible from a given set of inputs or, alternatively, the minimum inputs required to produce a given level of output.</td>
</tr>
<tr>
<td>Productivity</td>
<td>The ratio of output to input. Productivity change over time happens when the output change is different from the input change between two periods. Productivity change can be attributed to two main reasons: changes in the efficiency of the unit (catch-up effect) or the change in the state of the technology (frontier shift).</td>
</tr>
<tr>
<td>Returns-to-scale (RTS)</td>
<td>One of the characteristics of a production technology that shows how a proportional increase in the inputs, increases the outputs. It can be variable or constant.</td>
</tr>
<tr>
<td>Scale efficiency</td>
<td>Calculates the ratio of the aggregate efficiency to technical efficiency for a unit. It shows how much of the aggregate inefficiency is due to scale disadvantages.</td>
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<td>Technical change</td>
<td>See frontier shift.</td>
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Technical efficiency  

The ability of a unit to produce the maximum possible outputs from a given set of inputs (output oriented technical efficiency) or to produce a given level of outputs with the minimum possible inputs (input oriented technical efficiency). It is calculated as the ratio of observed output to maximum output (minimum input to observed input), when the production frontier is constructed using the variable returns-to-scale technology. This measure does not include the cost of production and a unit may be technically efficient but not be operating at minimum cost.

Technical efficiency change

See catch-up effect.

Total Factor Productivity

A productivity measure that incorporates multiple factors of production (e.g. labour, material, energy, ...).

Variable returns-to-scale (VRS)

Variable returns-to-scale exists when a proportional increase in the inputs results in other than proportional increase in the outputs. If the output increase is more (less) than the proportional increase in inputs, increasing (decreasing) returns-to-scale exists.

Weight restriction

An extension to the basic DEA model in order to incorporate managerial knowledge and preferences in the analysis. It controls the input (output) weights by imposing bounds on them in the model.
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I would have not been able to go through the past two years of my life, if it was not for the support of my especially dear friends, Shora, Nazly and Patrick. They provided me with their endless care and companionship that helped me adjust to my new life and grow in many aspects. Shora, with her kindness and helping hand in each and every moment of my life; Nazly, with a deep understanding and warmth, beyond my imagination; and Patrick, with his pure friendship and constant support. I am deeply grateful for all that you gave me.
To my parents, Sima and Abolghasem;
for making this possible with their endless love and support.
Thank you for believing in me.
Chapter 1

Introduction

1.1. Background on the manufacturing sector and the wood industry

Manufacturing is no longer seen as the mere transformation of raw materials into finished goods. Alternatively, it is viewed as a system that includes all the activities needed for delivering a product that meets customers' demands. These activities range from research and development to design and engineering, production, sales, and marketing. This integrated system goes beyond a single company and extends to business networks and supply chains that are becoming increasingly global. However, the manufacturing process is still the core of this integrated system.

Manufacturing industries are extremely important to the economic welfare of nations across the world. Production of goods directly contributes to the Gross Domestic Product (GDP) of a country and consequently affects the GDP per capita for that country - a common measure of the standard of living. Generating more than 17% of the total
national GDP, the manufacturing sector in Canada is undoubtedly a fundamental part of the economy. Canadian manufacturing production has grown by more than 50% between 1990 and 2004 (Canadian Manufacturers and Exporters [CME], 2004b). This output in growth has been accompanied by growth in employment and the number of establishments as well (Industry Canada, 2005).

In recent years, however, many export-oriented companies have emerged in China, Southeast Asia, South Korea, Mexico and South America. These countries are able to offer products at a much lower price compared to Canadian producers and have gained more global market share. The ability of these countries to produce cheaper products is mainly the result of their lower labour and material costs. China, for example, has, on average, labour costs of 1/40th of those in Canada (CME, 2004a). The U.S., the main target market for the Canadian manufacturers, has been importing more and more products from these emerging economies and this has intensified the competition for Canada. Figure 1-1 shows the changes in Canada and China’s share of total US imports. China’s share has been increasing strongly over the past 15 years, while Canada’s share, although still significant, has decreased over the same period.

![Figure 1-1. Canada and China’s Share of the total imports by U.S.; U.S. Census Bureau (2005)](image)

The appreciation of the Canadian dollar in recent years, compared to the U.S. dollar, has also been an issue for manufacturers. The Canadian dollar has appreciated sharply relative to the U.S. dollar since the beginning of 2003. Since more than 50% of
the manufactured products in Canada are exported (Industry Canada, 2005; Trade Data Online, 2005) and most of them are shipped to the U.S., Canadian producers experienced a rapid decline in their profit margins (CME, 2004a).

While the situation is already complicated, rising energy prices adds to the existing challenges. Manufacturing activities are energy consuming and a reliable low-cost supply of energy cannot be taken for granted anymore. Increasing demand for energy, especially oil, in North America has not been accompanied by enough of an increase in oil production. This has caused a jump in oil prices and, consequently, electricity prices in Canada and the U.S. (CME, 2004a). Energy is not the only production factor that has seen a price increase; costs of different production inputs have increased faster than the selling price of products in recent years, as shown in Figure 1-2.

Access to skilled labour has also been identified as a major factor that affects manufacturers in Canada. According to a survey of manufacturers and exporters in 2003, over 40% of the participants named this factor as a serious constraint for their performance improvements (CME, 2004a). Manufacturing industries need skilled workers to perform and monitor tasks, as well as bring in new and innovative ideas for improvements.

![Figure 1-2. Average price and cost increase for Canadian manufacturers, 1997-2003; CME (2004a)](image)

It is obvious that, as the manufacturing sector becomes more global, new challenges appear on the horizon. Increasing international competition, appreciation of
the Canadian dollar, energy prices, and the availability of skilled labour are only some of the existing challenges for Canadian manufacturers (Au, 2004; CME, 2004a). Canadian producers need to face these challenges to remain competitive in today’s global business environment. One way to see how effectively they are changing their operations is by benchmarking. Benchmarking compares the performance of an organization to the “best practice” organization that conducts similar activities. It helps in identifying the position of the organization under observation relative to others.

Like Canada, the manufacturing sector in the U.S. also plays an important role in the economy by contributing to the GDP and creating vast employment. In recent years, the U.S. manufacturing sector has been identified as one with the highest competitiveness ranking among G7 countries (CME, 2004a). However, the American manufacturers have been facing challenges of their own; competition from foreign producers has affected the demand for their domestic products and the economic recession of 2001 hit the manufacturing sector very hard. More than 1 million jobs were lost during the recession and output decreased significantly (US Census Bureau, 2003). Since the U.S. is Canada’s major trading partner, any fluctuations in its economic environment would also affect Canadian producers. Therefore, studying the changes in the performance of the U.S. manufacturing sector would be useful to better understand the changes in the Canadian manufacturing sector and also to benchmark this information against its leading competitor. Benchmarking of the manufacturing sector can be done in various ways; different industries within the manufacturing sector may be compared together, the whole sector may be studied across countries, or it can be compared with other sectors (services, utilities, transportation, etc.) in one country. In this research, the performance of different manufacturing industries was compared in Canada and the U.S.

Wood products manufacturing in Canada – one of the industries in the manufacturing sector – is an important component of the Canadian forest industries. This industry is involved in manufacturing activities for processing the harvested wood and producing different products, ranging from dimensional lumber to wood panels and millwork (Statistics Canada, 2003).
Wood products manufacturing relies heavily on exports, shipping more than half of its production abroad (Industry Canada, 2005; Trade Data Online, 2005). Nonetheless, similar to the manufacturing sector as a whole, increasing international competition has been an issue for producers in this industry. Figure 1-3 shows the global exports share of Canada, China and Indonesia in 1961 and 2003. The growth in Canada’s share has been approximately 0.25% per year\(^1\) on average, while this growth for China and Indonesia has been 9.4% and 597% per year, respectively. Indonesia has increased its share of global export from close to 0% in 1961 to more than 5% in 2003. Although Canada is still the largest global exporter of wood products, the competition from other countries cannot be ignored.

In addition, several trade barriers (e.g. the softwood lumber agreement in the U.S. and the green softwood lumber ban in Europe) have also made it harder for the Canadian wood products to enter the U.S. and some European countries (Eastin and Fukuda, 2001; Nagubadi and Zhang, 2004). Since most of the trade barriers have been imposed on commodity products such as lumber, the sub-sectors of wood industry have been changing accordingly; the sawmills and wood preservation sub-sector has had a decline in its share of exports, while wood panels and other wood products have been gaining more share of the total exports of the industry (Trade Data Online, 2005). Another reason

\(^1\) Growth for the whole period was calculated as the difference of shares in 1961 and 2003 divided by the share in 1961. Growth per year was calculated through dividing the overall growth by the number of years.
for these changes has been declining commodity prices that have encouraged wood producers to focus more on value added products. The wood industry has also been experiencing a transformation in order to face changing demands and evolving business environment. To determine how successful wood industry has been in achieving this goal, performance analysis can be very helpful. It is increasingly being applied in different sectors and industries and can be used for comparing operating units such as companies, organizations, or industries.

Comparing the wood industry with other manufacturing industries in Canada is useful because it makes it easier to see if this industry has improved its performance compared to other industries. It would be interesting to assess the performance of wood industry in the U.S. as well. Additionally, the sub-sectors of the wood industry in Canada were also further analyzed in order to generate additional insight on the subject.

1.2. Research objectives

Different measures can be used for performance assessment. Efficiency and productivity are common measures for comparisons of operating units such as companies or industries. Productivity is a measure of output per unit of input, while efficiency is a measure of how well a unit is performing compared to the best possible performance. Considering the importance of the manufacturing sector and the wood industry in Canada, this research had the following objectives:

1. Measure the Total Factor Productivity (TFP) changes of the manufacturing industries in Canada and the U.S.

2. Measure the efficiency changes of the wood products manufacturing sub-sectors in Canada.

In order to measure the TFP change of the manufacturing industries, an index was used: Malmquist Productivity Index (MPI). This index was selected because it was not based on price data and the resulting productivity changes could be decomposed into two main components: frontier shift and efficiency improvement. The relative position of the wood industry in Canada and the U.S. was determined based on the TFP change results.
Data Envelopment Analysis (DEA) was selected for measuring the relative efficiency of wood industry sub-sectors. It was selected because it is more flexible compared to the parametric techniques and because it did not need the assumption of a functional relationship between inputs and outputs of the production. DEA was also used for estimating the distance functions in the Malmquist analysis.

The DEA efficiency results for wood products manufacturing sub-sectors were compared to the existing partial measures used by Statistics Canada, using a non-parametric statistical test, Spearman's rank coefficient. This statistical test did not assume a specific distribution for the observations under study.

1.3. Thesis organization

The rest of this thesis is organized as follows:

Chapter 2 includes the review of the literature on performance measurement. It starts with a background on efficiency and productivity concepts. Data Envelopment Analysis methodology is explained later and then a summary of productivity and efficiency studies in different sectors is presented. Specifically, studies on the forest industries are mentioned in this chapter. Chapter 3 includes the productivity measurement of the manufacturing sectors in Canada and the U.S. and the Malmquist Productivity Index is also explained. Chapter 4 presents the results of an efficiency analysis of the wood products manufacturing sub-sector in Canada. Weight restricted DEA and Spearman's rank coefficient are used in this chapter. Finally, chapter 5 includes the conclusions and recommendations for future research.
Bibliography


Chapter 2

Literature Review on Performance Assessment

2.1. Introduction

There has been an extensive amount of research on evaluating the performance of manufacturing industries around the world. In some of these studies, different industries were compared together at one point in time (cross-sectional data) and best performers were identified. In others, the performance of one industry, its growth or decline, was studied over a period of time (time-series data). There have also been studies covering both aspects, looking at different industries during a period of time (panel data). Different methods have been utilized in these performance studies.

The main goal of this chapter is to introduce different efficiency measurement techniques, with a focus on Data Envelopment Analysis (DEA), and to review the
previous research on the performance of different sectors, and forest industries in particular, in various countries. First, in section 2.2 the concepts of efficiency and productivity are discussed. In section 2.3, the different techniques for measuring efficiency and productivity, including partial measures, parametric, and non-parametric methods, are introduced and the DEA method is discussed in detail. A review of the existing literature on efficiency and productivity measurement in different areas and on the forest industries is provided in sections 2.4 and 2.5, respectively. Finally, the summary of the chapter is presented in section 2.6.

2.2. Productivity vs. efficiency

Productivity and efficiency are usually used interchangeably. However, they are two different concepts. Figure 2-1 can be used to explain the difference between the two terms. A simple production technology is assumed with one input (labour) and one output (revenue). The curve, OF, represents the relationship between the input and the output and is called the production function or, in some cases, the production frontier. The production frontier gives the maximum output possible at each level of input (Coelli et al., 1998). All of the points on the frontier and below it are possible input and output combinations; the set consisting of all these points is called the production possibility set. If a unit is operating on the frontier, it is considered efficient, since it is producing the maximum output possible. The curve OF, therefore, is called the efficient frontier. If a unit is operating below the frontier, it is considered inefficient. This means that the unit can improve its performance by producing more output while using the same input level. Note that the term efficient here means technically efficient. This means that no price data are included and an efficient unit does not necessarily operate at minimum cost. If cost data are available, then cost efficiency of the unit can also be measured.

Three units are shown in Figure 2-1. Each unit uses a different amount of labour to generate revenue. Unit A is obviously inefficient since it is operating under the frontier. Technically, this unit can produce more output without using any more input (the same as unit B).
The efficiency of unit A is defined as the ratio of the observed output to the maximum possible output or \( \frac{y_A}{y_B} \). This is the measure of technical efficiency introduced by Farrell (1957). The productivity at this point, however, is the ratio of output to input or \( \frac{y_A}{x_A} \). The productivity, therefore, is the slope of the line connecting unit A to the origin.

Comparing unit B with unit A shows that the efficiency of unit B is higher (it is equal to one) since it is producing the maximum possible revenue considering the labour it uses. Productivity of unit B \( \frac{y_B}{x_A} \) is also higher than unit A, since the slope of line OB is more than the slope of line OA. Units B and C are both operating on the frontier, therefore, both have an efficiency score of unity. However, the productivity of unit C \( \frac{y_C}{x_C} \) is higher than unit B because the line OC is tangential to the production frontier and has the highest slope compared to all other points on the frontier. This is because unit C is operating at a more productive scale size. Therefore, it can be seen that productivity is a broader concept that includes both technical efficiency and scale efficiency. Consequently, a technically efficient unit may still be able to increase its productivity by changing its scale of operations.
When productivity is observed over time, it also includes another source of improvement: the progress (or regress) in the technology which is called the *technical change* or the *frontier shift*. When technological progress occurs, all the units in the sample are able to produce more outputs using the same level of inputs compared to previous time periods. Therefore, as shown in Figure 2-2, the whole frontier shifts upwards and the productivity of the units will increase (Coelli et al., 1998). Figure 2-2 illustrates a shift in the production frontier of time $t'$ ($OF'$) relative to that of time $t$ ($OF$).

![Figure 2-2. Upward frontier shift (positive technical change)](image)

### 2.3. Measuring efficiency and productivity

#### 2.3.1. Partial measures

There are different methods for measuring efficiency and productivity. Partial productivity measures are the most common approaches used. These measures, constructed as the output per unit of input (for example, labour productivity is the output divided by the labour input) are relatively easy to calculate and interpret. Furthermore, they help in identifying the savings that occur in the usage of one input per unit of output. Labour productivity, perhaps the most important partial measure used, is also closely related to the economic welfare of the nation (Mahadevan, 2002). However, partial measures do not incorporate the effect of multiple production factors simultaneously and can be misleading. For example, labour productivity may increase by substituting labour with capital. Therefore, if only labour productivity is studied, an improvement is
observed, while the ratio of output to capital will show a decline in productivity. Consequently, when multiple inputs and outputs are present, alternative approaches can be used for performance measurement (Coelli et al., 1998).

Methods for measuring efficiency and productivity when multiple inputs and outputs are present can be divided into two major groups: frontier and non-frontier approaches (Mahadevan, 2002). Frontier approaches, as it is obvious from their name, estimate a frontier of the maximum possible output (or minimum possible cost) at each input level. In other words, they construct a frontier of the "best practices". The performance of the units in the sample is then compared to this frontier. In frontier approaches, inefficiency is allowed. This means that a unit may be performing under the frontier and be considered inefficient. Non-frontier methods, conversely, do not construct a frontier to represent the technology. Alternatively, they estimate a production or cost function using the observed input and output data and assume that all the units are operating on this function and are efficient; i.e. all the variations from this estimated function are due to statistical noise, not inefficiency. In the example shown in Figure 2-1, a frontier approach to performance measurement was explained.

When using non-frontier methods for productivity measurement, it should be noted that, since they do not allow for inefficiency, any change in the productivity is assumed to the result of changes in the technology. Frontier methods on the other hand, differentiate between the efficiency improvements and the technology progress (regress).

The grouping of different measurement methods and some examples for each one are shown in Figure 2-3 (Coelli et al., 1998; Mahadevan, 2002). Figure 2-3 also shows another form of grouping for performance measurement methods. This grouping is based on the assumption of a functional relationship between inputs and outputs. A parametric method assumes a functional form for relating inputs and outputs, while this assumption is relaxed in a non-parametric method.

2.3.2. Parametric approach

Parametric methods represent a technology by relating the inputs and outputs together with a mathematical function. The basic process is to first choose a method for representing the technology (e.g. production or cost function), then to select a functional
### Performance measurement techniques

- **Partial measures**
  - Used for measuring productivity. E.g., business sector in Canada and U.S. (Faruqui et al., 2003)

- **Modeling approach**
  - **Frontier methods**
    - **Parametric approach**
      - Stochastic Frontier Analysis - for efficiency and productivity measurement
        - Introduced by Aigner et al. (1977) and Meeusen & van den Broeck (1977)
        - E.g., utilities sector (Park & Lesourd, 2000), pulp and paper (Yin, 2000), logging (Carter & Cubbage, 1995; Grebner & Amacher, 2000)
    - **Non-parametric approach**
      - Data Envelopment Analysis - for efficiency and productivity measurement
        - When used with Malmquist Index Number
        - Introduced by Charnes et al. (1978) and developed by Banker et al. (1984)
        - E.g., banking sector (Schaffnit et al., 1997), health care (Chang et al., 2004), forest management (Kao, 2000), sawmilling (Nyrud & Baardsen, 2003)

  - **Non-frontier methods**
    - **Parametric approach**
      - Econometric least squares methods - for productivity measurement
        - Introduced by Legendre (1805, cited in Denis, 2000) and Adrain (1808, cited in Denis, 2000)
        - E.g., logging sector (Kant & Nautiyal, 1997), pulp and paper (Nautiyal & Singh, 1986), sawmilling (Bernstein, 1994)
    - **Non-parametric approach**
      - Index numbers - for productivity measurement
        - Introduced by Laspeyres and Paasche in late 19th century, developed by Fisher (1922, cited in Coelli et al., 1998), and Tornqvist (1936, cited in Coelli et al., 1998)
        - E.g., pulp and paper (Oum et al., 1991), sawmilling (Nagubadi & Zhang, 2004), mining (Kulshreshtha & Parikh, 2002)

---

*Figure 2-3. Performance measurement techniques*
form (e.g. Cobb-Douglas), and finally to estimate the parameters of the function using the available data.

A parametric representation of a technology may be done using alternative methods: production, cost, revenue and profit functions (Coelli & Perelman, 1999). A production function indicates the maximum possible output at each input level. A cost function gives the minimum cost of producing a certain output level with given input prices. A revenue function indicates the maximum attainable revenue from certain inputs, given output prices. Finally, a profit function provides the maximum possible profit with given input and output prices (Lovell & Schmidt, 1988).

The most commonly used functional forms for the aforementioned representations are Cobb-Douglas and Translog. The Cobb-Douglas form is easy to estimate, but imposes some restrictions on the technology such as constant returns-to-scale. The Translog form is more flexible and does not impose such restrictions, but is more difficult to mathematically manipulate. There are also some other forms between these two extremes, such as the quadratic or Zellner-Revankar forms (Coelli et al., 1998).

After deciding on the appropriate functional form, statistical estimation techniques, such as least squares or maximum likelihood, are applied for finding the parameters of the functions.

The major disadvantage of parametric techniques is that the functional form is not always known with certainty. However, once a functional form is chosen and estimated, different inferences can be drawn based on the results; different characteristics of the production technology, such as return-to-scale or elasticity of substitution between different inputs, can be extracted from the estimated function (Coelli et al., 1998; Kumbhakar & Lovell, 2000).

The general form of a single output production function is shown in equation (2.1). Here, \( y \) is the output and \( x_i \) is the amount of input \( i \) (\( i = 1, \ldots, m \)).

\[
y = f(x_i)
\]

(2.1)

In (2.1), \( f(.) \) is the mathematical function relating the inputs and output. This production function can be estimated using input and output quantity data and estimation
techniques such as Least Squares (LS), Corrected Ordinary Least Squares (COLS), and Maximum-Likelihood (ML). The LS estimation technique is used when no technical inefficiency is allowed; i.e. when the non-frontier approach is selected. This means that any difference between the observed output of a unit and the production function is considered to be noise in the data. The general form of the LS estimation is presented in (2.2) (Coelli et al., 1998).

\[ y = f(x_i) + v \]  

(2.2)

where \( v \) accounts for the noise in the data and is assumed to be identically and independently distributed with the Normal distribution of \( N(0,\sigma_v) \). In order to account for inefficiency as well, Stochastic Frontier Analysis, introduced by Aigner, Lovell and Schmidt (Aigner et al., 1977), can be utilized. In stochastic frontiers, another error term is added to the estimation process which accounts for inefficiency. This term is shown by \( u \), and usually has a half Normal distribution, \( N^+(0,\sigma_u) \). For estimating stochastic frontiers, COLS or ML estimations are usually used. The general form for estimating a stochastic production function can thus be shown as in (2.3); (Coelli et al., 1998). Readers are referred to Kumbhakar and Lovell (2000) for more information on Stochastic Frontier Analysis.

\[ y = f(x_i) + v - u \]  

(2.3)

When more than one output is present, the outputs should be aggregated in order to estimate the production function. Since this aggregation can sometimes be problematic, profit or cost functions, which can easily accommodate multiple outputs and inputs (they combine all outputs as one monetary value), have widely been used in such cases. Using cost or profit functions instead of production functions is a result of the duality theory. Based on this theory, it is possible to represent a technology with the cost (profit) function and by making a behavioral assumption such as cost minimization (profit maximization). All the key characteristics of the technology, such as returns-to-scale and elasticity of substitution between inputs, can be easily derived from the cost (profit) function without having to define the underlying production function that can sometimes be too complex to estimate (Coelli et al., 1998).
Another reason for using cost or profit functions is the problem of simultaneous equations bias in the direct estimation of a production function. This happens if the Right Hand Side (RHS) variables in (2.2) or (2.3) are endogenous; i.e. if they are determined by the operating unit. The underlying assumption in estimating the production function is that the dependent variable, $y$ in (2.2) and (2.3), is endogenous, while the RHS variables are exogenous (determined outside the system). If both inputs and outputs are selected by the operating unit (i.e. inputs are partially affected by other inputs or outputs in the system), this assumption is violated. An example can be in farming, where rainfall and pest infestation are two of the many inputs considered in the system in order to produce crop (Little, 2006). The level of pest infestation, itself, is affected by many factors including the rainfall. Therefore, it can be considered an endogenous variable (Little, 2006). A similar case can be assumed for a manufacturing facility where material, labor, and capital are considered as inputs to produce a unit of output. It is possible in some cases to assume that the number of employees is partially affected by the capital input. When more machinery and equipment are purchased, less people may be needed to operate the plant. Therefore, labor input can be considered partially endogenous. In such cases, using a cost function (which has input prices and output quantity on the RHS) or a profit function (which has output and input prices on the RHS) is more appropriate. Prices of inputs and outputs are assumed to be determined by the market, therefore, they are exogenous. Also, when estimating a cost function, the objective is to find the input mix that minimizes the cost of producing a given amount of output. Therefore, the output amount is also considered exogenous. The general form of cost and profit functions is shown in (2.4) and (2.5), respectively. Input prices are denoted by $w_i$ and output prices are shown by $p_i$ ($i = 1, ..., m$).

$$c = c^*(y, w_i)$$

$$p = p^*(p_i, w_i)$$

(2.4)  
(2.5)

Here, $c^*(.)$ and $p^*(.)$ are the functional forms relating prices and quantities together (Coelli et al., 1998). The problem with cost or profit functions, however, is the need to have data on prices which may not be readily available.
Distance functions can also be used for defining a production technology. Their advantage over production or cost functions is that they can represent multi input – multi output technologies without requiring price data or any behavioral assumptions (e.g. cost minimization). Distance functions are estimated by using either parametric or non-parametric approaches. For more information on parametric distance functions, refer to Coelli et al. (1998) and Kumbhakar and Lovell (2000).

When used on cross-sectional data, parametric methods can measure technical or cost efficiencies. However, by applying these methods to time series or panel data, Total Factor Productivity (TFP) change can also be measured (Coelli et al., 1998). The basic idea is that a change in the output is caused by a change in the input and the TFP change. If the outputs grow at a faster rate compared to the inputs, the TFP also increases; otherwise decreases. This growth can be attributed to technical changes or the efficiency improvements. For more on this, refer to Coelli et al. (1998) and Kumbhakar and Lovell (2000).

As previously mentioned, the major disadvantage of parametric methods is that they require the assumption of a functional form which can be both arbitrary and difficult to estimate mathematically. The alternative is to use a non-parametric approach.

### 2.3.3. Non-parametric approach

The non-parametric approach for measuring efficiency represents a production technology without any functional form assumptions and has been increasingly used for efficiency measurement in various areas. Data Envelopment Analysis (DEA) is a non-parametric method for efficiency measurement and index numbers are non-parametric productivity measures. When DEA is combined with an index number – the Malmquist Productivity Index – it can be utilized for measuring the total factor productivity change over time as well. The rest of this section focuses on the DEA methodology.

DEA is a non-parametric approach used to measure the comparative efficiency of homogeneous operating units. It was introduced by Charnes, Cooper and Rhodes (Charnes et al., 1978) and has been used in evaluating the efficiency of bank branches, power plants, public forestry organizations, etc. (Schaffnit et al., 1997; Park & Lesourd, 2000; Kao & Yang, 1991; Kao, 2000).
Applying DEA helps in identifying the units that are performing better than others (efficient units). No assumptions on the functional form are needed in DEA and different performance factors can be included in the analysis. DEA also identifies possible improvements for inefficient units, known as "efficient targets". DEA optimizes the efficiency of each individual observation by defining a frontier determined by a set of efficient units (Charnes et al., 2001). A simple example with two outputs and one input is illustrated in Figure 2-4.

Six Decision Making Units (DMUs) are shown on the graph (A, B, C, D, E, and P). The points to the left and below the solid line represent all the possible combinations of the two outputs that are produced from a unit of input. The solid line is the efficient frontier; i.e. the units lying on this frontier produce the best combination of outputs compared to other units in the sample. If a unit is operating on the frontier, it is considered to be efficient. Unit P uses one unit of input to produce $Y_1$ units and $Y_2$ units of the two outputs and, since it is not lying on the frontier, its performance can be improved (by increasing its outputs in this case). The line connecting P to the origin intersects the frontier at point P'. The ratio $OP/OP'$ is the technical efficiency of unit P (Charnes et al., 1978). This ratio compares the observed level of output with the largest possible level for the unit. In Figure 2-4, this maximum output level is found radially by keeping the ratio of the two outputs constant.

The basic CCR model - named after Charnes, Cooper and Rhodes - is based on a fractional programming problem (2.6). Assume we have $n$ DMUs, using $m$ inputs to
produce \( s \) outputs. We denote the \( i^{th} \) input \((r^{th} \text{ output})\) used by DMU\(_j\) with \( x_{ij} \left( y_{rj} \right) \). The fractional model in (2.6) maximizes the efficiency of the unit under evaluation, DMU\(_0\), subject to the constraint that the efficiency of all DMUs is less than or equal to one (Charnes et al., 1978). Efficiency is defined as the weighted sum of outputs divided by the weighted sum of inputs. \( v_{io} \left( u_{ro} \right) \) is the weight of the \( i^{th} \) input \((r^{th} \text{ output})\) for DMU\(_0\). These weights are the variables to be found by the DEA model. \( x_{ij} \) and \( y_{rj} \) are the amount of input \( i \) used and output \( r \) produced by DMU\(_j\).

\[
\begin{align*}
\text{max} \quad h_o &= \frac{\sum_{r=1}^{s} u_{ro} \cdot y_{r0}}{\sum_{i=1}^{m} v_{io} \cdot x_{io}} \\
\text{s.t.} \quad \frac{\sum_{r=1}^{s} u_{ro} \cdot y_{rj}}{\sum_{i=1}^{m} v_{io} \cdot x_{ij}} &\leq 1 \quad j = 1, \ldots, n \\
\quad v_{io}, u_{ro} &\geq 0 \quad r = 1, \ldots, s \quad i = 1, \ldots, m
\end{align*}
\] (2.6)

In (2.6), \( h_o \) is the efficiency of DMU\(_0\) and is being maximized. By making the denominator of the objective function in (2.6) equal to one and maximizing the numerator, the above problem is transformed to a \textit{Linear Programming} (LP) form, called the CCR model (Charnes et al. 1978). This LP is shown in equation (2.7) which needs to be run \( n \) times, once for each DMU.

\[
\begin{align*}
\text{max} \quad h_o &= \sum_{r=1}^{s} u_{ro} \cdot y_{r0} \\
\text{s.t.} \quad \sum_{i=1}^{m} v_{io} \cdot x_{io} &= 1 \\
\quad \sum_{r=1}^{s} u_{ro} \cdot y_{rj} - \sum_{i=1}^{m} v_{io} \cdot x_{ij} &\leq 0 \quad j = 1, \ldots, n \\
\quad v_{io}, u_{ro} &\geq 0 \quad r = 1, \ldots, s \quad i = 1, \ldots, m
\end{align*}
\] (2.7)

Equation (2.7) is called the multiplier form since it gives the information about input and output weights (multipliers). Equation (2.7) shows an \textit{input-oriented} model. Input orientation means that the model minimizes the inputs while keeping the same level
of outputs. The output-orientated model formulation is shown in (2.8). Here, $z_o$ is the efficiency score.

$$\begin{align*}
\min z_o &= \sum_{i=1}^{m} v_i x_{io} \\
\text{s.t.} \quad &\sum_{r=1}^{s} u_r y_{ro} = 1 \\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad j = 1, \ldots, n \\
&u_r, v_i \geq 0 \quad r = 1, \ldots, s \quad i = 1, \ldots, m
\end{align*}$$

(2.8)

The output-oriented model maximizes the output without changing the input level. The orientation of a DEA model is more easily understood by looking at the dual formulation. A dual problem exists for any LP; the CCR model in (2.8) can also be shown using the dual representation. In the dual model, each variable is associated with a constraint in the primal form. Assume $\phi$ and $\lambda_j$ are the dual variables of (2.8). As it is observed in (2.9), the dual problem (also referred to as the envelopment form) maximizes $\phi$ or the output augmentation through multiplying $\phi$ by the observed output for DMU$_0$.

$$\begin{align*}
\max w_o &= \phi \\
\text{s.t.} \quad &\sum_{j=1}^{n} \lambda_j y_{rj} \geq \phi y_{ro} \quad r = 1, \ldots, s \\
&\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} \quad i = 1, \ldots, m \\
&\lambda_j \geq 0 \quad j = 1, \ldots, n
\end{align*}$$

(2.9)

If $\phi^*$ is the optimal value for the variable $\phi$ in (2.9), then $1/\phi^*$ represents the efficiency score for DMU$_0$ which is always between zero and one. The optimal value of a dual and a primal LP model are always equal. Therefore, the efficiency score resulting from both primal and dual DEA models is the same. If a DMU is on the efficient frontier, the efficiency score will be equal to one. If a DMU is inefficient, it can be projected to a point on the efficient frontier. This point is found using a linear combination of a number of efficient DMUs or "the reference set". The coefficients for calculating these projection points are $\lambda_j$s in (2.9).
As it can be seen in Figure 2-4, the output of unit P was radially increased to point P'. Extra contractions might be possible if a non-radial increase occurs in the outputs. Slack variables, $s_r^-$ and $s_r^+$, are added to the model to account for this extra increase (decrease) in outputs (inputs).

$$\text{max } w_o = \phi$$

$$s.t. \quad \phi \cdot y_{ro} - \sum_{j=1}^{n} \lambda_j \cdot y_{rj} + s_r^+ = 0 \quad r = 1, \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j \cdot x_{ij} + s_i^- = x_{io} \quad i = 1, \ldots, m$$

$$\lambda_j, s_i^-, s_r^+ \geq 0 \quad r = 1, \ldots, s \quad i = 1, \ldots, m \quad j = 1, \ldots, n$$

(2.10)

DMU_o is efficient if and only if $\phi^*=1$ and all slacks are equal to zero. However, based on (2.10) it is possible that a DMU has the efficiency score of 1, but has non-zero slacks. This can happen if a DMU is on the extensions of the efficient frontier (for example unit A in Figure 2-4). In order to remove this ambiguity, slack variables are also added to the objective function (Cooper et al., 2000). Therefore, the objective function in (2.10) is replaced by (2.11). $\epsilon$ is a very small positive real number. For detailed description of this modification, see Cooper et al. (2000).

$$\text{max } w_o = \phi + \epsilon \cdot \sum_{r=1}^{s} s_r^+ + \epsilon \cdot \sum_{i=1}^{m} s_i^-$$

(2.11)

The CCR model is based on the assumption of constant returns-to-scale. It means that if inputs increase (decrease) by a certain proportion, outputs will increase (decrease) by the same proportion. This assumption is modified in the BCC model, introduced by Banker, Charnes, and Cooper in 1984 (Banker et al., 1984). The BCC model adds a convexity constraint to the CCR model – as shown in (2.12) – and as a result, the envelopment surface changes from a linear form to a piecewise-linear form with variable returns-to-scale. It means that a change in inputs may result in a different than proportionate change in outputs.
max \( w_o = \phi + \varepsilon \sum_{r=1}^{s} s_r^+ + \varepsilon \sum_{i=1}^{m} s_i^- \)

s.t. \( \phi \cdot y_{r o} - \sum_{j=1}^{n} \lambda_j \cdot y_{r j} + s_r^+ = 0 \quad r = 1, \ldots, s \)

\( \sum_{j=1}^{n} \lambda_j \cdot x_{ij} + s_i^- = x_{io} \quad i = 1, \ldots, m \) \hfill (2.12)

\( \sum_{j=1}^{n} \lambda_j = 1 \quad j = 1, \ldots, n \)

\( \lambda_j, s_i^-, s_r^+ \geq 0 \quad r = 1, \ldots, s \quad i = 1, \ldots, m \quad j = 1, \ldots, n \)

The difference between the frontiers of CCR and BCC models is shown in an example in Figure 2-5. Figure 2-5 shows a simple production technology for five units with one input and one output. The CCR frontier is a facet (a line in this example) passing through the most efficient unit(s) — unit A in this example. All other units are considered inefficient. Some DMUs may seem inefficient simply because they are being compared with the units operating at a different scale. For example, in Figure 2-5, we see that unit C is operating at a smaller scale compared to unit D; it may not be fair to compare these two units together.

The BCC model takes into account these scale effects on performance, while the CCR model gives the aggregate efficiency of the DMUs. As it is observed in Figure 2-5, BCC frontier envelopes the data more closely and the number of efficient units increases. Unit P is inefficient in both cases. However, it is closer to the BCC frontier than the CCR frontier and, therefore, its efficiency score is higher based on the BCC model. The BCC model estimates the technical efficiency of the unit which results in higher efficiency scores for inefficient units compared to the CCR model. Scale efficiency of a unit can then be calculated as shown in (2.13). A scale efficiency of one indicates that the possible inefficiency of the DMU is technical, while a scale efficiency of less than one suggests that the observed aggregate inefficiency is not the result of technical inefficiency alone. Therefore, efficiency improvements may be possible by changing the scale of operations.

\[
\text{Scale efficiency} = \frac{\text{Aggregate efficiency}}{\text{Technical efficiency}} = \frac{\text{CCR Score}}{\text{BCC Score}} \quad (2.13)
\]
In order to identify the best performers, efforts have been made to extend the DEA methodology, increase its practicality, and reflect managerial and organizational factors. Some examples of these extensions are non-discretionary and categorical variables, weight restrictions, and window analysis. More information on these extensions can be found in Charnes et al. (2001), Angulo-Meza and Lins (2002), and Cooper et al. (2000).

2.4. Performance assessment in different industries

This section presents a review of productivity and efficiency measurement studies in various industries (excluding manufacturing industries). Table 2-1 summarizes the studies mentioned in this section.

2.4.1. Partial measures

Labour productivity is the most commonly used partial measure for performance evaluation. Examples include Faruqui et al. (2003) and Goodrum and Haas (2004). Labour productivity of the business sector in Canada and the U.S. from 1987 to 2000 were studied by Faruqui et al. (2003). The business sector is comprised of four major sectors: services, manufacturing, construction and primary industries. The results showed that the productivity growth in the U.S. picked up earlier than in Canada and remained higher during the study period. The main contributor to this productivity gap was found to be the services sector before 1996 and the manufacturing sector after 1996. Goodrum
and Haas (2004) attempted to find a relationship between the labour productivity growth and the technology progress in the U.S. construction industry. Instead of looking at the aggregate data, they studied 200 construction activities. Their results showed an overall increase in the labour productivity from 1976 to 1998 which was related to technological advances and the substitution of labour with capital.

2.4.2. Parametric approach

Examples of parametric efficiency and productivity studies can be found for airlines, railways, and power plants (Charnes et al., 1996; Coelli & Perelman, 1999; Park & Lesourd, 2000). Charnes et al. (1996) studied the efficiency of domestic and international operations of ten Latin American airline industries using a robustly efficient parametric frontier. This frontier was developed using the results of a multiplicative DEA model. The identified efficient units and the frequency of their appearance in the reference sets of other DMUs were used as additional information in estimating a Translog production frontier. They found that the underlying structure of the domestic and international operations were different, for example, output elasticity values. Efficiencies of 17 European railway companies were studied using multi-output distance functions by Coelli & Perelman (1999). They used three methods for estimating distance functions: parametric linear programming method, DEA, and Corrected Ordinary Least Squares. Their results showed that the alternative methods provided fairly correlated results, especially for the two parametric methods. They also suggested using an average of the efficiency scores from the three methods. Park & Lesourd (2000) examined the efficiency of South Korean power plants using DEA, Stochastic Frontier Analysis (SFA) and also developed a DEA-based stochastic frontier model. They incorporated the DEA-calculated efficiencies in the SFA as exogenous variables and showed that this improved the statistical properties of the stochastic frontier significantly.

2.4.3. Non-parametric approach

The non-parametric approach has mostly been used within the services sector. One reason for this may be the fact that, for many of the firms within this sector, such as health care centres or educational organizations, it is difficult to specify prices (costs) of input and outputs. Banking has probably been the industry with the highest number of
non-parametric performance studies (Grifell-Tatje & Lovell, 1997; Pastor et al., 1997; Schaffnit et al., 1997; Asmild et al., 2004). Other application examples include telecommunications, postal services, and mining (Madden & Savage, 1999; Odeck, 2000; Uri, 2000; Sueyoshi & Aoki, 2001; Kulshreshtha & Parikh, 2002; Chang et al., 2004).

Grifell-Tatje & Lovell (1997) used the Generalized Malmquist Productivity Index (GMPI) to study the productivity growth of the commercial and saving banks in Spain. They showed that, on average, scale changes accounted for a small amount of the productivity growth for the banks, while the frontier shift (improvements in the performance of best practice banks) was the primary source of growth. Savings banks, in general, were found to have had a superior performance compared to commercial banks. Pastor et al. (1997) compared the efficiency and productivity of the Spanish commercial banks with those of seven other countries. French banks were found to have the highest domestic efficiency and Austrian banks were the ones with the highest productivity levels. The interesting aspect of this study was that no time-series data were used. Therefore, instead of productivity growth rates over time, productivity levels were compared across countries. Schaffnit et al. (1997) examined the efficiency of Ontario-based branches of a large Canadian bank. They used multiplier constraints to incorporate managerial preferences into the model. Also, price information was used to measure the cost or allocative efficiency, which was found to be lower than technical efficiency. Using non-parametric statistical tests, the authors showed that the efficiency scores (technical and allocative) were correlated with profitability, service quality, and the location of the branch. By combining DEA window analysis and Malmquist productivity index, Asmild et al. (2004) studied the efficiency and productivity of five Canadian banks over the period 1982-2000. Changes in the efficiency and productivity levels were linked to changes in the economic environment such as recessions, regulatory changes, etc. Overall, all banks had increased their efficiency and productivity during the study period.
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<tr>
<td>Grifell-Tatje &amp; Lovell</td>
<td>1997</td>
<td>Saving and commercial banks</td>
<td>Spain</td>
<td>1986-1993</td>
<td>Non-parametric</td>
<td>Generalized Malmquist index</td>
<td>BCC model was applied on two groups of banks. The two groups were merged after adjustments for technical inefficiencies.</td>
</tr>
<tr>
<td>Pastor et al.</td>
<td>1997</td>
<td>Commercial banks</td>
<td>Spain and seven other countries</td>
<td>1992</td>
<td>Non-parametric</td>
<td>DEA, Malmquist index</td>
<td>Instead of comparing the productivity change between two periods, the productivity levels were compared.</td>
</tr>
<tr>
<td>Schaffnit et al.</td>
<td>1997</td>
<td>Bank branches</td>
<td>Canada (Ontario)</td>
<td>1993</td>
<td>Non-parametric</td>
<td>Weight restricted DEA</td>
<td>DEA model was modified to measure the cost efficiency. Non-parametric statistical test was used to examine the correlation between the efficiency scores and some additional factors.</td>
</tr>
<tr>
<td>Coelli &amp; Perelman</td>
<td>1999</td>
<td>Railway companies</td>
<td>Europe</td>
<td>1988-1993</td>
<td>Parametric and non-parametric</td>
<td>DEA, Translog distance functions</td>
<td>Distance functions were estimated using three methods. High correlations were found between the results of different methods.</td>
</tr>
<tr>
<td>Madden &amp; Savage</td>
<td>1999</td>
<td>Telecommunication industry</td>
<td>74 countries</td>
<td>1991-1995</td>
<td>Non-parametric</td>
<td>Malmquist index, productivity ratios</td>
<td>TFP growth was higher in industrialized countries than the developing countries.</td>
</tr>
<tr>
<td>Odeck</td>
<td>2000</td>
<td>Vehicle inspection agencies</td>
<td>Norway</td>
<td>1989-1991</td>
<td>Non-parametric</td>
<td>DEA, Malmquist index</td>
<td>DEA results indicated a 21-29% potential for input savings. No correlation was found between efficiency and the agency size.</td>
</tr>
<tr>
<td>Park &amp; Lesourd</td>
<td>2000</td>
<td>Conventional power plants</td>
<td>South Korea</td>
<td>1990</td>
<td>Parametric and non-parametric</td>
<td>DEA, SFA, DEA-based Stochastic frontier model</td>
<td>DEA results suggested that the older plants had lower efficiency scores compared to the new ones.</td>
</tr>
<tr>
<td>Uri</td>
<td>2000</td>
<td>Local Career Exchanges (LECs)</td>
<td>U.S.</td>
<td>1988-1998</td>
<td>Non-parametric</td>
<td>Malmquist index</td>
<td>MPI was decomposed to catch-up effect, frontier shift effect, and scale change.</td>
</tr>
</tbody>
</table>
Table 2-1. Performance studies on different sectors (Continued)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Operating units</th>
<th>Country/region</th>
<th>Study period</th>
<th>Approach</th>
<th>Method</th>
<th>Interesting outcomes or attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sueyoshi &amp; Aoki</td>
<td>2001</td>
<td>Regional administrative agencies of postal services</td>
<td>Japan</td>
<td>1983-1997</td>
<td>Non-parametric</td>
<td>Window Malmquist Approach</td>
<td>Larger postal services operated more efficiently than the small ones.</td>
</tr>
<tr>
<td>Kulshreshtha &amp; Parikh</td>
<td>2002</td>
<td>Mining regions</td>
<td>India</td>
<td>1985-1997</td>
<td>Non-parametric</td>
<td>DEA, Malmquist Index</td>
<td>Open cast mining had a higher frontier shift but a much lower efficiency growth that resulted in a lower TFP growth.</td>
</tr>
<tr>
<td>Faruqui et al.</td>
<td>2003</td>
<td>Business sector</td>
<td>U.S. and Canada</td>
<td>1987-2000</td>
<td>Partial measures</td>
<td>Partial measures (labour productivity)</td>
<td>Business sector was comprised of services, manufacturing, construction and primary industries</td>
</tr>
<tr>
<td>Asmild et al.</td>
<td>2004</td>
<td>Bank branches</td>
<td>Canada</td>
<td>1982-2000</td>
<td>Non-parametric</td>
<td>DEA window analysis, Malmquist index</td>
<td>Decomposition of Malmquist index when combined with Window Analysis was found inappropriate.</td>
</tr>
<tr>
<td>Chang et al.</td>
<td>2004</td>
<td>Hospitals</td>
<td>Taiwan</td>
<td>1996-1997</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Private hospitals may look more efficient than public ones because they are able to focus only on more profitable areas.</td>
</tr>
<tr>
<td>Goodrum &amp; Haas</td>
<td>2004</td>
<td>Construction activities</td>
<td>U.S.</td>
<td>1976-1998</td>
<td>Partial measures</td>
<td>Partial measures (labour productivity)</td>
<td>Labour productivity growth was related to the technology progress through developing a technology change index.</td>
</tr>
</tbody>
</table>
Productivity growth of the telecommunications industry across 74 countries was studied by Madden and Savage (1999). The authors introduced partial measures and showed that the ratios indicating the labour productivity were much higher in industrialized countries compared to developing ones, while the difference between industrialized and developing countries was not large based on the capital productivity ratio. Based on Malmquist index results, the productivity of the telecommunications industry had increased, on average, over the study period. In another study on the telecommunications industry, the productivity growth of a group of U.S. telecommunication LCEs (Local Career Exchange) was measured from 1988 to 1998 (Uri, 2000). A relatively high annual TFP growth (3%) was identified for the sample LCEs. Both of these studies suggested that the main reason for TFP growth had been due to the frontier shift rather than the efficiency improvements.

Odeck (2000) studied the efficiency and productivity of the vehicle inspection agencies in Norway to identify potentials for improvements. The Malmquist index decomposition showed that the observed TFP growth was mainly a result of the frontier shift.

Sueyoshi and Aoki (2001) proposed a new application of the non-parametric\(^2\) Kruskal-Wallis test to statistically test the occurrence of a frontier shift. Studying the Japanese postal service, they used this test on the results from a "Window Malmquist Approach" (combination of Window Analysis and Malmquist index) and identified a positive frontier shift over the study period. Their results were interesting since they introduced the possibility of making statistical inferences from the DEA results.

The efficiency and productivity of two types of coal mining operations (opencast and underground mining) in India were studied by Kulshreshtha and Parikh (2002). They identified underground mining as having higher productivity growth and efficiency levels compared to opencast mining. The major reason for low TFP growth in opencast mining was a decline in efficiency.

\(^2\) Here, the term "non-parametric" refers to a statistical test that has no assumption about the distribution of the data sample. It is different from non-parametric efficiency or productivity measurement.
Public and private hospitals in Taiwan were also compared using DEA (Chang et al., 2004). Their results showed that, in general, private hospitals had higher efficiency compared to public ones. They used the Wilcoxon test and two DEA-based statistical tests for their comparisons. The DEA-based statistical tests assumed that the efficiency scores had exponential or half-normal distributions. All tests proved the difference of efficiency scores between public and private hospitals.

2.5. Performance assessment in the forestry sector

Performance studies on forest industries have used both parametric and nonparametric approaches. They can be grouped based on their application area into four major groups: studies in forest management, logging, the pulp and paper industry, and the sawmilling sector.

2.5.1. Forest management

All of the studies identified in the area of forest management have used a nonparametric approach, since they can easily incorporate factors without market values. These studies have been mainly concerned with the management efficiency in public forest districts and how different management scenarios would affect performance. Table 2-2 contains a summary of the studies in the forest management area.

Kao and Yang (1991 and 1992) and Kao et al. (1993) used DEA to assess the efficiency of public forest management in Taiwan. The models used in these studies were later modified to add some bounds for the inputs and outputs range (Kao, 1994 and 2000). Shiba (1997) applied three different DEA models to data from the Forest Owner’s Association in Japan. The author used different inputs and outputs in each model to examine the changes in efficiency scores. Regional forestry boards in Finland were studied by Viitala and Hanninen (1998). After analyzing the prime efficiency determinants, they found out that management style and support had a significant effect on efficiency scores, in addition to climate and vegetation conditions. Using the same data, Joro and Viitala (1999) incorporated additional information into the DEA model by adding weight restrictions and comparing the results from different models. They found that the results are very sensitive to input and output weights. Bogetoft et al. (2003) decomposed efficiency scores to analyze the possible gains from mergers in the Danish
Forestry Extension Service. They revealed that, although a part of the inefficiency may be reduced by merging smaller forest districts together, the dominant part of the inefficiency is technical. Technical inefficiency can exist as a result of labour inefficiency, using the equipment inefficiently, or due to improper management practices.

2.5.2. Logging

There have also been a number of efficiency studies in the logging sector. Parametric studies mostly used Translog cost functions (Woodland, 1975; Stier, 1980; Kant & Nautiyal, 1997), while some used stochastic frontiers (Carter & Cubbage, 1995; Grebner & Amacher, 2000). These studies are summarized in Table 2-3.

Woodland (1975) and Stier (1980) compared the logging industry (in Canada and US, respectively) to other major industries, using cost functions. Kant and Nautiyal (1997) studied the production structure of the Canadian logging industries and found a negative technical change and total factor productivity growth during the study period 1964-1992. Carter and Cubbage (1995) analyzed efficiency and productivity growth of logging industry in 12 states in the U.S. using a stochastic production frontier. They attempted to explain efficiency variations based on the producer and firm-specific socioeconomic variables. Grebner and Amacher (2000) analyzed the cost efficiency of New Zealand's logging sector to study the effect of privatization and deregulation on its performance. Their results showed a negative effect.

Non-parametric studies on the logging sector mainly used DEA (Lebel & Stuart, 1998; Hailu & Veeman, 2003). LeBel and Stuart (1998) compared the efficiencies of a group of Southern US logging contractors and suggested a production level as the most productive scale size. They showed that the main reason for inefficiency was low capacity utilization. Hailu and Veeman (2003) looked at the productivity growth in the Canadian regional boreal logging industries using DEA. The results suggested regional differences in technical efficiency levels. Share of hardwood harvest and hardwood production per establishment were found to have positive effects on technical efficiency.
Table 2-2. Performance studies on the forest management sector

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Operating units</th>
<th>Country/region</th>
<th>Study period</th>
<th>Approach</th>
<th>Method</th>
<th>Interesting outcomes or attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kao &amp; Yang</td>
<td>1991</td>
<td>Forest districts</td>
<td>Taiwan</td>
<td>1978-1987</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Many units were identified as efficient, because the number of DMUs was too large compared to the sum of inputs and outputs.</td>
</tr>
<tr>
<td>Kao &amp; Yang</td>
<td>1992</td>
<td>Forest districts</td>
<td>Taiwan</td>
<td>1978-1987</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Different scenarios for merging the forest districts together were evaluated based on the resulting efficiency score.</td>
</tr>
<tr>
<td>Kao et al.</td>
<td>1993</td>
<td>Forest districts</td>
<td>Taiwan</td>
<td>1978-1987</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>In this study, slack variables are discussed and Multiplicative DEA is also applied.</td>
</tr>
<tr>
<td>Kao</td>
<td>1994</td>
<td>Forest districts</td>
<td>Taiwan</td>
<td>1978-1987</td>
<td>Non-parametric</td>
<td>DEA with bounds on input and output values</td>
<td>An additional modified DEA model was solved for inefficient DMUs to find the efficient targets. The bounds were imposed on input/output values, not their weights.</td>
</tr>
<tr>
<td>Shiba</td>
<td>1997</td>
<td>Forest Owner's</td>
<td>Japan</td>
<td>1991-1994</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Average values of factors over the period were used in the models. Three models with different inputs/outputs were compared.</td>
</tr>
<tr>
<td>Vittala &amp; Hanninen</td>
<td>1998</td>
<td>Forestry Boards</td>
<td>Finland</td>
<td>1993-1994</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>The efficiency of FBs was evaluated for different activities, using DEA. These scores were then combined to form a composite efficiency score for each FB.</td>
</tr>
<tr>
<td>Joro &amp; Vittala</td>
<td>1999</td>
<td>Forestry Boards</td>
<td>Finland</td>
<td>1993-1994</td>
<td>Non-parametric</td>
<td>DEA with weight restrictions and with cost information</td>
<td>Assurance region and ordering of weights were used to constrain the output weights. A cost efficiency model was also solved.</td>
</tr>
<tr>
<td>Kao</td>
<td>2000</td>
<td>Forest sub-districts</td>
<td>Taiwan</td>
<td>1990-1993</td>
<td>Non-parametric</td>
<td>DEA with bounds on one input</td>
<td>Efficiency was maximized for each district while controlling the budget allocated to different sub-districts.</td>
</tr>
<tr>
<td>Bogetoft</td>
<td>2003</td>
<td>Forestry Extension Service offices</td>
<td>Denmark</td>
<td>1997-1999</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>The analysis was intertemporal, performing one DEA run for the data in all years.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Operating units</td>
<td>Country/region</td>
<td>Study period</td>
<td>Approach</td>
<td>Method</td>
<td>Interesting outcomes or attributes</td>
</tr>
<tr>
<td>----------------</td>
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<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Woodland</td>
<td>1975</td>
<td>All industries (manufacturing, services, ...)</td>
<td>Canada</td>
<td>1946-1969</td>
<td>Parametric</td>
<td>Stochastic cost function</td>
<td>For each industry a separate function was estimated using Maximum-Likelihood method.</td>
</tr>
<tr>
<td>Stier</td>
<td>1980</td>
<td>Logging, sawmilling and paper industry</td>
<td>U.S.</td>
<td>1958-1974</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Higher growth in labour productivity than in TFP was reported for the forest industries.</td>
</tr>
<tr>
<td>Kant &amp; Nautiyal</td>
<td>1997</td>
<td>Logging sector</td>
<td>Canada</td>
<td>1964-1992</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Negative TFP change was found for the industry.</td>
</tr>
<tr>
<td>Lebel &amp; Stuart</td>
<td>1998</td>
<td>Logging contractors</td>
<td>Southern U.S.</td>
<td>1988-1994</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>No adjustment for inflation was made for the data. Effect of environmental factors on efficiency was studied using a non-parametric test.</td>
</tr>
<tr>
<td>Hailu &amp; Veeman</td>
<td>2003</td>
<td>Boreal forest regions</td>
<td>Six provinces in Canada</td>
<td>1977-1995</td>
<td>Non-parametric</td>
<td>DEA, Distance functions</td>
<td>Both efficiency and productivity growth were measured. Balk and Althin's productivity measure was used instead of Malmquist.</td>
</tr>
</tbody>
</table>
2.5.3. Pulp and paper

Parametric approaches for evaluating the performance of the pulp and paper sector either used cost functions (Sherif, 1983; Rao & Preston, 1984; Nautiyal & Singh, 1986; Frank et al., 1990; Oum et al., 1991) or distance functions (Hailu & Veeman, 2000a and 2000b). These studies mainly reported slow technical efficiency progress and increased labour productivity (Sherif, 1983; Nautiyal & Singh, 1986; Frank et al., 1990; Oum et al., 1991). Table 2-4 gives a summary of these studies.

Rao and Peterson (1984) compared major Canadian industries together, including the pulp and paper and wood industries. Their findings showed increasing returns-to-scale for the paper industries. Increasing returns-to-scale (decreasing returns-to-scale) means that if all inputs are increased by a proportion, the output will increase by a higher (lower) proportion. Constant returns-to-scale occurs when the resulting output increases by the same proportion. Returns-to-scale (RTS) properties of the operating units can help in identifying possible performance improvement alternatives. For example, if a unit is operating under increasing returns-to-scale (IRS) and is inefficient, expanding its operating scale may have a positive impact on its efficiency. Frank et al. (1990) applied both a non-parametric Total Factor Productivity (TFP) analysis (index number) and a parametric method (cost function) to the data from the pulp and paper industry during the period 1963-1984 in order to measure TFP changes and the returns-to-scale. They found that the TFP growth was mostly due to changes in the economies of scale rather than technical efficiency improvements. This result matched that of a previous study by Oum et al. (1991). The same finding was also presented in a more recent study by Hailu and Veeman (2000b). They used a parametric input distance function and also index numbers to study the productivity changes of the Canadian pulp and paper industry from 1959 to 1994. Using the same data, Hailu and Veeman (2000a) compared the conventional productivity analysis approaches with the environmentally adjusted ones. They not only included the increase in desirable outputs, but also the decrease in the amount of undesirable outputs such as pollution. They found that incorporating environmental factors in the analysis resulted in significantly higher productivity growth rates for the industry which showed that conventional measures had not accounted for industry’s efforts to reduce undesirable outputs.
Non-parametric studies on the pulp and paper industry included applications of DEA (Yin, 1998, 1999 and 2000; Hailu and Veeman, 2001). In a series of non-parametric studies on the pulp and paper industries, Yin (1998 and 1999) measured the technical, scale, and cost efficiencies of North American pulp producers by applying DEA. He showed that, for most of the mills in the sample, the technical efficiency was higher than the cost efficiency. He also studied the technical and allocative efficiency of global bleached softwood pulp producers using both DEA and Stochastic Frontier Analysis (SFA) (Yin 2000). The findings showed that, although efficiency results from DEA and SFA conformed to a large extent, differences in ranking DMUs still existed between them. It was also suggested by both methods that most of the inefficiency was related to cost rather than technical inefficiency. Hailu and Veeman (2001) conducted a study regarding the effect of environmental factors on efficiency. Using DEA, they reached the same conclusion as in their previous parametric studies. They showed that incorporating the environmental factors improved the efficiency scores of pulp producers.

2.5.4. Sawmilling

Parametric studies on sawmilling sector have used both cost functions (Greber & White, 1982; Merrifield & Haynes, 1985; Nautiyal & Singh, 1985; Banskota et al., 1985; Singh & Nautiyal, 1986; Martinello, 1987; Meil & Nautiyal, 1988; Meil et al., 1988; Puttock & Prescott, 1992) and profit functions (Constantino & Haley, 1988; Bernstein, 1994). These studies are summarized in Table 2-5.

The studies on the American lumber and plywood industries reported positive technical change and increasing returns-to-scale, with the exception of Pacific Northwest-westside region that showed decreasing returns-to-scale (Greber & White, 1982; Merrifield & Haynes, 1985).
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Operating units</th>
<th>Country/region</th>
<th>Study period</th>
<th>Approach</th>
<th>Method</th>
<th>Interesting outcomes or attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sherif</td>
<td>1983</td>
<td>Pulp and paper industry</td>
<td>Canada</td>
<td>1958-1977</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Technological progress was not reflected in the results.</td>
</tr>
<tr>
<td>Rao &amp; Peterson</td>
<td>1984</td>
<td>Industries in manufacturing, services, etc.</td>
<td>Canada</td>
<td>1958-1979</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Decreasing returns-to-scale was found for the manufacturing sector. A TFP growth slowdown after 1973 was observed in all industries.</td>
</tr>
<tr>
<td>Nautiyal &amp; Singh</td>
<td>1986</td>
<td>Pulp and paper industry</td>
<td>Canada</td>
<td>1956-1982</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Input misallocation was found during the study period. Technical change was slow.</td>
</tr>
<tr>
<td>Frank et al.</td>
<td>1990</td>
<td>Pulp and paper industry</td>
<td>Canada</td>
<td>1963-1984</td>
<td>Parametric and non-parametric</td>
<td>Tornqvist index, Translog cost function</td>
<td>Increase in scale had a greater effect on TFP growth compared to technical change.</td>
</tr>
<tr>
<td>Oum et al.</td>
<td>1991</td>
<td>Pulp and paper industry</td>
<td>Canada, U.S., Sweden</td>
<td>1970-1080</td>
<td>Parametric</td>
<td>Tornqvist index, Translog cost function</td>
<td>Labour productivity grew faster in Sweden while TFP growth was higher in U.S. and Canada.</td>
</tr>
<tr>
<td>Yin</td>
<td>1998</td>
<td>Linerboard mills</td>
<td>North America</td>
<td>1994</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Technical, cost and allocative efficiencies were calculated using an additive DEA model.</td>
</tr>
<tr>
<td>Yin</td>
<td>1999</td>
<td>Bleached softwood pulp</td>
<td>10 Pacific Rim countries</td>
<td>1994</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Cost variations were analyzed across nine regions. Latin American producers had the lowest production cost.</td>
</tr>
<tr>
<td>Hailu &amp; Veeman</td>
<td>2000a</td>
<td>Pulp and paper industry</td>
<td>Canada</td>
<td>1959-1994</td>
<td>Parametric</td>
<td>Translog distance function, Malmquist index</td>
<td>Incorporating the reduction in undesirable outputs increased the TFP growth estimates.</td>
</tr>
<tr>
<td>Hailu &amp; Veeman</td>
<td>2000b</td>
<td>Pulp and paper industry</td>
<td>Canada</td>
<td>1959-1994</td>
<td>Parametric</td>
<td>Translog distance function, Malmquist &amp; Tornqvist index</td>
<td>Slow technical change was reported for the sector.</td>
</tr>
<tr>
<td>Yin</td>
<td>2000</td>
<td>Bleached softwood pulp</td>
<td>World</td>
<td>1996</td>
<td>Parametric and non-parametric</td>
<td>SFA, DEA</td>
<td>Stochastic Translog and Cobb-Douglas cost functions were estimated. The DEA and SFA results were then compared using Spearman's rank coefficient.</td>
</tr>
<tr>
<td>Hailu and Veeman</td>
<td>2001</td>
<td>Pulp and paper industry</td>
<td>Canada</td>
<td>1959-1994</td>
<td>Non-parametric</td>
<td>DEA, Chavas and Cox's productivity measure</td>
<td>Undesirable outputs are incorporated into this analysis.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Operating units</td>
<td>Country/region</td>
<td>Study period</td>
<td>Approach</td>
<td>Method</td>
<td>Interesting outcomes or attributes</td>
</tr>
<tr>
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<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Greber &amp; white</td>
<td>1982</td>
<td>Lumber and wood products industry</td>
<td>U.S.</td>
<td>1951-1973</td>
<td>Parametric</td>
<td>Translog production function</td>
<td>Technical change was found to be the main reason for productivity growth.</td>
</tr>
<tr>
<td>Banskota et al.</td>
<td>1985</td>
<td>sawmills</td>
<td>Canada (Alberta)</td>
<td>1978</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Larger sawmills showed higher scale efficiency than the smaller mills.</td>
</tr>
<tr>
<td>Merrifield &amp; Haynes</td>
<td>1985</td>
<td>Lumber and plywood sector</td>
<td>U.S. (Pacific Northwest)</td>
<td>1950-1979</td>
<td>Parametric</td>
<td>Translog production function</td>
<td>Rate of technical change was inconsistent in different regions.</td>
</tr>
<tr>
<td>Nautiyal &amp; Singh</td>
<td>1985</td>
<td>Sawmilling and planing sector</td>
<td>Canada</td>
<td>1965-1981</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>No technical progress was identified for the sector.</td>
</tr>
<tr>
<td>Singh &amp; Nautiyal</td>
<td>1986</td>
<td>Sawmilling and planing sector</td>
<td>Canada</td>
<td>1955-1982</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Slow technical progress was found over the study period.</td>
</tr>
<tr>
<td>Martinello</td>
<td>1987</td>
<td>Sawmilling and planing sector</td>
<td>Canada (British Columbia)</td>
<td>1963-1979</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Productivity declined in both coastal and interior sawmills.</td>
</tr>
<tr>
<td>Constantino &amp; Haley</td>
<td>1988</td>
<td>Sawmilling sector</td>
<td>U.S. Pacific Northwest West side, BC coast</td>
<td>1957-1981</td>
<td>Parametric</td>
<td>Translog profit function</td>
<td>Wood quality was incorporated into the model. Positive technical change was found over the study period.</td>
</tr>
<tr>
<td>Meil &amp; Nautiyal</td>
<td>1988</td>
<td>Softwood lumber producing sawmills</td>
<td>Canada (four regions)</td>
<td>1968-1984</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Annual productivity change was not identified as being significant.</td>
</tr>
<tr>
<td>Meil et al.</td>
<td>1988</td>
<td>Softwood lumber sector</td>
<td>Canada (BC interior)</td>
<td>1948-1983</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Positive frontier shift and slow efficiency improvement rate was proved to exist.</td>
</tr>
<tr>
<td>Constantino &amp; Haley</td>
<td>1989</td>
<td>Sawmilling sector</td>
<td>U.S. Pacific Northwest West side, BC coast</td>
<td>1957-1982</td>
<td>Non-parametric</td>
<td>Index number</td>
<td>Authors modified their previous study by using a non-parametric method. U.S. Pacific Northwest West side was found to have a higher productivity growth.</td>
</tr>
<tr>
<td>Puttock &amp; Prescott</td>
<td>1992</td>
<td>Hardwood lumber producing Sawmills</td>
<td>Canada (Ontario)</td>
<td>1980-1984</td>
<td>Parametric</td>
<td>Translog cost function</td>
<td>Possible improvements for small sawmills were possible through increasing their scale of operations.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Operating units</td>
<td>Country/region</td>
<td>Study period</td>
<td>Approach</td>
<td>Method</td>
<td>Interesting outcomes or attributes</td>
</tr>
<tr>
<td>-------------------</td>
<td>------</td>
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<td>--------------</td>
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<td>--------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Abt et al.</td>
<td>1994</td>
<td>Lumber producing sector</td>
<td>Six regions in North America</td>
<td>1965-1988</td>
<td>Non-parametric</td>
<td>Tornqvist index</td>
<td>The highest productivity growth was found in the U.S. West and BC coast and interior.</td>
</tr>
<tr>
<td>Bernstein</td>
<td>1994</td>
<td>Softwood lumber sector</td>
<td>Canada</td>
<td>1963-1978</td>
<td>Parametric</td>
<td>Translog profit function</td>
<td>Technical change was the main contributing factors to productivity.</td>
</tr>
<tr>
<td>Fotiou</td>
<td>2000</td>
<td>Sawmills</td>
<td>Greece</td>
<td>-</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Logistic operations of sawmills were related to the efficiency scores using Anova.</td>
</tr>
<tr>
<td>Nyrud &amp; Bergseng</td>
<td>2002</td>
<td>Sawmills</td>
<td>Norway</td>
<td>1974-1991</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>Kruskal-Wallis test was used to see if the efficiency was correlated with size and time.</td>
</tr>
<tr>
<td>Nyrud &amp; Baardsen</td>
<td>2003</td>
<td>Sawmills</td>
<td>Norway</td>
<td>1974-1991</td>
<td>Non-parametric</td>
<td>DEA, Malmquist index</td>
<td>Large sawmills were found to be more efficient in general.</td>
</tr>
<tr>
<td>Nagubadi &amp; Zhang</td>
<td>2004</td>
<td>Sawmills and wood preservation sector</td>
<td>U.S. and Canada</td>
<td>1958-2001</td>
<td>Non-parametric</td>
<td>Tornqvist-Theil productivity index</td>
<td>Constant returns-to-scale was assumed. Canada-US productivity gap had widened during the study period.</td>
</tr>
<tr>
<td>Salehirad &amp; Sowlati</td>
<td>2005</td>
<td>Sawmills</td>
<td>Canada (British Columbia)</td>
<td>2002</td>
<td>Non-parametric</td>
<td>DEA</td>
<td>BC sawmills showed high scale efficiency. Kruskal-Wallis test was used to see if efficiency scores were different in various regions.</td>
</tr>
</tbody>
</table>
In Canada, most of the studies reported increasing returns-to-scale with little or no technological progress with the exception of BC interior sawmills (Nautiyal and Singh, 1985; Banskota, 1985). Singh and Nautiyal (1986) suggested that slow technological progress in the Canadian sawmilling sector might be because the measured technical change is a combination of technological advancement and other factors such as management quality, worker skills, changing resource characteristics (log size and quality), and input misallocation. In British Columbia, Martinello (1987) studied the sawmilling and wood panels manufacturing sector to analyze their production technology characteristics and found that interior sawmills showed constant returns-to-scale. BC interior sawmills were also studied by Meil et al. (1988) who found the same results as Martinello (1987), and by Constantino and Haley (1988) who showed the importance of wood quality in estimating the technical progress. Meil and Nautiyal (1988) performed an intraregional economic analysis of four major Canadian softwood lumber producing regions over time. Their results showed that there were regional differences in productivity growth rates. In another study on the BC coast and US Pacific Northwest region, Bernstien (1994) measured the productivity growth of the Canadian lumber industry and showed that frontier shift (technology improvement) was the main contributor to this growth.

Non-parametric studies have used index numbers (Constantino & Haley, 1989; Abt et al., 1994; Nagubadi & Zhang, 2004) or DEA (Fotiou, 2000; Nyrud & Bergseng, 2002; Nyrud & Baardsen, 2003; Salehirad & Sowlati, 2005). Constantino and Haley (1989) used index numbers to compare the productivity levels of sawmills on the BC coast with those in the U.S. Pacific Northwest region. They showed that higher productivity levels in the US were due to their better wood quality. In a study on the North American lumber industry, Abt et al. (1994) compared the productivity and price trends of six major lumber producing regions from 1965 to 1988. They used index numbers (total and single factor productivity indices) and, since no functional form was used to relate inputs and outputs, this study can be considered to be a non-parametric method. In contrast to Meil and Nautiyal (1988), their results showed that TFP growth rates were consistent in all regions. In Europe, Fotiou (2000) related the operational logistics of a group of Greek sawmills to their DEA efficiency scores. He reached the
conclusion that sawmills with extensive purchase networks had higher efficiencies. In Norway, Nyrud and Bergseng (2002) and Nyrud and Baardsen (2003) used DEA to study the production efficiency of sawmills and suggested that larger sawmills had higher efficiency scores compared to others. In a recent study in British Columbia (Salehirad & Sowlati, 2005), performance of sawmills were analyzed using DEA and it was showed that BC sawmills enjoyed high scale efficiency but their average technical efficiency was not very high. Efficiency scores in different regions in BC were also found to be different. A comparison between sawmilling industries in Canada and US was performed by Nagubadi and Zhang (2004). They found that the productivity gap between the two countries had widened during the period from 1958 to 2001. The main reason for this was suggested to be the lower amount of new capital investment in the Canadian industries as well as the price instabilities caused by the Softwood Lumber Agreement.

To the best knowledge of the author, there has only been one study trying to compare different forest industries together in Canada (Martinello, 1985). However, even this study did not compare the technical efficiency. It was mainly concerned with identifying the production structure of pulp and paper, logging, and sawmilling industries in Canada. Estimates of factor substitution, technical change, and returns-to-scale for the Canadian forest industries were presented and all three sectors were found to have increasing returns-to-scale during the study period.

Considering the increasing number of efficiency studies on forest industries and the lack of quantitative studies for comparing the performance of different wood industry sub-sectors, it is interesting to see how these sub-sectors are performing relative to each other. Since it has never been done before, this research compares the efficiency levels of three sub-sectors of wood products manufacturing in Canada over time using DEA. DEA was selected because of its flexibility and the fact that it does not require a functional form for the production frontier. Results from the DEA analysis will be compared to the partial measures currently used by Statistics Canada.

2.6. Summary

Performance assessment using firm-level and industry-level data continues to gain importance, mainly because of the need to remain competitive in today’s global market.
Benchmarking helps organizations and industries to evaluate how they are performing compared to others and to determine how to improve their competitive position.

Different techniques have been developed and used to study the efficiency and the productivity of a firm and compare it to others. Techniques for measuring productivity and efficiency can be grouped in different ways. They can be divided into frontier and non-frontier methods or parametric and non-parametric ones. For each application, a specific method fits better, based on the included factors and the expected characteristics of the results. A review of different performance measurement methods was provided in this chapter. DEA, a non-parametric method for measuring efficiency, was discussed in detail. DEA offers more flexibility for defining the production frontier of a sample of units since it does not need a functional form for relating the inputs and outputs. It can be used for measuring the relative technical, cost, or scale efficiency of firms, industries, etc.

A review of the existing literature on performance assessment in different industries, including the forest industries, was also presented in this chapter. This review revealed that although parametric methods have frequently been used for economic analyses of the production technologies, DEA has also been utilized in recent years and its applications continue to increase. There have been several applications of DEA in different forestry areas. It has most frequently been used for evaluating the efficiency of forest management. This is because forest management usually deals with multiple outputs that are sometimes difficult to value and can be hard to incorporate in conventional ratio analyses or parametric methods. In recent years, DEA has also been gaining more popularity in other areas of forest industries, especially in the sawmilling and pulp and paper sectors.

The growing number of performance measurement studies on the forest industries in Canada and across the world shows the increasing importance of such studies. The Canadian forestry sector can undoubtedly benefit from these studies by determining its relative performance compared to other industries and countries.
Bibliography


Chapter 2: Literature Review on Performance Assessment


Chapter 2: Literature Review on Performance Assessment


Chapter 3

Productivity Changes of the Manufacturing Sector in Canada and the U.S.

3.1. Introduction

One of the major sources of growth and prosperity in nations is manufacturing. Canada is not an exception. Manufacturing contributes to the Canadian economy both directly and indirectly. It generates more than 17% of the national GDP and more than 2.2 million jobs (Statistics Canada, 2005b).

Manufacturing industries also contribute indirectly to the Canadian economy by creating demand for goods and services from other sectors, such as primary resources, energy production, transportation, financial services, and so on. For every dollar of manufactured output, an average of $3.05 is created in total economic activity in Canada.
Similarly, for every $1 million increase in demand for manufacturing products, about eight jobs are created (Au, 2004). Furthermore, manufacturing activities create investment and research opportunities for the economy. Foreign Direct Investment (FDI) in the manufacturing sector was approximately $155 billion in 2004, accounting for more than 40% of the total FDI in Canada (CME, 2004). Also, R&D expenditure of the sector has more than doubled during the past decade (CME, 2004), currently accounting for more than 60% of the total industrial R&D in Canada (Au, 2004). Manufacturing sector is also responsible for over 30% of the business taxes paid to all levels of the Canadian government (CME, 2004).

As can be seen in Figure 3-1, manufacturing is the largest contributor to GDP in Canada among the goods producing industries. Since one of the most common measures of a nation’s living standard is GDP per capita (Sharpe, 2001), the manufacturing sector plays an important role in improving the living standards of all Canadians.

Currently, there are about 54,000 manufacturing establishments across Canada, with the majority of them being concentrated in Ontario, Quebec and British Columbia (Industry Canada, 2005a). Most of these establishments are small and medium-sized enterprises – with 84% of them having less than 50 employees (CME, 2004). The largest industries in terms of revenue are the transportation, food, and chemical products manufacturing sectors. Manufacturing sector is export oriented; currently, exports make up more than 50% of the manufacturing shipments in Canada (Industry Canada, 2005b; Trade Data Online, 2005). This means that more than half of what is produced inside

Figure 3-1. GDP share of goods producing industries in Canada in 2004; Statistics Canada (2005b)
Canada is shipped abroad; therefore, the ability to offer quality products at competitive prices is essential for the manufacturing sector.

The Canadian manufacturing sector has experienced many ups and downs through the years. The recession of 1990 and 1991 caused both the real manufacturing output and GDP share to decrease. The upward trend started again after the recession and, in 1994, the real output in manufacturing reached the same level as that of before the recession. At the end of the 1990's, the manufacturing sector was operating at 90% capacity, but this growth had slowed down a bit by 2001, as a result of the recession (Statistics Canada, 2004). From 2000 to 2003, the GDP share of the manufacturing sector had a decreasing trend, followed by a slight improvement in 2004, as illustrated in Figure 3-2. It has been suggested that the manufacturing sector is more volatile to business cycles compared to the whole economy (Au, 2004).

![Figure 3-2. GDP share of the Canadian manufacturing sector; Statistics Canada (2005b)](image)

Exports from the manufacturing sector has accounted for more than 75% of the total Canadian exports during the past decade (Trade Data Online, 2005). The United States has been the largest export market for the Canadian manufacturing sector. Over the past decade, on average, 85% of the manufacturing exports have been sent to the U.S. (Trade Data Online, 2005). Although the proximity of this market and its strong demand has helped the growth of exports in the Canadian manufacturing sector, it has also made this sector dependent upon the U.S. market. This has created some challenges for the manufacturing sector in the recent years because of the emergence of new exporting competitors such as China (CME, 2004). Furthermore, the share of the manufacturing sector...
Chapter 3: Productivity Changes of the Manufacturing Sector in Canada and the U.S.

The manufacturing sector from Canada’s total exports has been fluctuating in the past decade with a total decrease of about 5%, as shown in Figure 3-3.

![Figure 3-3. Manufacturing sector’s share of Canada’s exports; Trade Data Online (2005)](image)

Wood products manufacturing is one of the manufacturing industries in Canada accounting for 5.7% of the total manufacturing shipments in 2003 (Industry Canada, 2005b). More than half of the manufacturing shipments in wood products industry is exported (Trade Data Online, 2005). However, increasing global competition has affected the position of Canada as an exporter of wood products (FAOSTAT, 2005) and various trade barriers have made it more difficult for the Canadian producers to access global export markets (Eastin & Fukuda, 2001; Nagubadi & Zhang, 2004). In response to the changing trade environment, structural changes have been occurring in wood products manufacturing, focusing mainly on the production of more value-added products and developing new markets (Industry Canada, 2002 and 2005b).

Like Canada, the manufacturing sector in the U.S. is a very important component of the economy. Every $1 in manufacturing demand creates an additional $0.55 in manufacturing activities and $0.45 in non-manufacturing activities. The sector currently accounts for more than 14% of the GDP and 11% of the employment in the whole economy (U.S. Department of Commerce, 2004). This sector is a source of high paying jobs and, consequently, creates an increase in the real income and standard of living of Americans. The U.S. manufacturing sector, however, has faced harsh economic conditions since 2000. The recession of 2001, although mild with respect to the output of
the whole economy, hit the manufacturing sector fairly hard. Manufacturing output
decreased by 6% in less than a year and more than 2.5 million jobs were lost. The slow
recovery of the manufacturing sector, compared to previous economic downturns, has
created some concerns related to its performance (U.S. Department of Commerce, 2004).

Apart from the current recession, U.S. manufacturers have been facing similar
challenges as their Canadian counterparts. Global trade agreements have opened the U.S.
market to many exporters of manufactured products and have caused the domestic
manufacturers to face intense competition. U.S. manufacturers, therefore, have been
driven to outsource parts and components from a global supply chain that allows them to
produce their products with a lower final price and remain competitive in the market

Considering the importance of the manufacturing sector and the observed trends
in its GDP and export share in Canada, the need to evaluate the performance of this sector
becomes apparent. The wood industry, an important part of the forest industries in
Canada, has also faced challenges in recent years and needs to be evaluated with respect
to its performance. It is important for the economic welfare of the Canadians that the
output of the manufacturing sector – including the wood industry- increases steadily.
Output increases are driven by two main sources: increases in inputs and productivity
growth (Coelli et al., 1998). Input growth, by itself, is limited in increasing outputs as a
result of the law of diminishing returns. This law states that increasing one input while
keeping all other inputs constant will result in less and less increase in the outputs after a
certain point. In order for the output to grow, productivity must grow as well.
Productivity growth enables the industry to increase the output, keeping the input levels
constant. This, consequently, results in lower prices for the final product and increases
the competitiveness of the industry. Productivity growth, in the long run, affects the
living standards of the nation by increasing the “real” wages of the workforce (Rao &
Lampriere, 1992; Harris, 1999). This is why international comparisons of productivity
levels have been carried out extensively in the literature. Adding to the previous
literature, this research measures the productivity change of the manufacturing industries
in Canada in recent years, with a focus on wood products manufacturing.
The objectives of this research, therefore, are to:

1. Compare the Total Factor Productivity (TFP) change of different manufacturing industries in Canada from 1994 to 2002 with a focus on the wood products manufacturing sector.

2. Compare the TFP change of the U.S. manufacturing industries during the period 1997 to 2002, again focusing on wood products manufacturing.

In order to achieve these objectives, a non-parametric measure of TFP, the Malmquist Productivity Index (MPI), was selected among various TFP measures. This index has a major advantage over other productivity indices since it does not need any price data and can be decomposed into two main components of productivity change: frontier shift and efficiency improvements\(^3\). These will be further discussed in this chapter. For the purpose of calculating the Malmquist index, non-parametric distance functions were selected that could be estimated using the Data Envelopment Analysis (DEA) technique.

Traditionally, labour productivity levels have been used for comparison purposes (Rao & Lampriere, 1992; Carree et al., 2000; Hitomi, 2005). Although labour productivity generally moves in the same direction as the total factor productivity (Rao & Lampriere, 1992), it only includes the effect of one input (labour) and, therefore, cannot provide a reliable measure of productivity. For example, an increase in the labour productivity might be a result of an increase in the physical capital input which will not be shown in the labour productivity measure. Total Factor Productivity (TFP) measures incorporate multiple inputs and outputs of the production in order to generate a more accurate picture of the productivity change. This is why TFP was selected for the purpose of productivity measurement in this research.

For Canada, most of the comparisons have been made with the U.S., since it is Canada’s most important trading partner (Lee, 1999; Macklem, 2003). There has been a debate on the existence and causes of the so-called productivity gap between Canada and

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\(^3\) A method has been recently proposed by Diewert and Fox (2005) in order to decompose another index - Tornqvist index - into technical progress and returns-to-scale components.
the U.S. Macklem (2003) showed that the recent labour productivity growth for the business sector (including manufacturing, services, primary industries and construction) started a year later (1996) in Canada. Also, the TFP change rates in the U.S. were found to be higher than that in Canada in many of the previous studies. Considering the importance of the manufacturing sector in the U.S. and the fact that the economic recessions and recovery of the U.S. manufacturing directly affects the demand for Canadian manufactured products, it would be useful to study its performance, as well. Therefore, it was appropriate in this research to conduct a productivity measurement of the manufacturing industries in the U.S.

Comparing different industries together based on productivity or efficiency levels may not be justified. Since the nature of industries can be very different. However, looking at the productivity change rates helps in identifying the industries that are improving their performance with higher rates. This has been the main reason why, in this study, productivity change measurement was chosen over efficiency level comparisons.

Because of the unavailability of the appropriate data, it was not possible to compare the results of the two countries quantitatively. That being the case, qualitative observations will be presented and discussed.

The remainder of this chapter is organized as follows: a literature review of the previous performance studies on the manufacturing sector is provided in Section 3.2. Index numbers and Malmquist productivity index are introduced in Section 3.3. Manufacturing data definitions and sources for both countries are explained in Section 3.4. Finally, analyses, results and a discussion are presented in Section 3.5, followed by the conclusion and directions for the future research in Section 3.6.

3.2. Review on performance evaluation of manufacturing industries

Both efficiency and productivity analyses have been previously conducted on the manufacturing industries in Canada and also worldwide. These studies have either compared different industries together in one or more countries (for example, Carree et al., 2000; Kim & Han, 2001; Arcelus & Arrozena, 1999) or focused on a specific industry (Chandra et al., 1998; Ma et al., 2002; Shao & Shu, 2004). This section covers the
previous studies in Canada as well as the comparisons across the countries. It should be noted that the focus of this review is mainly on the employed techniques rather than the geographical coverage of different studies.

### 3.2.1. Partial Measures

Some studies have used partial measures for productivity measurement (Carree et al., 2000; Hitomi 2002, 2004, & 2005). In a study on the Korean manufacturing sector, Hitomi (2002) studied the growth of the manufacturing industries from 1988 to 1999 by using some partial measures of performance. He defined an efficiency index in his study as the GDP share of the industry (of the total economy) divided by its labour population share (of the total labour force). Based on this index, he showed that manufacturing industries in Korea were more efficient than the service industries. In a similar study, Hitomi (2004) studied Japanese manufacturing industries from 1955 to 2000. Again, he showed that the primary and manufacturing industries in Japan were more efficient than the service industries. He also looked at the manufacturing labour productivity level (value added divided by hours per employee) in Japan and compared it to China and the U.S. The labour productivity level in Japan was shown to be close to that of the U.S. but much higher than that of China. Hitomi (2005) studied the U.S. manufacturing sector in a similar manner and found that it had higher efficiency indices compared to other countries such as Japan or China.

### 3.2.2. Parametric approach

Parametric studies that included multiple inputs and outputs have used a variety of methods to either identify the production structure of the sector using the returns-to-scale properties (Robidoux & Lester, 1992; Bennaroch, 1997) or to measure the efficiency (Green & Mayes, 1991; Ferrantino & Ferrier, 1995; Kaynak & Pagan, 2003) and the productivity (Mahadevan & Kalirajan, 2000; Kim & Han, 2001) of manufacturing industries.

There have been some parametric studies conducted on the Canadian manufacturing sector as a means of measuring the returns-to-scale in different industries. This issue is important in developing strategies for different industries, for example to see whether mergers in the industry should be encouraged or not. Robidoux and Lester
(1992) used a Translog cost function for this purpose and found that the majority of the industries showed increasing return-to-scale (IRS) and constant returns-to-scale (CRS). Benaroch (1997) also showed that there were increasing returns-to-scale in the Canadian manufacturing industries.

Green and Mayes (1991) measured the technical efficiency of manufacturing industries in the U.K. using a Translog production function. Through the use of a multivariate regression technique, they related the technical efficiency to unobservable random factors such as the competitiveness of the industries, openness to foreign trade, and the extent of product differentiation. Using the stochastic frontiers, Ferrantino and Ferrier (1995) estimated a Translog stochastic production function for sugar producers in India in order to compare their efficiency levels. Overall, high technical efficiency levels were found for the producers. Smaller firms were found to be more efficient and private firms also performed better compared to the public ones. Kaynak and Pagan (2003) used a Translog production frontier to evaluate the effect of Just-In-Time purchasing (JITP) techniques on the technical efficiency of US manufacturing industries. Top management commitment to JITP was found to have a significant effect on technical efficiency.

In Singapore, Mahadevan and Kalirajan (2000) measured the TFP change of the manufacturing sector from 1975 to 1994 using industry level data and the Cobb-Douglas production function. The productivity change was decomposed into efficiency growth and the frontier shift and it was shown that low technical efficiency was the main reason for low and declining TFP change. They showed that input growth, rather than TFP growth, was the main reason for the output growth in the manufacturing sector. Kim and Han (2001) utilized a Translog production function to measure and decompose the TFP change of the Korean manufacturing sector during the period 1980 to 1994. They found large variations in TFP change among industries and showed that the main part of the growth was due to the frontier shift.

3.2.3. Non-parametric approach

Non-parametric studies mainly involved the use of indices. A number of these studies have specifically used the DEA-based Malmquist productivity index (Zaim & Taskin, 1997; Arcelus & Arozena, 1999; Maudos et al., 1999; Ma et al., 2002; Chen,
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2003; Shestalova, 2003; Shao & Shu, 2004), while others used indices such as Tornqvist index (Denny et al., 1981; Fluet & Lefebvre, 1987; Denny et al. 1992; Malley et al., 2003; Domazlicky & Weber, 2004). There have also been studies using DEA to measure the efficiency of industries (Kao et al., 1995; Thore et al., 1996; Chandra et al., 1998; Linton & Cook, 1998; Al-Shammari, 1999; Zhu, 2000; Murillo-Zamarano & Vega-Cervera, 2001). The common finding in almost all of these studies was that the frontier shift (technology improvement) was the main component of productivity growth in different industries and countries.

Zaim and Taskin (1997) compared the productivity changes of the Turkish public and private manufacturing sector, using Malmquist index and showed that the private sector had higher productivity change than the public sector. Arcelus and Arozena (1999) used the generalized Malmquist index for measuring the sectoral productivity and efficiency across 14 OECD countries from 1970 to 1990. The generalized Malmquist index adds a scale factor to the original decomposition of the productivity change. Based on DEA efficiency results, the manufacturing sector in Canada showed decreasing returns-to-scale and an average technical efficiency of 0.85 during the study period. The TFP change results showed that the U.S. manufacturing sector had the highest growth among other countries in the study. Maudos et al. (1999) compared the productivity changes of 23 OECD countries during the period 1975 to 1990. They added the schooling years of the labour force as an additional factor to represent the human capital input. It was found that Japan had the highest TFP growth. The authors suggested that including the human capital in the analysis caused an important change in the relative positions of the U.S. and Japan by improving the efficiency change estimates for Japan. Ma et al. (2002) studied the iron and steel industry in China from 1989 to 1997 to measure the changes in efficiency and productivity. They found that average efficiency increased during the study period but was still relatively low. Their Malmquist analysis results showed an inverse relation between the frontier shift and efficiency change. It was argued that the rapid progress of the technologies of some leading enterprises in the beginning of the period shifted the frontier upward. Therefore, the distance between the remaining enterprises and the efficient frontier increased and the efficiency of the whole sample

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dropped. The efficiency of three other major Chinese industries (textiles, chemical and metallurgical) over a 20-year time period were compared by Chen (2003). He used both radial and non-radial DEA models for calculating the Malmquist indices. The radial Malmquist index includes only the radial contraction (increase) of inputs (outputs); therefore, it ignores additional improvements through the use of slack variables. The non-radial model, on the other hand, includes such improvements. It was argued that the non-radial index provided more realistic estimates of productivity change and its components.

Using DEA-based Malmquist index and industry level data, Shestalova (2003) studied the productivity of six manufacturing industries in a sample of OECD countries from 1970 to 1990. Two approaches for identifying the production frontier were used. The first one was the contemporaneous frontier in which a separate frontier was constructed for each time period. The second approach used sequential frontiers to construct a frontier in each time period and all the previous periods were also considered. In other words, in the latter approach, technologies of all previous time periods were considered possible. Therefore, in the sequential frontier approach, a decline in technology (regress) was not possible. The TFP change results from the two approaches were found to be highly correlated. However, the decomposition results turned out to be very different; the sequential frontier approach had less volatility in the frontier shift component. The highest productivity growth for the whole sample was observed for the textile industries and Canada was found to be in a leading position in this industry.

Information and computing technology (ICT) industries in a sample of OECD countries were studies by Shao and Shu (2004). Similar to Arcelus and Arozena (1999), they also used GMPI to separate the effect of scale change. Japan and the US were found to have the most efficient ICT industries in all years from 1978 to 1990. TFP change rates however showed that Japan actually had a decline in productivity, while the U.S. had a 4% growth.

Denny et al. (1981) used the Tornqvist index number to study the TFP change of the Canadian manufacturing industries across provinces from 1961 to 1975. Based on their results, the wood industry was among the poor performers while transportation and chemical industries had high growth rates. The majority of industries had higher growth rates in the 60's compared to that in the 70's. In another study on the Canadian manufacturing sector using the index number theory, Fluet and Lefebvre (1987)
measured the TFP change of the sector from 1965 to 1980 and described how productivity improvements were shared among different factors such as labour, capital, etc. This study also found that the wood industry was performing below average, while the transportation industries performed above average. Using the Tornqvist index, Denny et al. (1992) compared the productivity changes of the manufacturing industries in Canada, Japan and the U.S. from 1973 to 1980. The efficiency levels in Canada and Japan improved relative to the U.S. during the study period. In contrast to the findings of the previous studies, the wood industry was found to be among the industries with high productivity growth. Lumber industry in Canada was found to have a higher efficiency compared to the U.S. Using index numbers, Malley et al. (2003) presented comparative measures of TFP at the sectoral level for manufacturing industries in the G-7 economies from 1971 to 1995. Like the majority of the studies, they also found that the U.S. had the highest TFP levels and that other countries showed a slow convergence towards the levels in the U.S. the wood and paper industries in Canada, however, showed a higher productivity compared to all other countries. Domazlicky and Weber (2004) studied the effect of pollution abatement on the efficiency and productivity change of the chemical industries across different states in the U.S. They included both desirable and polluting outputs in the analysis. Their findings showed higher efficiency levels compared to conventional methods. This was due to the fact that conventional measures included the input necessary for pollution abatement, but did not account for the reduction of undesirable outputs.

Kao et al. (1995) used DEA to study the productivity improvement possibilities in the machinery industry in Taiwan. They used the technology and management indices (which they developed themselves) as inputs and the productivity (calculated as value added divided by the sum of capital and labour input) as the output. Their study suggested that a firm can increase its output (productivity in their case) either through the efficiency or the effectiveness approach. The efficiency approach would not require the use of any more inputs and is achieved by improving input utilization patterns. The effectiveness approach, on the other hand, is only possible through utilizing more resources (technology and management in this case). DEA efficiency was linked to the product cycle concept through the work of Thore et al. (1996). In their study on the U.S.
computer companies, they suggested that the efficiency of a company would change based on its product life cycle. Efficiency scores would be lower in the introduction phase when the product is relatively new in the market and then would start rising until the product reaches maturity. In a DEA efficiency study on 55 manufacturing companies in Jordan, Al-Shammari (1999) suggested that the managers were receptive to the DEA results. However, they did not accept it as a substitute for currently used financial measures. Zhu (2000) used a two-stage DEA model to study the profitability and marketability performance of Fortune 500 companies. He found that the top 20 companies identified by Fortune magazine were showing serious scale inefficiencies. Companies in the sample were from various industry groups in manufacturing and services. The results showed that most industries had a better performance on profitability than on marketability. Murillo-Zamarano and Vega-Cervera (2001) compared the performance of a number of the US electric utility firms employing the stochastic frontier method (Cobb-Douglas production function) as well as DEA. The rankings of the units based on the parametric approach and the constant returns-to-scale (CRS) DEA were correlated. However, no correlation was found when the variable return-to-scale (VRS) assumption was selected. The returns-to-scale results also matched with the size of the establishments; i.e. larger firms showed decreasing returns-to-scale (DRS) while smaller ones showed increasing returns-to-scale (IRS). Using DEA, Chandra et al. (1998) studied the efficiency and returns-to-scale of the Canadian textile companies in 1994 and concluded that most of the companies were not performing efficiently. In another study, Linton and Cook (1998) compared the performance of Canadian and American electronic circuit assembly factories in implementing a new cleaning technology. Using Wilcoxon rank-sum test, their findings showed a significant difference in efficiency levels in the two countries, with the American factories being superior.

Evidently, the issue of comparing the performance of different manufacturing industries together has received great attention in the literature, especially for the purpose of international comparisons. Both parametric and non-parametric methods have been used for this purpose. The Canadian manufacturing sector has not been an exception and several studies have been conducted to compare the performance of different manufacturing industries together, as mentioned in this section. Malmquist index has
been used to compare the industries across different countries. However, to the best of the author’s knowledge, it has not yet been used to compare manufacturing industries within Canada. Furthermore, even the most recent study (Malley et al. 2003) has not included any data beyond 1995. This research, therefore, will add to the current literature by utilizing the most recent data available and also by employing the non-parametric Malmquist index.

3.3. Methods

3.3.1. Index numbers

In contrast to the partial measures, Total Factor Productivity (TFP) measures include multiple inputs and outputs. As a result, they provide a more accurate picture of the performance of the unit under observation. As mentioned before, index numbers are examples of non-parametric measures that can be used for productivity change assessment.

Index numbers may be used to measure the changes in the prices or quantities of inputs and outputs over time or among different units. In general, index numbers measure the changes in a set of variables by comparing their current values with a base period (or with a benchmark unit). If \( p_{iy} \) and \( q_{iy} \) are the prices and values of commodity \( i \) \((i = 1, ..., N)\) at time period \( j \) \((j = s, t)\), a general index number that measures the value change can be written as shown in (3.1). Note that the current and base time periods are represented by \( t \) and \( s \), respectively.

\[
V_{st} = \frac{\sum_{i=1}^{N} p_{it}q_{it}}{\sum_{i=1}^{N} p_{is}q_{is}}
\]

(3.1)

This index measures the change in the value of a basket of \( N \) commodities in time \( t \) compared to the same basket in time \( s \). Obviously, \( V_{st} \) represents changes in two sets of variables: the quantities and the prices. One might wish to separate the effect of the two factors by using price and quantity indices. There are different indices that can be used for measuring price and quantity changes. Some examples of price and quantity indices include Laspeyres, Paasche, Fisher, and Tornqvist; for more information on these index
numbers, refer to Coelli et al. (1998). In case of temporal comparisons with more than two time periods, index numbers may be calculated between two consecutive time periods (chained index) or using a fixed-base period. Based on the application context, one of the two approaches would be selected. The chained index measures the changes in smaller periods; therefore, some approximations in deriving the index formulations are more likely to hold. Furthermore, the results from different index numbers are more likely to be similar when two consecutive time periods are being compared. On the other hand, the weights for constructing the price or quantity index numbers need to be changed for calculating the index in every period while they remain unchanged if a fixed base period is used (Coelli et al., 1998).

A Total Factor Productivity (TFP) index measures the change in the outputs relative to the change in the inputs (Coelli et al., 1998) as shown in (3.2). Again, \( s \) and \( t \) are the base and current time periods, respectively.

\[
\text{TFP}_{st} = \frac{\text{Output Index}_{st}}{\text{Input Index}_{st}}
\]

(3.2)

Any index number can be used in (3.2); usually, Tornqvist, Fisher, or Malmquist indices are used. The Malmquist index is a common index number for measuring the TFP changes. Malmquist (1953) introduced the Malmquist input and output \textit{quantity} indices. His work was later extended by Caves, Christensen, and Diewert (Caves et al., 1982) to develop a TFP change index. Malmquist index can be calculated using either quantity index numbers or distance functions. Deiwert (1992) showed that Malmquist productivity index can be calculated by entering Malmquist input and output quantity indices into (3.2). The resulting index was called Hicks-Moorsteen (Deiwert, 1992) and was later shown to be equal to the distance functions-based Malmquist index under special circumstances (Fare et al., 1997). The Malmquist productivity index has some advantages over other productivity indexes: it does not require any price data and can be decomposed into productivity change components – frontier shift and efficiency change. This decomposition will be explained shortly. However, one drawback of the Malmquist index is that it requires panel data, unlike other indices like Tornqvist or Fisher that can be calculated using time series data (Coelli et al., 1998).
3.3.2. Malmquist Productivity Index

The Malmquist Productivity Index (MPI) is explained for the output orientated case using Figure 3-4. A simple example of a constant returns-to-scale technology with one input and one output is used here. Note that this production frontier is estimated using all the data in the sample which are not shown in this example. Unit A is using \( x_s \) amount of input to produce \( y_s \) amount of output in period \( s \). The same unit in time period \( t \) is using less input, \( x_t \), to produce more output, \( y_t \). Obviously, unit A has improved its performance from period \( s \) to \( t \).

![Figure 3-4. Malmquist Productivity Index for a single input/single output technology](image)

Based on the original Malmquist index, this improvement can be decomposed into two main effects: Catch-up effect and frontier shift. The catch-up effect represents the changes in the technical efficiency of the unit; i.e. how the unit has caught up with the other units in the sample. If the distance of \( A_t \) to the frontier of period \( t \) (\( D_4 \)) is less than the distance of \( A_s \) to the frontier of period \( s \) (\( D_1 \)), then unit A has improved its technical efficiency from period \( s \) to \( t \). The frontier shift effect, on the other hand, shows the technological change between the two periods. If the technology improves, all units in the sample perform better and the frontier shifts upward. Therefore, a part of a unit's improved performance can be attributed to this frontier shift effect. The frontier shift
effect is calculated using the distance of a unit in a time period to the frontier of the other time period ($D_2$ and $D_3$).

Distance functions are used to measure the distances between the unit and frontier in the two time periods. The output oriented MPI, with reference to period $s$, is defined as the ratio of two distance functions, as shown in (3.3).

$$M_o^s(x^s, y^s, x', y') = \frac{d^s_o(x', y')}{d^s_o(x^s, y'^s)}$$ (3.3)

The distance function, $d(.)$, measures the distance of a unit from the efficient frontier. The subscript "o" denotes the orientation (output-oriented) and the superscript "s" states which time period’s frontier is being considered. The Malmquist index in (3.3) measures the change in the distance of the unit in the two time periods relative to the frontier of the first period. The MPI, with reference to period $t$, can similarly be written as in (3.4).

$$M_o^t(x^t, y^t, x', y') = \frac{d^t_o(x', y')}{d^t_o(x^t, y'^t)}$$ (3.4)

Since the choice of the reference period can be arbitrary, MPI is usually defined as the geometric mean of the two indices:

$$M_o(x^s, y^s, x', y') = \sqrt{M^s_o \times M^t_o} = \left[ \frac{d^s_o(x', y')}{d^s_o(x^s, y'^s)} \times \frac{d^t_o(x', y')}{d^t_o(x^t, y'^t)} \right]^{1/2}$$ (3.5)

Equivalently, (3.5) can be rewritten as:

$$M_o(x^s, y^s, x', y') = \frac{d^t_o(x', y')}{d^t_o(x^t, y'^t)} \times \left[ \frac{d^s_o(x', y')}{d^s_o(x^s, y'^s)} \times \frac{d^t_o(x', y')}{d^t_o(x^t, y'^t)} \right]^{1/2}$$ (3.6)

The first ratio on the right hand side of (3.6) measures the the catch-up effect (efficiency change) and the phrase inside the brackets measures the frontier shift effect (technical change). A value of more than one for MPI and each of its components means that progress has occurred, while a value of less than one represents a regress. A value of one means that no change has occurred in the level of productivity or its components.
The Malmquist productivity index, therefore, has a very important advantage: it decomposes the productivity changes into efficiency and technology changes. This creates a new way of looking at possible productivity improvements. Based on this view, productivity can be improved through two different approaches: improvements in the technologies of the firm (e.g. obtaining new machinery) or improvements in the efficiency of the firm in using existing technologies (e.g. more training). The idea of decomposing the productivity change was first introduced by Nishimizu and Page (1982) through using a parametric approach for estimating distance functions. Later, the same idea was utilized by Fare et al. (1994) using the non-parametric mathematical programming techniques.

3.3.3. Distance functions

Distance functions allow for the representation of a multi input-multi output technology without assuming any behavioral assumptions such as cost minimization or profit maximization. They can be used to define the Malmquist index number and can be estimated using either parametric (Stochastic Frontier Analysis) or non-parametric methods (Data Envelopment Analysis). Therefore, the Malmquist index may be considered parametric or non-parametric based on the method that is chosen for estimating the distance functions. Distance functions may be input or output oriented. If \( P(x) \) – the output set for the production technology – is defined as (3.7), then the output oriented distance function is written as (3.8).

\[
P(x) = \{y : x \text{ can produce } y \} \tag{3.7}
\]

\[
d_{o}(x,y) = \min \{\delta : (y/\delta) \in P(x)\} \tag{3.8}
\]

In (3.8), output is being proportionally increased (through diving \( y \) by \( \delta \)) so that the resulting \( y/\delta \) still belongs to the output set. Therefore, \( \delta \) has a value of between 0 and 1 (Grifell-Tatje & Lovell, 1995a; Coelli et al., 1998). The closer the unit is to the frontier, the larger is the \( \delta \). A value of 1 means that, given a fixed input, the output cannot be increased (or the distance between the unit and the frontier can not be decreased) anymore; i.e. \((x,y)\) belongs to the production frontier and the unit is efficient.
In this research, DEA is used to estimate the distance functions because of its flexibility compared to the parametric approach. An example for finding the value of a within period output distance function using DEA is shown in (3.9). Here, $x_{it}$ and $y_{it}$ are input and output vectors of unit $i$ in time $t$. Also, $X_t$ and $Y_t$ are input and output matrices at time $t$, comprised of the input and output vectors of all units. The distance function of unit $i$ in time $t$, relative to the frontier of time $t, d_o^t(x_{it}, y_{it})$, can be found by solving the following linear programming problem.

$$\left[ d_o^t(x_{it}, y_{it}) \right]^{-1} = \max \phi$$

s.t. 
$$\phi y_{it} - \lambda Y_t \geq 0$$
$$x_{it} - \lambda X_t \geq 0$$
$$\lambda \geq 0 \quad i = 1, \ldots, n$$

Note that the subscript $i$ has been removed for simplicity in equations (3.3) to (3.6). It can be seen that (3.9) is an output oriented CCR model and the value of the distance function $(1/\phi)$ is actually the CCR efficiency score of the unit. For finding intertemporal distance functions, such as $d_s(x_{it}, y_{it})$, another DEA model like (3.10) can be used.

$$\left[ d_s^t(x_{it}, y_{it}) \right]^{-1} = \max \phi$$

s.t. 
$$\phi y_{it} - \lambda Y_s \geq 0$$
$$x_{it} - \lambda X_s \geq 0$$
$$\lambda \geq 0 \quad i = 1, \ldots, n$$

It should be noted that, in order to obtain accurate measures of TFP change and its components, the constant returns-to-scale (CRS) assumption needs to hold, as is the case in (3.9) and (3.10). Grifell-Tatje and Lovell (1995a) used an example to show that MPI does not provide correct measures of TFP change when variable returns-to-scale (VRS) are present. There have been efforts to introduce new methods of decomposing the Malmquist index (see for example Ray & Desli, 1997; Grifell-Tatje & Lovell, 1995b; and Balk, 2001). Ray and Delsi (1997) proposed an alternative decomposition for the MPI. Based on their study, the CRS MPI could be written as the product of the VRS MPI and
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the scale effect. Grifell-Tatje and Lovell (1995b) also developed a Generalized MPI (GMPI) that took into account the effect of scale change. GMPI can be written as the product of the original MPI and a scale effect. Balk (2001) proposed a scale effect factor with a slight difference from the one introduced by Ray and Desli (1997).

However, apart from the possible inaccurate productivity decompositions, using the VRS DEA models to estimate the distance functions may also result in some computational difficulties and infeasible LPs (this may happen when calculating the intertemporal distance functions). The CRS assumption is, therefore, still suggested by many researchers and is utilized in this research.

Additionally, the choice between radial and non-radial DEA models is also important. In radial models, slack variables – non-radial input excess (output shortfall) – are neglected. There have been some efforts to develop non-radial Malmquist indices (Tone, 2001 and 2002; Chen, 2003). Tone (2001) developed a Slack-Based Measure (SBM) of efficiency and then further developed it to include super-efficiency, as well (Tone, 2002). This measure, when used to estimate the distance functions, would lead to a non-radial Malmquist index. Chen (2003) also proposed a more relaxed non-radial measure in which free slacks were allowed. The non-radial Malmquist index was found suitable for the purpose of this research because it provides a more realistic picture of the changes in the efficiency by including the slack variables. The basic SBM model was first proposed by Tone (2001 and 2002). The formulation of this model is presented here.

Assume we have \( n \) DMUs, using \( m \) inputs to produce \( s \) outputs. If the input and output sets are shown by \( X \) and \( Y \) matrices where \( X = (x_\cdot) \in R^{m \times n} \) and \( Y = (y_\cdot) \in R^{s \times n} \) and \( x \) and \( y \) are input and output vectors for one DMU, then the production possibility set can be written as:

\[
P = \{ (x, y) | x \geq X \lambda, y \leq Y \lambda, \lambda \geq 0 \} \tag{3.11}
\]

where \( \lambda \) is a non-negative vector in \( R^a \). The input and output vectors for DMU \(_0\) can be written as (3.12) and (3.13)

\[
x_\cdot = X \lambda + s^- \tag{3.12}
\]
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\[ y_o = Y\lambda - s^+ \]  \hspace{1cm} (3.13)

where \( \lambda, s^, \text{ and } s^+ \) are non-negative. The vectors \( s^- \in \mathbb{R}^m \) and \( s^+ \in \mathbb{R}^r \) are input *excess* and output *shortfall*, respectively, and are used to transform the inequalities in (3.11) into the form of equalities in (3.12) and (3.13). They are also called *slacks*.

A slack based index, \( \rho \), is defined using \( s^- \) and \( s^+ \) (Tone, 2001).

\[
\rho = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s_i^-}{1 - \frac{1}{s} \sum_{r=1}^{s} s_r^+}
\]  \hspace{1cm} (3.14)

It can be shown that \( 0 < \rho \leq 1 \). The mathematical programming problem for finding the SBM efficiency is as shown in (3.15), which is basically a DEA model with a modified objective function (Tone, 2001 and 2004).

\[
\begin{align*}
\text{min} & \quad \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s_i^-}{1 + \frac{1}{s} \sum_{r=1}^{s} s_r^+} \\
\text{s.t.} & \quad x_o = X\lambda + s^- \\
& \quad y_o = Y\lambda - s^+ \\
& \quad \lambda, s^-, s^+ \geq 0
\end{align*}
\]  \hspace{1cm} (3.15)

The fractional problem in (3.15) can be transformed into a linear programming (LP) problem to facilitate calculations. The reader is referred to Tone (2001) for details of such a transformation. A DMU is considered SBM-efficient if \( \rho^* = 1 \). This is equivalent to having slack vectors equal to zero. Tone (2001) proved that a DMU is SBM-efficient if and only if it is CCR efficient. It should also be mentioned that the non-radial model in (3.15) is non-oriented as well, meaning that it tries to minimize both input and output slacks simultaneously. Changing the objective function to include only input (output) slacks will result in an input oriented (output oriented) model (Tone, 2002). The main advantage of the non-oriented model is that it takes into account the unit’s improvement in both input reduction and output increase. Furthermore, non-oriented models always result in a feasible answer, even in the presence of VRS (Tone, 2004).
The SBM model can further be improved by incorporating additional bounds on the slacks to limit the amount that inputs (outputs) can be decreased (increased). Super SBM efficiency is another concept introduced by Tone (2002) as a solution for the problem of ranking the efficient units in DEA. This method measures the efficiency of any DMU₀ relative to a frontier which excludes DMU₀. Therefore, the resulting efficiency score might be more than 1 and units that are all efficient in the original DEA model can be ranked based on the new super-efficiency score (Tone, 2002). The software package used for the analysis in this research was based upon the SBM and super-SBM models discussed here.

3.4. Data

3.4.1. Canada

Beginning in 1971, Statistics Canada has been gathering principal industrial statistics (such as shipments, employment, salaries and wages, cost of materials and supplies used, cost of energy, etc.) from manufacturing establishments in Canada through the Annual Survey of Manufactures (ASM). This survey is intended to cover all manufacturing establishments and their associated sales offices (Statistics Canada, 2005a). Data for the Canadian manufacturing industries in this study were obtained from Statistics Canada (Industry Canada, 2005b) based on principle establishments data. Principle establishments are those establishments with employees (therefore excluding non-employers) and an income greater than $30,000 per year (Industry Canada, 2005a).

Statistics Canada is currently classifying the data on different industries according to North American Industry Classification System (NAICS). Starting from 1997, NAICS was adopted by Canada, Mexico and the United States in conjunction with the conditions of NAFTA, to provide common definitions of the industrial structure and facilitate the analysis of the three economies. In 2002, a revision was made on NAICS (Statistics Canada, 2003).

Data items available in the original dataset are listed below. The data were available in the aggregate form at the industry level, not for individual establishments.

- Number of active establishments in each industry
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- Number of production and administrative employees
- Total wages and salaries paid to production and administrative employees
- Manufacturing shipments
- Manufacturing value added
- Total revenue
- Total hours worked by production employees
- Cost of material and supplies for manufacturing and non-manufacturing activities
- Cost of fuel and electricity
- Annual capital investment in machinery and in construction
- Accumulated capital investment in machinery and in construction

Because of the data availability, the study period was selected to be from 1994 to 2002. Although desirable, it was not possible to include all the inputs (capital, labour, material and energy) in the production model. The data for annual capital expenditure were not available for two of the industries (beverage and tobacco products manufacturing, leather and allied products manufacturing); therefore this input could not be included in the analysis. Consequently, the production model in this study was developed using three inputs and one output. The production model is shown in Figure 3-5.

![Figure 3-5. Production model for the Canadian manufacturing industries](image)

Since the number of employees and the total hours worked and the total wages paid were interdependent, only one of them (number of employees) was included in the model. It was not possible to look at the manufacturing activities only, since the data for fuel and electricity were not available for manufacturing and non-manufacturing activities separately. In addition, no manufacturing facility can operate without the non-manufacturing support activities such as design and development, marketing, etc. Therefore, total activity is also an appropriate measure for identifying how the overall
business is being performed. Consequently, the total costs of materials and energy and the total number of employees were used in the model. Total revenues were used as a measure of output that included revenues from both manufacturing and non-manufacturing activities. For detailed definitions of all inputs and outputs as well as survey description, refer to Industry Canada (2005c).

The data were available in current dollar values; therefore, they needed to be adjusted for inflation over time. The data included dollar values at the industry level; therefore instead of using Consumer Price Index (CPI), Industrial Products Price Index (IPPI), obtained from Statistics Canada (2005d), was used. The IPPI measures price changes for major commodities sold by manufacturers in Canada. Unlike CPI, IPPI reflects the prices of the manufactured goods up to the point that they are sent out of the manufacturing establishment. These prices include the changes in the price of raw materials but exclude indirect taxes and all the costs (e.g. transportation, wholesale, and retail costs) that occur until the final user purchases the products (Statistics Canada 2005c). Therefore, IPPI is a suitable indicator of the changes in the prices of manufactured goods in Canada at the industry level. The summary statistics shown in Table 3-1 are presented in constant 1997 Canadian billion dollars. The first three columns show the summary statistics for the inputs and the last column summarizes the output data.

Table 3-1. Summary statistics for the Canadian manufacturing sector data

<table>
<thead>
<tr>
<th></th>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Employees</td>
<td>Energy</td>
</tr>
<tr>
<td>Average</td>
<td>243,797</td>
<td>2.97</td>
</tr>
<tr>
<td>Maximum</td>
<td>9,974</td>
<td>0.01</td>
</tr>
<tr>
<td>Minimum</td>
<td>86,974</td>
<td>0.52</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>59,139</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Data for energy, material and total revenues are presented in constant 1997 Canadian billion dollars.

3.4.2. United States

Data for the U.S. manufacturing sector were extracted from the U.S. Census Bureau (2003 and 2005). The data were based on 2001 and 2003 Annual Survey of Manufactures (ASM) conducted in the U.S. This survey gathers data from all
establishments with one or more paid employees. Starting from 1997, data on manufacturing establishments have been classified using the NAICS system. Therefore, the definitions of the U.S. industries are the same as the Canadian industries. For time periods before 1997, the industries are classified based on the Standard Industrial Classification and, therefore, could not be included in the analysis. The study period was selected to be from 1997 to 2002 because of the data availability.

The reports from the Census Bureau include data on:

- Number of all employees and their wages
- Number of production employees and their wages and hours worked
- Total shipments
- Total value added
- Total cost of materials
- Cost of purchased fuel and electric energy
- Annual capital investment in machinery and in construction

In order to have a similar model for productivity measurement in Canada and the U.S., number of employees, cost of materials, and cost of energy were used as inputs. However, the data on the total revenue of industries were not available in this report. Instead, “total shipments” data were available. The definition of “total shipments” was very similar to the “total revenues” in the Canadian industries, except that it specifically excluded the revenue generated from the rental or lease of products or real property while the definition of total revenue in Statistics Canada included such an income. The production model used for the analysis of the U.S. manufacturing sector is the same as in Figure 3-5 (page 73), with the exception that the output is the “total shipments”. Therefore, the data for the two countries could not be used in a single combined analysis and had to be analyzed separately. Consequently, it should be kept in mind that the results from the two analyses are not directly comparable.

Again, a deflator is needed to make dollar values comparable across time. Similar to the Canadian data, the U.S. manufacturing data were also at the industry level and therefore, Producer Price Index (PPI) was selected for deflation. PPI, similar to IPPI for Canada, measures the changes in the prices of the manufactured goods and includes only
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the prices that the first purchaser of the product pays. It does not include taxes or other expenses that occur after the products leave the plant (U.S. Bureau of Labour Statistics, 2005). PPI was found most suitable for the purpose of deflating the data in this study and was used to transform the data to constant 1984 U.S. dollars. The summary statistics of the U.S. manufacturing sector data are shown in Table 3-2.

Table 3-2. Summary statistics for the U.S. manufacturing sector data

<table>
<thead>
<tr>
<th></th>
<th>Employees</th>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>1,886,700</td>
<td>12.13</td>
<td>321.05</td>
</tr>
<tr>
<td>Maximum</td>
<td>44,728</td>
<td>0.04</td>
<td>2.49</td>
</tr>
<tr>
<td>Minimum</td>
<td>775,253</td>
<td>2.55</td>
<td>75.91</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>528,199</td>
<td>2.49</td>
<td>70.65</td>
</tr>
</tbody>
</table>

Data for energy, material and total shipments are presented in constant 1984 U.S. billion dollars.

It should be noted that what is referred to as “wood industry” in this chapter includes only sawmilling and wood preservation, veneer, plywood and engineered wood products and other wood products such as millwork, etc. Based on NAICS definitions, “wood furniture” and “pulp and paper” products are excluded from the wood products manufacturing and results should be interpreted based on these definitions.

3.5. Analysis, results and discussion

The productivity change of the manufacturing industries in both Canada and the U.S. were measured using the Malmquist Productivity Index. The change was then decomposed into technical efficiency growth and the frontier shift (technical change) in order to further identify the sources of the productivity change. A DEA model with the CRS assumption was used to estimate the required distance functions. Although a VRS assumption would have better represented the different sizes of the industries, it also would have created problems in decomposing the productivity changes accurately. The scale effect factor could also create some interpretation issues. Therefore, in order to have an accurate and straight forward measure of productivity change, the CRS frontier was selected. This CRS model was both non-radial (slack-based) and non-oriented, as explained in section 3.3.3. A software program (DEA-Solver Pro 4.0) was used to perform the analysis.
For both countries, the fixed-base period approach was selected for productivity change measurement. This provided a better picture of how the performance of the industries had changed during the study period compared to their initial position.

3.5.1. Canada

The summary of results for the Canadian manufacturing sector is presented in Table 3-3. Note that the TFP change and its components relate to the base period of 1994. The results are presented for the whole sector (average over all 21 industries), the industries with highest and lowest TFP change and the wood products manufacturing industry.

<table>
<thead>
<tr>
<th>Table 3-3. Malmquist analysis summary for the Canadian manufacturing industries</th>
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<tbody>
<tr>
<td><strong>Productivity change</strong></td>
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<tr>
<td>Manufacturing sector (Average)</td>
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<tr>
<td>Petroleum and coal products manufacturing</td>
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<td>Wood products manufacturing</td>
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<td>Food manufacturing</td>
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</table>

The manufacturing sector as a whole showed a 9% growth in productivity during the study period. This growth had been the result of both efficiency improvements and the frontier shift. However, frontier shift had a slightly larger share. This matches the findings of previous studies that showed higher impact of technological progress on the productivity growth in manufacturing industries across the world (Zaim and Taskin, 1997; Maudos et al., 1999; Kim & Han, 2001; Shestalova, 2003). In a study by the Centre for the Study of Living Standards (CSLS), the TFP growth for the Canadian manufacturing sector were reported to be 1.1% per year (Sharpe, 2003) over the period 1987 to 2001, which matched the findings of this study. Detailed results for MPI and its components are presented in Appendix A.

The highest productivity change during the period 1994-2002 was that of the petroleum and coal products manufacturing with a total growth of 1.78. The lowest TFP change was found for the food manufacturing with a TFP change of 0.92. Based on the results, wood industry had an overall decline in the total factor productivity during the period 1994 to 2002. The productivity fell by 5% during this period, due to the combined
effect of the efficiency change and the frontier shift. The efficiency of the wood product manufacturing sector declined by 7% from 1994 to 2002, while the frontier shift effect was 1.04. Wood industry was performing below the manufacturing sector average and the technical inefficiency accounted for most of this gap. Based on the TFP change, wood products manufacturing was ranked 20\textsuperscript{th} out of 21 industries, ahead of only food manufacturing. This low performance could be attributed to the low efficiency growth of this industry - it was ranked 19\textsuperscript{th} based on the catch-up effect, while based on frontier shift, it was ranked 11\textsuperscript{th}.

Figure 3-6 illustrates the relative position of the wood industry compared to the industries with highest and lowest TFP change and the average for the manufacturing sector. Note that all values are relative to the base year of 1994. An important thing to note here is that the food industry performed better than wood products manufacturing in most years; however, the TFP change over the whole period showed a decline, larger than that of the wood industry. It is also seen that the gap between the growth rate of wood industry and the petroleum industry increased rapidly, especially towards the end of the period. Different components of productivity change for wood industry are illustrated in Figure 3-7. It is clear that the total factor productivity level during the study period never grew higher than the 1994 level. Since the study period for this research was different from that of the previous studies and the data sources and the classification of the industries have also been different, it is not possible to compare the results of this study with previous studies. Some of the previous studies (Denny et al., 1981; Fluet & Lefebvre, 1987) identified the wood industry as a poor performer among other manufacturing industries, while others (Denny et al., 1992; Malley et al., 2003) reported the opposite.
Petroleum and coal products manufacturing revenue increased rapidly during the study period; $35.3 billion in 2002 compared to $17.2 billion in 1994 (Industry Canada, 2005b). This rapid output growth was accompanied by a decrease in the number of employees; the number of employees decreased by about 5,000 from 1994 to 2002 (Industry Canada, 2005b). This increase in the outputs, along with a decrease in inputs, could have been the reason for the rapid productivity growth of this industry. The sharp increase in the revenues of the petroleum industry was most likely the result of increasing oil prices. Oil prices changed from approximately U.S. $10/barrel in January 1999 to
around US $30/barrel in January 2000, because Organization of Petroleum Exporting Countries (OPEC) reduced its production and the production increases from other exporting countries was not enough to cover the demand (Horn, 2004). The prices have been increasing ever since and have contributed to the rise in total revenues (Statistics Canada, 2005b). It should be mentioned here that these results are based on the technical efficiency and technology change analysis rather than a cost efficiency analysis. If the data on the unit prices of all inputs were available, a cost efficiency analysis could have been performed and the effect of price changes on the results could have been studied more closely.

Food manufacturing showed an overall TFP decline over the study period that was larger than all other industries, including the wood industry. However, it was performed better than wood products manufacturing until 1999. A sharp increase in the number of employees from 1998 to 1999 (more than 17,000) and also from 1999 to 2000 (more than 13,000), along with a decline in the total revenues in 2000, could have been partially responsible for this productivity decrease (Industry Canada, 2005b). The prices for food products showed a decline between 1998 and 2001 (Statistics Canada, 2005b). This price decline was also observed at the global scale, when demand from large importers, such as China, decreased significantly as a result of changing policies (FAO, 2002). Low prices could have resulted in lower revenues of the food industry after 1998. Food industry had previously been identified as having low TFP change rates (Denny et al., 1981; Fluet & Lefebvre, 1987; Denny et al., 1992).

Looking at wood products manufacturing, it is seen that the efficiency change moved almost in the opposite direction of the frontier shift during the study period. This can be explained based on what was suggested by Ma et al. (2002). Their results also showed an inverse relation between the frontier shift and the efficiency change. It can be suggested that the rapid progress of the technology of some leading industries (such as chemical or clothing industries) in the beginning of the period resulted in an upward shift in the frontier. Therefore, the distance between the wood industry and the efficient frontier increased and resulted in a decrease in efficiency. The wood industry caught up somewhat by 2002, although it was still performing below its efficiency levels of 1994. It can be argued that, after the technological progress, the wood industry needed time to
adapt to the new technology and gain enough knowledge to utilize it in a more efficient manner. A slowdown in the technological progress (frontier shift) could also help the industry to catch up. One issue that might arise here is that the technical "regress" has no real interpretation, since the past technologies would not be forgotten. It must be pointed out, however, that the possibility of a certain technology is not solely dependent upon the technical knowledge. Changes in regulations, economic conditions and competitive situations also affect the possible technologies at a given time (Asmild et al., 2004). In the case of wood products manufacturing, the effect of regulatory changes such as imposition of the softwood lumber dispute after 1996 and the economic recession of 2001, could have contributed to the technical regress.

It should be mentioned again that this study focused on comparing productivity change rates, rather than productivity or efficiency levels. Considering that the frontier of each time period was constructed using the observations from all industries, the efficiency level would not be a fair measure for comparing industries. Therefore, in case of wood industry, the rate of productivity change showed that it did not improve its productivity compared to other industries. It is important to mention that these results are based on the factors included in the model, the available data, and the included years and units. Therefore, they need to be interpreted with caution.

3.5.2. United States

The results for the U.S. manufacturing industries are presented in Table 3-4. The U.S. manufacturing sector on average showed a 5% growth in TFP over the whole period, with the major growth contributor being the frontier shift. The efficiency of the sector decreased by 4% over the study period. Since the study period was relatively short and included the recession years of 2000 and 2001, this result is not surprising. The highest productivity change was found for the transportation equipment manufacturing with a TFP growth of 1.23 and the lowest change was that of the computer and electronic product manufacturing with an MPI value of 0.81. The results for MPI and its components for the U.S. are shown in Appendix B.

The results for wood products manufacturing in the U.S. indicated that, like the Canadian wood industry, it had a TFP change below the average of the whole sector
For the wood industry, changes in the components of the productivity change are shown in Figure 3-9. Like the Canadian analysis, the declining frontier shift effect after 1999 can be attributed to the economic recession.

One important thing to point out here is that the numbers obtained for TFP change rate and its components are not comparable between Canada and the U.S. Since the Malmquist index is calculated relative to the efficient frontier and the frontier of the two analyses are constructed separately, the findings can not be compared directly. Only the trend in the TFP change or the relative rankings of the industries can be compared.

A sharp decrease in TFP is seen for the transportation industry in 2001, but the industry bounced back in 2002 with a strong TFP growth. As a matter of fact, with the exception of petroleum and coal products manufacturing, all American industries showed a decline in TFP change rates in 2000 and 2001. This, again, has mainly been the effect of the recession that hit the North American economy. The transportation industry had a decline in the output starting from 1999; it decreased from more than $670 billion in 1999 to $602 billion in 2001 (U.S. Census Bureau, 2003 and 2005). The recession of 2000 hit this industry hard by lowering the demand for transportation equipment, including but not limited to automobiles, and caused a downturn in revenues (Langdon et al., 2002).

The decline in TFP change of the computer and electronic products industry is not surprising since the high tech industries were affected the most by the recession (Federal
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For the wood industry, changes in the components of the productivity change are shown in Figure 3-9. Like the Canadian analysis, the declining frontier shift effect after 1999 can be attributed to the economic recession.

![Figure 3-9. Productivity change components for the American wood products manufacturing (1997=1.0)](image)

One important thing to point out here is that the numbers obtained for TFP change rate and its components are not comparable between Canada and the U.S. Since the Malmquist index is calculated relative to the efficient frontier and the frontier of the two analyses are constructed separately, the findings can not be compared directly. Only the trend in the TFP change or the relative rankings of the industries can be compared.

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The decline in TFP change of the computer and electronic products industry is not surprising since the high tech industries were affected the most by the recession (Federal
Deposit Insurance Corporation, 2004). The main part of the business investment during the late 1990s was linked to computers and information technology (Federal Reserve Bank of San Francisco 2003). In the late 1990's, firms overspent in obtaining new technologies and capacity to meet the high demand for their products. Gordon (2003) listed factors that enhanced the demand for technology products during this period of the new economy: telecom industry deregulation that led to the creation of new firms, each demanding large amounts of equipment to build communication networks; the need to replace computers in order to run a new generation of software starting with Windows 95; the one-time invention of the world wide web, etc. However, the new economy did not last as long as expected. The factors mentioned above were limited in their ability to create enough demand for the increasing supply. After the burst of the stock market bubble and the slowdown of the new economy, high tech industries were the ones who experienced the highest decline. Total shipments growth of the computer and electronic products slowed down in 2000 and declined significantly in 2001 (U.S. Census Bureau, 2003 and 2005).

3.5.3. Wood products manufacturing productivity change

The results indicated that the wood products manufacturing in both countries had a decline in TFP and was performing below the average for the manufacturing sector. The ranking of the industry relative to other industries showed that it was among the industries with the lowest TFP change in both Canada and the U.S. Based on what was suggested in previous studies, two main determinants of the productivity change are physical capital and human capital (Harris, 1999; Mahadevan, 2002). Other factors that can affect the productivity are openness to trade, foreign direct investment, market demand, and research and development (Harris, 1999; Mahadevan, 2002). Because the data on other factors were not available, the two main factors are discussed here.

Investments in machinery and equipment are believed to improve technology and, consequently, productivity. Also, new technology combined with the right knowledge would, after some time, increase the technical efficiency (Harris, 1999; Mahadevan, 2002). Investments in infrastructure is also argued to have an effect on the productivity (Mahadevan, 2002). In both Canada and the U.S., the real value of the total capital
investments in the wood industry decreased from 1994 to 2002. In Canada, the total capital expenditure decreased from $1.38 billion in 1994 to $0.741 billion in 2002 (Industry Canada, 2005b), while in the U.S., the amount declined from $2.25 billion in 1997 to $1.81 billion in 2002 (U.S. Census Bureau, 2003 and 2005). This could have been a factor leading to the decline in TFP of wood products manufacturing in the two countries.

Human capital is another factor that might have affected the TFP change. Having access to a skilled labour force is more likely to result in new technology (through product or process innovation) and productivity improvements (Harris 1999). Based on a report by Human Resources and Skills Development of Canada (HRSDC) (2005), a high proportion of the 1996 labour force in the Canadian wood industry did not have a certificate or a diploma (45% of the workers, compared to the national average of less than 25%). Additionally, the proportion of the workers with a university degree was 5.2% compared to the national average of 21% (HRSDC, 2005). Although the national average includes the service industries (such as health care, banking, etc.) that usually need higher education levels, the statistics indicate that the wood industry had been lagging behind other industries with respect to an educated labour force and this could have had a negative effect on its productivity change. Low levels of education may prevent the industry from obtaining new technologies and creating new ideas. For example, although the employees may still be able to operate the existing machinery and equipment, it will be difficult for them to work efficiently with new equipments. To the best knowledge of the author, no relevant data on the education level of the workforce in the U.S. wood industry is available and, therefore, no additional discussion can be made here.

3.6. Conclusion

The manufacturing sector is a very important part of the economy both in Canada and the U.S. It is a major contributor to GDP and affects the economic well-being of each nation, both directly and indirectly. Over the long run, productivity growth is the only factor that can guarantee the manufacturing output growth and, consequently, improve the living standards of the population.
In this research, the productivity changes of the manufacturing industries in Canada from were evaluated 1994 to 2002. The U.S. manufacturing industries were also studied from 1997 to 2002. Considering the importance of wood products manufacturing in Canada, the performance of this industry was highlighted. A Malmquist index number with non-parametric distance functions was used for the purpose of TFP change measurement in both countries. The Malmquist index has the advantage of not requiring any price data, unlike other productivity indices. Furthermore, the productivity change can be decomposed into two main components: frontier shift and technical efficiency change.

The manufacturing sector as a whole had a TFP growth in both countries with the frontier shift being the main reason for growth. The recession of 2001 was shown to have negatively affected almost all industries, although the effect was higher for some industries such as transportation equipment manufacturing. Another finding of the study was that the wood products manufacturing was among the industries with the lowest TFP change in Canada and the U.S. and had a decline in TFP. Frontier shift in the industry was positive in both countries while the technical efficiency change accounted for the decline in the TFP. This decline could have been due to various factors such as the decline in capital expenditure and the low education level of the work force. Since the frontier shift was positive during the study period, having a more educated workforce could have been helpful in utilizing the new technologies and, consequently, in improving the technical efficiency.

The results of this research are helpful in realizing how different industries performed during a time that included both growth and recession periods. It also suggests that, in order to improve its productivity, the wood industry needs to invest more in both physical and human capital. Investing in machinery and equipment alone cannot generate productivity growth since the efficient use of the new technology requires the knowledge and training of the workforce. Efficiency declines seemed to be the major source of TFP decline in the wood products manufacturing and, therefore, more attention should be paid to this component of productivity change. Better management techniques, a by-product of an educated workforce, and improved input utilization patterns can help to improve the technical efficiency over time.
This research, of course, has drawbacks. Comparisons among manufacturing industries have been previously done in the literature and can be justified by emphasizing common features; operating in the same country and in a similar economic environment. However, since the industries are very different in nature and the underlying frontier in the Malmquist analysis was constructed using a non-parametric CRS model including all industries, it can be argued that the comparisons were not fair to some industries, such as wood products manufacturing. An attempt to overcome this issue was made by focusing on the productivity change rates rather than the absolute efficiency levels. However, the frontier shift was still affected by the movement of some leading industries through time that affected the TFP change rates of all industries. Furthermore, data availability issues limited the study by preventing the inclusion of capital investment data and the quantitative comparison of the results between Canada and the U.S.

This work can be extended in different ways. Depending on the availability of the data, the same analysis can be carried out in a way that the results from the two countries are comparable. Also, more factors can be included to generalize the production model. One important improvement to the study would be the addition of weight constraints in order to account for the different importance of the input factors. Using a VRS model for estimating the distance functions may also add to our understanding of the productivity change components in the observed industries. Using a parametric distance function and comparing the TFP change and its components could also provide interesting insights on how the estimates differ between the two methods.
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Chapter 4

Efficiency Changes of the Canadian Wood Products Manufacturing

4.1. Introduction

4.1.1. Wood product industries in Canada

Forestry has a vital role in Canada's economy. It is the largest single contributing industry to the national GDP, accounting for $33.7 billion of the total in 2003. Furthermore, forestry is a major source of employment for Canadians, creating close to one million direct and indirect jobs (Forest Products Association of Canada, 2003). A major part of the economic contribution of the forest industries is through exports. Currently, Canadian forest products are being exported to over 120 countries around the world (Natural Resources Canada, 2003). In 2003, trade surplus (exports minus imports)
for the forest industries was about 65% of Canada’s total trade surplus (Canadian Forest Service, 2004). This clearly indicates that forest products play an important role in the economic well-being of the Canadians.

Forest industries can be divided into three major sectors: logging, pulp and paper, and wood products manufacturing. Wood products manufacturing refers to processing harvested wood to manufacture lumber, wood panels, and other wood products. It accounts for more than half of the direct employment in the forestry sector (Canadian Forest Service, 2004). Wood products manufacturing is comprised of three sub-sectors: sawmills and wood preservation, veneer, plywood and Engineered Wood Products (EWP) manufacturing, and other wood products manufacturing. The 2003 employment and revenue share of each sub-sector is shown in Figure 4-1. The sawmills and wood preservation sub-sector has the highest share in both cases.

![Figure 4-1. Employment and revenue share of wood products manufacturing sub-sectors in 2003; Industry Canada (2005a)](image)

Similar to the forestry sector, wood products manufacturing is an export oriented industry. In 2003, 57% of the total production of the wood products manufacturing in Canada was exported (Industry Canada, 2005c). Therefore, it is very important for the wood industry to remain competitive in the international market. Historical data indicate that the global trade for wood products has been increasing during the last 40 years and it is expected to grow even more; the global trade for wood products (sawnwood and wood based panels) has increased from around $2 billion in 1961 to more than $44 billion in 2003 (FAOSTAT, 2005). However, many countries have entered the market with an
advantage over Canadian producers, namely access to cheaper resources (Hashiramoto et al., 2004). This means that the Canadian producers need to become more efficient in their operations to lower their costs without sacrificing the quality of their products.

Trade regulations have also impacted Canada’s competitiveness in the global market (Natural Resources Canada, 2003; Eastin & Fukuda, 2001; Nagubadi & Zhang, 2004). There have been different tariff and non-tariff barriers imposed on the Canadian wood industry in recent years. The European Union enforced a ban on the import of the green softwood lumber in 1993 to prevent the introduction of pinewood nematode. This has been considered a non-tariff barrier that limited Canada’s access to one of its important export markets, the United Kingdom (Cohen et al., 2003). In addition, the Softwood Lumber Agreement (SLA), from 1996 to 2001, limited the amount of lumber exported from Canada to the US (Cohen et al., 2003; Eastin & Fukuda, 2001). These regulations have challenged the export opportunities of the Canadian wood industry and appropriate actions are required in response.

An important response to the changing environment in the wood industry has been the shifts in the structure of this industry. Figure 3 shows that the export share of sawmilling products out of total wood products exports has decreased from 85% in 1992 to almost 57% in 2004, while wood panels and other wood products have been gaining share (their export shares more than doubled during the same period). The SLA has been partially responsible for a movement towards producing more processed wood products that were not regulated under it (Eastin & Fukuda, 2001). It has been argued that the reliance of the Canadian wood industry on lumber products has made it susceptible to the demand changes caused by the changing trade regulations (Industry Canada, 2002). Based on a recent study, the lumber prices during the period from 1996 to 2001 (after the SLA was in effect) showed larger fluctuations compared to the preceding 30 years (Nagubadi & Zhang, 2004). This concern, along with changes in resource characteristics, has shifted the wood industry towards more value-added products such as wood panels and Engineered Wood Products (EWP). The manufacturing of EWP has been encouraged by the government in order to optimize resource utilization, create jobs and increase exports (Industry Canada, 2002; Sustainable Forest Management Network, 2005). This can be seen through specific research funding for promoting or manufacturing these
products, such as a $15 million budget allocated in 2002 for research initiatives in the area of value-added wood products (Natural Resources Canada, 2002).

![Figure 4-2. Share of total exports for wood industry sub-sectors in Canada; Industry Canada (2005a)](image)

Considering what was said, the challenges have resulted in a trend to transform a commodity-based industry into a value-added one. The importance of the wood industry for the Canadian economy requires closely monitoring its performance during this transformation stage. Performance assessment techniques can be used for this purpose. They help in creating benchmarks for the wood industry and make it possible to compare its performance at different points in time. As a matter of fact, Statistics Canada is currently using some performance measures to monitor industries' performance over time (Industry Canada, 2005d). These measures will be discussed briefly in turn.

### 4.1.2. Performance measures used by Statistics Canada

A simple method for measuring the performance of an operating unit is a performance indicator, which is typically a ratio of one output to one input; e.g. labour productivity which is the ratio of output to labour input. These ratios are also called partial measures of productivity; since they take into account only one input and one output of the production process. Statistics Canada is currently reporting some partial performance measures for wood industry sub-sectors. These measures are (industry Canada, 2005d):
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- Manufacturing shipment per employee
- Manufacturing shipment per production employee
- Manufacturing value-added per employee
- Manufacturing value-added per production employee
- Manufacturing value-added per hours worked (labour productivity)
- Net revenue (Although it is used as a performance measure, net revenue is not a ratio. It is calculated as the total revenue minus the cost of material, labour and energy.)

These measures are reported for each sub-sector in different years and the trends are studied to see if the sub-sector’s performance has improved or declined. For example, manufacturing shipment per employee for the three sub-sectors is shown in Figure 4-3. Based on this indicator, sawmilling and wood preservation has been the best performer during the period 1994 to 2002.

![Figure 4-3. Manufacturing shipment per employee; Industry Canada (2005a)](image)

Although these partial indicators can help in understanding individual aspects of the production, they can not provide an overall picture of how the sub-sectors are performing. For example, if manufacturing shipment per employee has increased for a sub-sector, it might be the result of substituting labour with capital. An industry might have invested intensively in machinery and equipment and, therefore, less labour input is needed to produce the same level of output. Figure 4-4 shows the ratio of manufacturing
shipment to annual capital investment for the Canadian wood products manufacturing sub-sectors for example. This is a ratio representing one output and one input of the sub-sectors’ production process. This ratio gives a completely different picture of how the sub-sectors have performed during the period 1994-2002. Other wood products manufacturing is identified as the best performer. This is because other wood products manufacturing is more labour-intensive and uses less capital input compared to the other sub-sectors (Industry Canada, 2005a). Therefore, it appears to be performing better when capital is used to construct the partial measure. It should be noted that currently, Statistics Canada does not report any performance measures that include capital input.

Statistics Canada reports these performance indicators for each sub-sector separately. Studying each sub-sector individually makes it more difficult to see how sub-sectors are performing relative to each other. Therefore, an alternative methodology was selected in this research.

4.1.3. Research Objectives

This study has two main objectives:

1. It aims to measure the efficiency changes of the Canadian wood products manufacturing sub-sectors during the period 1994-2002. Sub-sectors in different years are compared together and the relative efficiency of each sub-
sector in each year is measured. This comparison has not been done previously and this study will provide a better understanding of how the wood industry sub-sectors have performed relative to each other during the study period. A non-parametric efficiency measurement technique called Data Envelopment Analysis (DEA) is used for this purpose. DEA can measure the relative efficiency of comparable units by considering multiple inputs and outputs.

2. This study also intends to compare the obtained results with the partial performance measures provided by Statistics Canada. This is done to see if there are any correlations between the results of this study and what is currently being reported. This helps in further validating the current performance measures or identifying possible discrepancies among different indicators. A non-parametric statistical test – Spearman’s rank coefficient – is utilized for this comparison.

The rest of this chapter is organized as follows. A brief introduction on DEA with weight restriction and related studies is given in section 4.2. The DEA methodology and the statistical test are explained in section 4.3, followed by the data set description in section 4.4. Section 4.5 includes the analysis, results and discussions. Conclusions are provided in section 4.6.

4.2. Literature review

4.2.1. Review of DEA studies with weight restrictions

Although partial measures are simple and easy to calculate and interpret, they have some shortcomings. They cannot incorporate multiple inputs and outputs at the same time. Furthermore, if different partial measures are used to evaluate a unit’s performance with regards to different factors, each measure may produce a different result. Consequently, it is difficult to decide how the unit is actually performing. In these cases, a modeling approach to measuring efficiency has to be used. This approach uses modeling techniques to incorporate multiple inputs and outputs of the production in one performance measure. It may or may not require a functional relationship between the inputs and the outputs (parametric and non-parametric approaches, respectively).
The non-parametric approach to efficiency measurement, DEA does not require a priori assumption on the input/output relationship and is more flexible compared to parametric methods. However, DEA does not consider the errors and noise in the data and is deterministic in nature. This means that DEA assumes that all the variations from the efficient frontier are because of inefficiency, not because of noise in the data (Murillo-Zamarano & Vega-Cervera, 2001). Also, DEA does not incorporate random variables and probabilities. In such cases, stochastic DEA can be used.

There have been different improvements and additions made to DEA since it was first introduced by Charnes et al. (1978). One of the important extensions to DEA was weight restrictions, introduced by Thompson et al. (1986).

Basic DEA models maximize the efficiency score through the allocation of the most favourable weights to inputs and outputs. This has been identified as one of the important advantages of DEA. However, sometimes this can be a drawback. If a DMU utilizes high levels of some inputs to produce the outputs, the DEA model assigns very small, even zero, weights to those inputs. Similarly, if a DMU is producing low levels of certain outputs, the DEA model gives lower weights to those outputs. This may result in considering only a subset of inputs and outputs of a DMU in the efficiency score in order to present it in the best possible way. Furthermore, if some production factors are more important in management’s view, it is important to be able to control their weights and incorporate additional preferences. High variation of the same input and output weights among different DMUs might also be unacceptable in some cases.

Weight restriction in DEA helps in incorporating managerial preferences and additional knowledge into the model. Weight restriction was introduced in 1986 by Thompson et al. (1986) and has been used in different contexts thereafter (e.g. Dyson & Thanassoulis, 1988; Thompson et al., 1990; Schaffnit et al., 1997; Joro & Vittala, 1999). The main objective of weight restriction is to create some bounds within which the weights can vary (Angulo-Meza & Lins, 2002).

Weight restriction techniques can also be used for discriminating between efficient units (Allen et al., 1997; Thanassoulis, 2001). If a large proportion of the DMUs under observation are found to be efficient by the basic DEA models, we may wish to use
the restricted model to choose only those units whose weights are within the acceptable range. Generally, the DEA efficiency scores are decreased by adding the multiplier constraints and units previously identified as efficient might consequently be classified as inefficient (Cooper et al., 2000; Joro & Viitala, 1999). Interpretation of the results, efficiency scores and efficiency targets may also differ in restricted models (Allen et al., 1997; Thanssoulis, 2001).

There are different approaches to weight restriction. Applying absolute bounds on weights is one method (Dyson & Thanassoulis, 1988; Beasley, 1990; Roll et al., 1991). Thanassoulis et al. (1987) studied the relative efficiency of the local rate collection offices in London and found that some offices were identified as efficient because of the extremely high weights of their favorable outputs. In order to incorporate the preferences of the managers who were concerned about these results, Dyson and Thanassoulis (1988) used upper and lower bounds to restrict the flexibility of the weights. In this approach, numerical values are imposed as the limits to input and output weights. Beasley (1990) used this technique to compare the performance of university departments in the U.K. Roll et al. (1991) generalized this approach and discussed the ways to choose these numerical bounds. The upper and lower bounds should be chosen after running the original unbounded DEA model. The bounds are selected based on the assigned weights in the original DEA model. If the restricted model faces infeasibility, the bounds should be relaxed until a feasible solution is reached (Roll et al., 1991). It should be mentioned that even under constant returns-to-scale, this approach produces different efficiency results based on different orientations (output or input) of the model (Angulo-Meza & Lins, 2002).

Another way to incorporate additional restrictions on weights is the ordering of input and output weights. This method was proposed by Golany (1988) and the idea is to maintain the ordering of weights based on some additional knowledge. For example, if the price of input 1 is higher than input 2, then it should have a higher weight, too. However, this method does not use the price information to determine the relative magnitude of these weights; i.e. how much higher should the weight for input 1 be relative to input 2.
A different method, the *Cone ratio* model, was developed by Sun (1988) and Charnes et al. (1989 and 1990). In this approach, the input-output weights are restricted to be in a convex cone by adding some constraints. In the cone ratio formulation, the cones are defined using a number of direction vectors. The main advantage of this model is that DEA software that cannot incorporate weight constraints can be used to solve it. This is because of the formulation process in this method (Allen et al., 1997; Angulo-Meza & Lins, 2002). Furthermore, the cone ratio model always gives at least one efficient DMU (Allen et al., 1997). The data from the DMUs that are considered good performers can be used in order to define the closed cones (Cooper et al., 2004). However, one drawback of the cone ratio model is that the input and output data need to be transformed using the direction vectors before the model can be solved and, in order to interpret the results, they should be transformed back to the original form (Allen et al., 1997; Angulo-Meza & Lins, 2002). For detailed description of the cone ratio formulation, see Cooper et al. (2000 and 2004).

The Assurance Region (AR) model was introduced by Thompson et al. (1986 and 1990) to solve the problem of infeasibility resulting from absolute weight restrictions. They used this approach to compare six different sites for the location of a high-energy physics lab in Texas. In AR models, upper and lower bounds are imposed on the relative magnitude of the weights for certain inputs (outputs). The advantage of the AR model is that it is relatively easy to interpret since it is reflecting the relative importance of inputs or outputs compared to each other. The AR approach is especially useful when unit prices for input and outputs are not known exactly, but a range can be defined for their values. The generality of AR models also provides more flexibility in using them (Cooper et al., 2004). However, there are cases that no explicit ranges can be identified for the ratio of weights. In these cases, the cone ratio method can be more helpful since it *transforms* the data instead of imposing bounds on the weight ratios. The direction vectors to transform the data can be obtained from selected DMUs within the sample. Under constant returns-to-scale, both AR and cone ratio methods generate the same efficiency score for input and output oriented cases.

Schaffnit et al. (1997) used the AR model to compare the performance of the branches of a large Canadian bank in Ontario. The author imposed bounds on the ratio of
output weights. These bounds were determined by adding a tolerance range to the ratio of
the observed outputs. Joro and Viitala (1999) applied both AR and the ordering of
weights – as proposed by Golany (1988) – to data from 19 public forestry boards in
Finland. They found that high and low performers were consistent using both models, but
that the ranking of other DMUs varied across the models.

4.2.2. Review of non-parametric statistical tests

There are different statistical tests used to infer the existence of a relationship
between two sets of observations; they can be divided into two major groups: parametric
tests and non-parametric or distribution-free tests (Sachs, 1982).

Parametric tests need a priori knowledge about the distributions of the population
that samples come from and this can sometimes be difficult to obtain. Parametric tests
have been used in efficiency studies before (Park & Lesourd, 2000; Nyrud & Baardsen,
2003). However, it is not always possible to assume that samples come from certain
distributions. Although goodness of fit tests can be used in such cases, they usually need
large sample sizes. In these cases non-parametric tests can be used which do not require
a priori assumptions about the distributions of the variables. Almost all tests involving
ranked data are non-parametric (Sprent & Smeeton, 2001). It should be noted, however,
that parametric tests have a higher test power compared to non-parametric ones using the
same sample size. Power of a test is defined as 1-β, which is the probability of rejecting
the null hypothesis when it is not true. It is dependent upon the sample size and the
significance level (α). The value of α gives the probability of rejecting the null hypothesis
when it is true. With a fixed α, the value of β has an inverse relationship with the sample
size (n); increasing the sample size will result in a decrease in β. Usually, it is desirable to
use statistical test with a relatively high power. The comparison of the power between a
parametric and a non-parametric test can be done using the concept of “efficiency”\(^5\)
(Sprent & Smeeton, 2001). Efficiency of a non-parametric test compared to an equivalent
parametric test can be found using (4.1) (Sachs, 1982).

\(^5\) Here, “efficiency” is used in the context of comparison between two statistical tests. It is different from
the “efficiency” as a measure of performance of operating units.
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Efficiency = \frac{n_1 \text{ (for the parametric test)}}{n_2 \text{ (for the non-parametric test)}} \tag{4.1}

where \( n_1 \) and \( n_2 \) are the sample sizes for the two tests that result in the same power (1- \( \beta \)) for a given significance level. This ratio may be less than, equal to, or more than one, depending on the distribution of the underlying data (Conover, 1980; Sachs, 1982; Sprent & Smeeton, 2001).

As mentioned above, non-parametric tests are often the only ones available for ranked data (Sprent & Smeeton, 2001) and have been previously used in DEA studies (Schaffnit et al., 1997; Lebel & Stuart, 1998; Yin, 2000; Nyrud & Bergseng, 2002; Salehirad & Sowlati, 2005). Schaffnit et al. (1997) used two non-parametric tests, the Mann-Whitney U test and the Kruskal-Wallis test, to identify possible effects and causes of the performance of bank branches. The Mann-Whitney test is used to test if the means of two independent samples are the same, while the Kruskal-Wallis test is used when more than two independent samples are present.

In a study on logging contractors, Lebel and Stuart (1998) used the Spearman’s rank coefficient to find the correlation between a complexity factor (which they developed themselves) and DEA efficiency scores. They found that loggers with higher complexity factor (e.g. more difficult tracts, longer hauling distance, etc.) had a lower technical efficiency.

In a study on the softwood pulp sector, Yin (2000) employed the Spearman’s rank coefficient to examine the correlation between the results from a DEA model and a Stochastic Frontier model. The rankings based on DEA scores were compared to rankings based on Translog stochastic cost function and Cobb-Douglas stochastic cost function. The correlation between DEA scores and the Translog function was lower compared to the Cobb-Douglas function.

In another DEA study, a Kruskal-Wallis test was used to study the relationship between mill efficiency and mill size in different time periods (Nyrud and Bergseng, 2002). For most of the periods under study, the largest mills were found to have higher efficiency scores. Salehirad and Sowlati (2005) used two non-parametric tests (Median Quartile test and Kruskal-Wallis) to see if the efficiency of BC Sawmills in different
forest regions were different and also to test the effect of the number of operating days on the DEA efficiency scores.

4.3. Methods

4.3.1. Assurance Region weight restriction

An assurance region (AR) imposes bounds on the ratio of weights for two inputs/outputs. As an example, a constraint may be added on the ratio of weights for input 1 and input 2 \( (v_1) \) and \( v_2 \), with lower bound of \( L \) and upper bound of \( U \), as shown in (4.2). Information on relative prices or costs and the decision maker's preferences can be used to generate these upper and lower bounds. Weights from the unrestricted DEA models can also be used for defining these bounds (Cooper et al., 2000; Allen et al., 1997).

\[
L \leq \frac{v_2}{v_1} \leq U
\]  

Adding the AR constraint shown in (4.2) to a DEA model can be considered a special case of the cone ratio model. Therefore, the resulting DEA model is always feasible. AR models can relate the weights of only inputs or only outputs (AR type I) or relate the weights of inputs and outputs together (AR type II). AR type I approaches are more commonly used in practice since AR type II approaches might provide unfeasible solutions in some cases (Thanassoulis, 2001; Allen et al., 1997).

4.3.2. Spearman's rank coefficient

As mentioned previously, one of the objectives of this research is to compare the DEA scores with some partial measures. The values to be compared here are not the performance measures themselves, but the rankings that result from different measures. Considering its ease of use, a non-parametric test seemed more appropriate for the purpose of this comparison, since no specific distribution could be expected for rankings based on different measures.

The most common nonparametric method for testing the correlation of ranked data is the coefficient of Spearman's rank correlation (hereafter shown as \( r_s \)). This method can be applied to small samples (as small as 4 observations in each sample) and
shows a relatively high efficiency compared to the Pearson's product moment correlation – a common parametric measure of correlation (Sachs, 1982).

Spearman's rank coefficient is used to check the correlation of two sets through their ranks. The hypotheses to be tested are:

\[
\begin{align*}
H_0 &= \text{The two rankings are independent} \\
H_1 &= \text{The two rankings are correlated}
\end{align*}
\]

The alternative hypothesis \((H_1)\) can be two or one-sided. The one-sided hypothesis states that the two rankings are either positively or negatively correlated. If \(X\) and \(Y\) are the two sets of paired variables being compared, these two assumptions must hold before using \(r_s\):

1. \(X\) and \(Y\) values are continuous random variables or nonnumeric values that can be ranked (Conover, 1980).
2. The data are independent paired observations.

The observations in each sample are ranked. The resulting ranked sets are shown by \(X'\) and \(Y'\). Each data pair includes two different ranks. Let \(D_i (i = 1, \ldots, n)\) be the difference between the two ranks. The Spearman's rank correlation coefficient, \(r_s\), is calculated as (4.3) (Sachs, 1982).

\[
r_s = 1 - \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2 - 1)} \tag{4.3}
\]

The value of \(r_s\) is between 1 and -1. Values of 1 and -1 show strong positive or negative correlation, respectively, while a value close to zero shows no significant correlation between the two sets. If there are equal values within a set (ties), the mean of the ranks is assigned to them; e.g. if there are two equal values that are supposed to be ranked third and fourth, we would give the mean rank of 3.5 to both of them. If ties are present, it is better to use equation (4.4) (Sachs, 1982).
where $M = \frac{1}{6}(n^3 - n)$, $T_x = \frac{1}{12} \sum_{j=1}^{J} (t_{xj}^3 - t_{xj})$, and $T_y = \frac{1}{12} \sum_{k=1}^{K} (t_{yk}^3 - t_{yk})$. The number of groups of ties in $X'$ and $Y'$ are shown by $J$ and $K$, respectively. For example, if there are two observations ranked 1.5 and three observations ranked 6 in the $X'$ set, then $J$ is equal to 2. For the input set, the number of ties (equal rank quantities) in the $j^{th}$ group ($j = 1, ..., J$) is represented by $t_{xj}$. In the example stated above, $t_{x1}$ is 2 (two observations with the same rank of 1.5) and $t_{x2}$ is 3 (three observations with the same rank of 6). Similarly, for the output set, $t_{yk}$ is the number of ties in the $k^{th}$ group ($k = 1, ..., K$). Consequently, $T_x$ for the above example is calculated as (4.5).

$$T_x = \frac{1}{12} \times \left[ (2^3 - 2) + (3^3 - 3) \right] = 2.5$$

(4.5)

The null hypothesis is rejected if the absolute value of the correlation coefficient ($r_s$) is higher than the critical value, $r_s^*(n;\alpha)$, at a given $\alpha$ significance level. This value can be found from tables in statistical references for sample sizes of up to 100. For sample size $n>100$, the null hypothesis is rejected at $\alpha$ significance level, if $\hat{t}$ in (4.6) is more than $t_{n-2,\alpha}$. The value of $t_{n-2,\alpha}$ can be found using the Student $t$ distribution with $n-2$ degrees of freedom.

$$\hat{t} = |r_s| \cdot \sqrt{\frac{n-2}{1-r_s^2}}$$

(4.6)

For more information on the test procedure, see Sachs (1982) and Sprent and Smeeton (2001).

### 4.4. Data

Data for the wood products manufacturing sector in this study were obtained from Statistics Canada (Industry Canada, 2005a) based on principle establishments data and
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North American Industry Classification System (NAICS). In order to be able to interpret the results accurately, definitions used in NAICS for the wood industry need to be disclosed here.

4.4.1. Wood products manufacturing and its sub-sectors

The NAICS definition for wood products manufacturing (NAICS 321) is used in this study, based on which this industry includes three sub-sectors (Statistics Canada, 2003):

- Sawmills and wood preservation,
- Veneer, plywood and engineered wood products (EWP) manufacturing
- Other wood products manufacturing

Definitions of each sub-sector from Statistics Canada are provided below.

“Sawmills and wood preservation sub-sector includes those establishments engaged in manufacturing boards, dimension lumber, timber, poles and ties from logs and bolts. They produce lumber that may be rough, or processed to achieve smoothness, but is generally not further worked or shaped. Establishments that preserve wood are also included.” (Statistics Canada, 2003)

“Veneer, plywood and engineered wood products manufacturing includes establishments that manufacture softwood and hardwood veneer and plywood; structural wood members, except lumber; and reconstituted wood panel products.” Structural wood members are made by laminating, joining and assembling wood components; and reconstituted wood panel products are made through processes involving pressure, adhesives and binders. The laminated products may have layers of materials other than wood (Statistics Canada, 2003).

“Other wood products manufacturing comprises establishments that are primarily engaged in manufacturing wood products but are not classified under any other industry group. Some examples of products within this sub-sector are millwork such as wooden doors and windows,
wood container and pallet manufacturing, mobile homes, and prefabricated wood buildings.” (Statistics Canada 2003)

It should be noted that what is commonly referred to as “wood industry” includes sawmilling products, wood panels, engineered wood products, wood furniture, and paper products. However, based on NAICS definitions, wood furniture and pulp and paper products are excluded from the wood products manufacturing and results should be interpreted having these exclusions in mind. Wood furniture is included in “furniture and related products manufacturing” (NAICS 337) and “paper manufacturing” is also a separate category (NAICS 322). In this document, “wood industry” is used interchangeably with “wood products manufacturing”.

4.4.2. Dataset

Items that were selected from the original dataset to be included in the analysis are listed below. It should be noted that the data were available in the aggregate form at the industry level, not for individual establishments.

- Number of employees
- Manufacturing shipments
- Total revenues
- Costs of material and supplies for manufacturing and non-manufacturing activities
- Costs of fuel and electricity
- Annual capital investment in machinery and in construction

All data were available from 1993 to 2002, except for the capital investment data which was available from 1994. Therefore, in order to have a comprehensive production model, the study period was selected to be from 1994 to 2002.

A production model for the purpose of studying the process of transforming inputs to outputs needs to include the major inputs (capital, labour, materials and energy) and outputs (production volumes or values). The DEA model in this study was developed using four inputs and one output. The production model is shown in Figure 4-5.
Annual capital investment was used as a measure of capital input in this study. The total costs of materials and energy and the total number of employees were also used as inputs. Total revenues were used as a measure of output, including revenues from both manufacturing and non-manufacturing activities.

Table 4-1 shows the summary statistics of the data used in this research. The rule of thumb in DEA studies is that the number of DMUs should be greater than or equal to three times the number of inputs and outputs in order for the results to be reliable (Kao & Yang, 1992). In this research, five inputs and outputs and 27 DMUs were present, so this condition held.

Table 4-1. Summary statistics for the Canadian wood products manufacturing data; 1994-2002

<table>
<thead>
<tr>
<th>Sub-sector</th>
<th>Input/output</th>
<th>Average</th>
<th>S.D.</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Employees</td>
<td>66,012</td>
<td>4,386</td>
<td>74,928</td>
<td>59,116</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>0.412</td>
<td>0.048</td>
<td>0.485</td>
<td>0.357</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>10.875</td>
<td>0.863</td>
<td>12.133</td>
<td>9.891</td>
</tr>
<tr>
<td></td>
<td>Capital</td>
<td>0.637</td>
<td>0.180</td>
<td>0.867</td>
<td>0.368</td>
</tr>
<tr>
<td></td>
<td>Revenues</td>
<td>17.395</td>
<td>1.079</td>
<td>19.472</td>
<td>15.976</td>
</tr>
<tr>
<td>Sawmills and wood preservation</td>
<td>Employees</td>
<td>21,073</td>
<td>3,397</td>
<td>25,643</td>
<td>16,670</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>0.186</td>
<td>0.051</td>
<td>0.255</td>
<td>0.124</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>2.754</td>
<td>0.583</td>
<td>3.532</td>
<td>1.957</td>
</tr>
<tr>
<td></td>
<td>Capital</td>
<td>0.489</td>
<td>0.249</td>
<td>0.963</td>
<td>0.251</td>
</tr>
<tr>
<td></td>
<td>Revenues</td>
<td>5.251</td>
<td>1.177</td>
<td>6.751</td>
<td>3.927</td>
</tr>
<tr>
<td>Veneer, plywood and engineered</td>
<td>Employees</td>
<td>37,208</td>
<td>7,894</td>
<td>47,989</td>
<td>27,847</td>
</tr>
<tr>
<td>wood products</td>
<td>Energy</td>
<td>0.071</td>
<td>0.019</td>
<td>0.099</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>3.011</td>
<td>0.753</td>
<td>4.368</td>
<td>2.224</td>
</tr>
<tr>
<td></td>
<td>Capital</td>
<td>0.148</td>
<td>0.045</td>
<td>0.230</td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td>Revenues</td>
<td>5.151</td>
<td>1.374</td>
<td>7.435</td>
<td>3.640</td>
</tr>
</tbody>
</table>

Data for energy, material, capital and revenues are in constant Canadian billion dollars (1997=100).
Since the data were available in current dollar values, they needed to be adjusted for inflation over time. Because the efficiency change measurement depends on the change in “real” input and output values, the issue of choosing the appropriate price index becomes very critical. Errors in choosing price indices result in incorrect estimates of the real values, which consequently affects the measured efficiency score. The data included dollar values at the industry level; therefore, Industrial Product Price Index (IPPI), obtained from Statistics Canada (2005b), was used for deflating the values. Readers are referred to Statistics Canada (2005a) for more information on this index. The data in Table 4-1 are presented in constant 1997 Canadian billion dollars.

4.5. Analysis, Results and Discussion

4.5.1. Efficiency analysis

In order to find the technical efficiencies of industries in different years, the BCC model was used. Aggregate efficiency was obtained using the CCR model. It should be noted that weight constraints in the form of equation (4.2) were added to both the BCC and CCR formulations. The details of constructing these constraints will be explained shortly. After constructing the extra constraints, a software program (DEA-Solver Pro 4.0) was used to solve the DEA models. Each sub-sector in each year was treated as an individual DMU; therefore, 27 DMUs were present in the analysis. Finally, scale efficiency was calculated. Output orientation was selected for the purpose of this study, because it was more realistic to assume that industries would be interested in increasing their revenues, using the same level of inputs.

Table 4-2. Input cost shares for wood products manufacturing sub-sectors

<table>
<thead>
<tr>
<th></th>
<th>Labour</th>
<th>Material</th>
<th>Energy</th>
<th>Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.96%</td>
<td>71.67%</td>
<td>2.88%</td>
<td>5.49%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-2 shows the cost shares of different inputs. The total cost for each input factor was calculated as the average of the cost over the study period and for all three sub-sectors. It can be seen that the shares range from very high to low. On average during the study period, material and labour accounted for more than 90% of the input cost in total. It is, therefore, expected that they have more importance in the analysis compared
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to capital and energy inputs. For this reason, weight restrictions were added to the DEA models.

The method described in Schaffnit et al. (1997) was used for adding constraints. Total input cost shares (shown in Table 4-2) with a tolerance range of $p = 10\%$ were used to construct the bounds. If $c_i$ and $c_j$ are the cost shares for input $i$ and $j$ ($c_i =$ cost of input $i$ divided by the total input cost), then the upper and lower bounds for weights of input $i$ and $j$ are defined as follows (Schaffnit et al., 1997):

$$\frac{c_j^+}{c_i^+} \leq \frac{v_j}{v_i} \leq \frac{c_j^-}{c_i^-} \quad i = 1, \ldots, m-1, \quad j = i+1, \ldots, m$$  \hspace{1cm} (4.7)

$$c_i^+ = (1 + p) \cdot c_i, \quad c_j^+ = (1 + p) \cdot c_j$$  \hspace{1cm} (4.8)

$$c_i^- = (1 - p) \cdot c_i, \quad c_j^- = (1 - p) \cdot c_j$$  \hspace{1cm} (4.9)

In total, six constraints with the form of (4.7) were added to the model. For the purpose of calculation, $i = 1, 2, 3, \text{ and } 4$ were assigned to employees, energy, materials, and capital, respectively. The procedure for constructing one of the constraints (the relative weights of energy and labour) is shown in equations (4.10) to (4.13). The remaining five constraints are shown in equations (4.14) to (4.19).

$$c_1 = 0.1996, c_2 = 0.0288$$  \hspace{1cm} (4.10)

$$c_1^+ = 1.1 \times 0.1996 = 0.220$$  \hspace{1cm} (4.11)

$$c_1^- = 0.9 \times 0.1996 = 0.180$$  \hspace{1cm} (4.12)

$$c_2^+ = 0.032, c_2^- = 0.026$$  \hspace{1cm} (4.13)

$$0.118 \leq \frac{v_2}{v_1} \leq 0.178$$  \hspace{1cm} (4.14)

$$2.932 \leq \frac{v_3}{v_1} \leq 4.378$$  \hspace{1cm} (4.15)
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\[0.223 \leq \frac{v_4}{v_1} \leq 0.333\]  

(4.16)

\[20.156 \leq \frac{v_4}{v_2} \leq 30.308\]  

(4.17)

\[1.531 \leq \frac{v_4}{v_2} \leq 2.308\]  

(4.18)

\[0.062 \leq \frac{v_4}{v_3} \leq 0.093\]  

(4.19)

The summary of the DEA results is shown in Table 4-3. Detailed results, including technical, aggregate and scale efficiency scores for all DMUs, can be found in Appendix C. It should be mentioned here that the results of this analysis are all based on the included factors and the definitions of the sector. Therefore, they should be interpreted with caution. Furthermore, considering the deterministic nature of DEA, effects of noise and error in the data were not accounted for.

<table>
<thead>
<tr>
<th></th>
<th>Sawmills and wood preservation</th>
<th>Veneer, plywood and EWP</th>
<th>Other wood products</th>
<th>Average for all sub-sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical efficiency (BCC)</td>
<td>Average</td>
<td>0.96</td>
<td>0.91</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.04</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>1.00</td>
<td>1.00</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.89</td>
<td>0.81</td>
<td>0.38</td>
</tr>
<tr>
<td>Number of DMUs in:</td>
<td>IRS</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>CRS</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>DRS</td>
<td>9</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Aggregate efficiency (CCR)</td>
<td>Average</td>
<td>0.91</td>
<td>0.85</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.04</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.99</td>
<td>1.00</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.85</td>
<td>0.75</td>
<td>0.38</td>
</tr>
<tr>
<td>Scale efficiency</td>
<td>Average</td>
<td>0.94</td>
<td>0.94</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.03</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.90</td>
<td>0.83</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Table 4-3. Summary of DEA results for wood products manufacturing sub-sectors
Five DMUs were found to be technically efficient (i.e., their BCC score was equal to one) while only one DMU — veneer, plywood and EWP in 1999 — was aggregately efficient. This was also the only DMU that was scale efficient. The average technical efficiency score for all DMUs was 0.78, while the average aggregate efficiency was found to be 0.75. This resulted in a scale efficiency of 0.96; a relatively high score. The scale efficiency shows whether an industry has unexploited economies of scale and can improve its efficiency by expanding or contracting the scale of operations.

Based on both technical and aggregate efficiency results, it was found that the sawmills and wood preservation sub-sector had the highest score, on average, while other wood products manufacturing was identified as the worst performer during the study period. Sawmills and wood preservation had a technical efficiency of 0.96 and an aggregate efficiency of 0.91. The veneer, plywood and EWP sub-sector had a technical efficiency of 0.91 and its aggregate efficiency was 0.85. Both sub-sectors had a scale efficiency of 0.94. In the case of sawmills and wood preservation, the numbers suggested that technical and scale inefficiencies had relatively equal shares in the aggregate inefficiency of the sub-sector, while for veneer, plywood and EWP, technical inefficiency seemed to be the main contributor. Other wood products manufacturing’s technical efficiency of 0.48 was extremely low compared to the other sub-sectors. However, it had the highest scale efficiency.

It was observed that all sub-sectors had improved their aggregate efficiency during the study period. However, the sources of the improvement were different among the sub-sectors. Sawmills and wood preservation increased both technical and scale efficiency. Veneer, plywood and EWP improved its scale efficiency but had a decline in its technical efficiency score and, finally, other wood products experienced a growth in technical efficiency but had a slight drop in its scale efficiency.

DRS (IRS) means that an increase in the inputs level will result in a less (more) than proportionate increase in the outputs. CRS exists when the output increases with the same proportion as the input. When a unit is in the DRS (IRS) region, it is operating in a scale larger (smaller) than the most productive scale size. An interpretation of the DRS stage is that, when the DMU grows larger than a certain scale, its ability to manage and
utilize its inputs decreases; therefore, it becomes scale inefficient. In the case of IRS, DMU can still improve its efficiency by using more resources and increasing its size – through merging with other DMUs for example. It is reasonable to expect units that have been operating for a long time to be in the CRS or DRS region, while the newer units are most probably operating under IRS.

Based on the returns-to-scale (RTS) results, the sawmilling and other wood products manufacturing sub-sectors were operating in the DRS in all years, while the veneer, plywood and EWP sub-sector started in the IRS, moved on to the CRS region (in 1999), and was operating in the DRS region after that. RTS results for the sawmilling sector was expected, since the sector was mature and contained many large establishments. The results suggested that mergers in the sawmilling industry might not help in increasing the efficiency, since it is already in the DRS region. For veneer, plywood and EWP, the RTS changes reflected the growth stages of the industry. The sub-sector was performing at its best in 1999, when it was both technically and scale efficient. After this point, probably because of the increasing demand for panel board and EWP products, the number of establishments and employees kept increasing, while the total revenues started to decrease. The number of employees had an increase of over 700 people from 1999 to 2000, while the total revenue decreased by about $0.2 billion (Industry Canada, 2005a). This might have been one of the reasons why the sub-sector moved to the DRS region. The RTS results suggested that, instead of adding more establishments and expanding input consumption to increase the output, this sub-sector should try to focus more on technical efficiency improvements. This can be achieved through acquiring equipment, stronger technical knowledge, better management practices, and more training. The other wood products sub-sector was highly scale efficient during the study period and this makes sense because this sub-sector consists of very small establishments (Industry Canada, 2005b) that are operating mostly within the same scale and the major problem they are facing is their ability to utilize their inputs efficiently. For this sub-sector, RTS results also suggested improvements in technical efficiency rather than input expansion (note that other wood products manufacturing consumed more labour and materials compared to veneer, plywood and EWP to produce almost the equivalent amount of revenues).
One of the important factors that can improve the technical efficiency in the long run is capital investment for machinery and equipment (Kao et al., 1995; Macklem, 2003; Mahadevan, 2002). Technical efficiency refers to the ability of an industry to utilize its inputs to produce the desired outputs. It is affected by the way the industry uses available technology and equipment. Furthermore, it involves the management practices, resource allocation, and labour skills. According to Kao et al. (1995) there are two main approaches that can increase the productivity of a DMU; the efficiency approach vs. the effectiveness approach. The efficiency approach can be utilized by inefficient units only. It simply states that an inefficient unit can increase its productivity by increasing its technical efficiency; i.e. it can increase the output level using the same level of inputs. The effectiveness approach, on the other hand, is when a unit uses additional resources to increase productivity. The effectiveness approach can be used by both efficient and inefficient units. What is discussed here is more closely related to the efficiency approach, since the objective is to increase the output without changing the level of inputs. The effectiveness approach can be viewed as a need for greater levels of investments in equipment or in labour/managerial skills.

Based on our results, efficiency approach could be utilized by all three sub-sectors, since they all were identified as inefficient at some point during the study period. More specifically, the other wood products manufacturing sector could greatly benefit from increasing its output level. As for the effectiveness approach, all sub-sectors can improve their technological ability through capital investments. These investments help the industry to utilize its inputs better and, therefore, in the long run help to increase its efficiency. In the wood products manufacturing sector, investments have been more concentrated in sawmills and wood preservation, accounting for about $640 million or 50% of the total capital investment, on average, during the study period (Industry Canada, 2005a). This could be partially responsible for higher revenues and, consequently, higher efficiencies in this sub-sector. These investments have been mainly focused on higher recovery ratios and reducing operation costs (Industry Canada, 2002) in sawmills. The veneer, plywood and engineered wood products sub-sector has also invested in capital machinery during the last few years, but not as much as the sawmilling sub-sector. The average annual capital investment for veneer, plywood and EWP during
the study period was approximately $495 million. Of course, the larger size of the establishments in these two sub-sectors made it possible for them to invest larger amounts of capital; 15% of the establishments in the sawmills and wood preservation sub-sector and 17% of the establishments in veneer, plywood and EWP sub-sector had more than 100 employees in 2003, while this percentage was less than 5% for the other wood products manufacturing sub-sector (Industry Canada, 2005b). On average, other wood products manufacturing invested $150 million annually during the study period, a much lower value compared to the other sub-sectors. Therefore, one reason for its low revenue level might be its comparatively smaller levels of capital investment which have resulted in low efficiency scores. The good news, however, is that the capital expenditure in other wood products manufacturing has been increasing. Its share of total capital expenditure in the wood products manufacturing increased from approximately 8% in 1994 to more than 16% in 2002 (Industry Canada, 2005a). As a result, one can expect this sub-sector to improve its technical efficiency in the coming years.

Since total revenue is used as the output of the DEA model, it is important for the industry to have enough demand for its products to generate more revenue and eventually increase the efficiency. Therefore, looking at the major markets for wood products might help in better understanding the efficiency changes. The main export market for Canadian wood products is the U.S. Residential construction market is an important part of the demand for these products in the U.S. and also in Canada. Housing starts can be used as a proxy for residential construction. In Canada and US, after a slowdown in 1995, housing starts began an upward trend because of record low interest rates (MacGregor & Datta, 2004; Statistics Canada, 2005c). This meant strong demand for sawmilling products and veneer, plywood and EWP during most of the study period. The Softwood Lumber Agreement also affected the revenues from wood industry sub-sectors. Although it limited the exports of some lumber products to the U.S., it also contributed to the extra production of panel board products and other wood products in recent years (Eastin & Fukuda, 2001). The relatively high efficiency scores of the sawmills and wood preservation, and veneer, plywood and EWP sub-sectors compared to the other wood products sub-sector may be related to the stronger demand for these products. Nonetheless, other wood products manufacturing had an overall efficiency growth during
the study period and it can be expected to grow even more in the future, considering the increasing demand and also the efforts of the government to encourage value-added production (Industry Canada, 2002).

4.5.2. Comparison with partial performance measures

The partial performance measures currently reported by Statistics Canada were mentioned in the introduction. Since many of them had interrelationships, manufacturing shipment per employee and manufacturing value-added per employee were selected. Manufacturing value-added per hours worked by production employee (also referred to as “labour productivity”) was also an interesting measure. However, no analysis could be done based on it since the related data had not been gathered beyond 1999. As it was mentioned before, Statistics Canada did not report any performance measures that included the capital input. However, it was interesting to see the relationship between such measures and the ones being reported. The ratio of the manufacturing shipment to the capital investment was thus formed and added to the analysis. Therefore, three partial measures were available for comparison with the DEA results.

In order to illustrate the potential problems that may arise when using partial measures, the relationship between the manufacturing shipment per employee and the manufacturing value added per employee – two measures reported by Statistics Canada – was tested first. Using Spearman’s rank coefficient, it was seen that for one sub-sector, sawmills and wood preservation, these two ranks were not correlated ($\alpha=0.05$), meaning that these reported measures would result in different pictures of how this sub-sector was performing during the time. Based on the manufacturing shipment per employee, for example, the sawmills and wood preservation sub-sector was the worst performer in 1994 (compared to other years). However, the same DMU was ranked second based on manufacturing value added per employee. Clearly, in deciding whether the sawmilling sub-sector was performing well in 1994 or not, these partial measures would only create confusion. Choosing between the partial measures can be hard since each of them represent one aspect of the performance which might be important to the decision maker. DEA on the other hand, incorporates these multiple factors simultaneously and, therefore, is more reliable.
In order to perform the correlation test for efficiency scores and the partial measures, DMUs were ranked based on the DEA technical efficiency scores and also based on each of the three selected partial measures. Three pair-wise comparisons were made between technical efficiency rankings and rankings based on each partial measure. Comparisons were made separately for each sub-sector. A one-sided alternative hypothesis was chosen for each comparison: "the two rankings are positively correlated". Results of the comparison are presented in Table 4-4. If the rank coefficient was more than the critical value at either 0.01 or 0.05 significance levels, the null hypothesis was rejected, which means the two rankings were, in fact, correlated.

Table 4-4. Spearman's rank coefficients for comparing DEA results with the partial measures

<table>
<thead>
<tr>
<th></th>
<th>Sawmills and wood preservation</th>
<th>Veneer, plywood and EWP</th>
<th>Other wood products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical efficiency vs.</td>
<td>0.509</td>
<td>0.418</td>
<td>0.883ab</td>
</tr>
<tr>
<td>manufacturing shipment /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>employee</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical efficiency vs.</td>
<td>0.424</td>
<td>0.644a</td>
<td>0.867ab</td>
</tr>
<tr>
<td>manufacturing value added /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>employee</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical efficiency vs.</td>
<td>0.525</td>
<td>-0.176</td>
<td>0.467</td>
</tr>
<tr>
<td>manufacturing shipment /</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>capital</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a: significant at $\alpha=0.05$

b: significant at $\alpha=0.01$

Critical value for $r$ is 0.600 at $\alpha=0.05$ and is 0.783 at $\alpha=0.01$

The results showed that there were no correlations between the technical efficiency scores and any of the partial measures at 0.01 significance level for sawmills and wood preservation and also for veneer, plywood and EWP manufacturing. Even at 0.05 significance level, only one partial measure – manufacturing value added per employee – was found to be correlated to technical efficiency for veneer, plywood and EWP manufacturing. For other wood products manufacturing, however, it was found that technical efficiency scores were correlated to the manufacturing shipment per employee and manufacturing value added per employee, while they were independent from the manufacturing shipment per capital input. It was expected that the technical efficiency scores would not match with the partial measure involving the capital input, because the weight restricted DEA assigned relatively low weights to the capital inputs.
Technical efficiency scores, therefore, do not perfectly match with the results from the partial measures. This is because DEA takes multiple factors into account and presents their combined effect. The case of capital input further proves this point. If one would have to make a decision based on the partial measures only, the outcome would have to be different depending on which measure was selected. For example, based on manufacturing shipment per employee, sawmills and wood preservation in 1997 is ranked 7th (out of 27), while the same unit is ranked 18th based on manufacturing shipment per capital input. Using DEA helps to avoid this confusion.

Furthermore, it should be noted that Statistics Canada is comparing each sub-sector only with itself in different years and this can be misleading. If a sub-sector is studied without having the other sub-sectors in the analysis, only the progress through the time would be observed and it would be difficult to see the relative performance of each of the sub-sectors. A further advantage of the DEA results in this study is that they incorporated comparisons with other sub-sectors.

4.6. Conclusion

The Canadian wood industry is currently going through a transition to remain competitive in the changing global market and to increase profits despite the introduction of several tariff and non-tariff trade barriers. The size of different sub-sectors is changing and a shift towards more value-added products is seen. It is crucial for the industry to be able to evaluate its progress through time and assess its performance.

This research evaluated the efficiency changes of the three sub-sectors of the wood products manufacturing in Canada: 1) sawmills and wood preservation, 2) veneer, plywood and EWP and 3) other wood products.

A non-parametric efficiency measurement technique, DEA, was used in this research. All sub-sectors were found to have increased their aggregate efficiency during the study period, while contribution of scale and technical efficiencies to this improvement differed among the sub-sectors. The results indicated that sawmills and wood preservation was the most efficient sub-sector, on average, and other wood products was the worst performer. Effects of some factors, such as capital investment and demand, on the efficiency were discussed. Also, it was suggested by the results that the
major source of inefficiency in wood industry has been technical rather than related to scale. The sub-sectors were found to be mainly operating under decreasing returns-to-scale. However, caution must be used in interpreting these results since they are not directly applicable to individual establishments and may be used in providing a general understanding of the entire wood industry.

The findings of this study can be helpful for making strategic decisions for the various wood industry sub-sectors. The sawmilling industry performed at a relatively high technical and scale efficient manner; however improvements were still possible. More in-depth analysis is required to investigate ways to improve the performance of this industry. It was suggested that mergers and acquisitions may not be the best solution for sawmills and wood preservation sub-sector. For veneer, plywood and EWP, it seems that a lot more could be done in improving the technical efficiency. Like sawmills and wood preservation, input expansion and scale increase was not recommended based on the efficiency results. Perhaps focusing more on promoting these products and finding new markets will create more demand and increase the efficiency. For other wood products manufacturing, a strong focus on improving the input utilization patterns was suggested. Most of the establishments in this sub-sector are small in size. This has prevented them from large capital expenditures; therefore it is important to find ways of enabling them to invest more in machinery and equipment in order to increase their technical efficiency in the long run. Overall, improving the technical and managerial knowledge in wood industry is expected to have a stronger positive effect on efficiencies, compared to increases in the consumption of resources.

Clearly, this study has its own limitations and can be improved by further research. Performing this analysis for a longer period might result in a better picture of the efficiency changes in the long-run. In addition, it would increase the number of DMUs in the analysis and would further enhance the discriminating power of the DEA. The efficiency change results during the study period included the effect of both efficiency improvements and technology progress. This was inevitable since the small number of DMUs limited the author's ability to perform other analyses (such as Malmquist productivity analysis) in order to separate these two effects. This shortcoming can also be removed by including more DMUs in the analysis. Finally, although some
factors that could have affected the efficiency were discussed here, more comprehensive research is required to fully explain the variations in the efficiency of the sub-sectors during the study period.
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Bibliography


Chapter 4: Efficiency Changes of the Canadian Wood Products Manufacturing


5.1. Conclusions

The manufacturing sector plays a significant role in the economic well-being of Canadians. It is the second largest contributor to the national GDP, after the finance, insurance, and real estate industries. Being a major source of employment, generating demand for other sectors, and providing opportunities for foreign direct investments are some features of the manufacturing sector that illustrate its significance for Canada. However, manufacturers have been facing several challenges in recent years, including increasing international competition, increasing costs, changing trade regulations, etc. Manufacturing industries need to remain competitive in this challenging environment and grow to improve the welfare of the Canadians. It is, therefore, very important to develop benchmarks for the manufacturing industries and study their performance changes over
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time. Since productivity growth is an important factor that affects the output growth and, consequently, the living standards of the Canadians, this research set out to measure the productivity growth of the Canadian manufacturing industries.

Like Canada, the manufacturing sector in the U.S. is very important to its national economy and is facing somewhat similar challenges. Since the U.S. has traditionally been and continues to be the main trading partner for Canada, the performance of the Canadian manufacturing industries have been frequently compared to that of the U.S. This research also measured the productivity changes of the U.S. manufacturing industries.

Productivity can be measured using two-factor ratios or by using multifactor productivity measurement methods. Labour productivity is the most common productivity ratio used to study manufacturing industries worldwide. Although this measure is easy to calculate, it cannot explain how the output per unit of other inputs has changed. At the same time, using several productivity ratios can be confusing and obtaining an overall picture of the performance might prove difficult. Multifactor productivity measures can be used as an alternative. They can be parametric or non-parametric in nature, depending on whether they require a functional relationship between inputs and outputs or not. Parametric methods are limited in their practicality, because they require a known functional relationship, which can be difficult to decide upon. Non-parametric methods, on the other hand, do not require any assumptions on the functional form and can incorporate multiple inputs and outputs. A non-parametric Malmquist Productivity Index was, therefore, used in this research to study the productivity changes of the manufacturing sector.

Wood products manufacturing in Canada is the second largest sector among the forest industries, after pulp and paper, and accounts for most of the direct employment in the forestry sector and a significant part of the exports. It is made up of three sub-sectors: sawmills and wood preservation; veneer, plywood and engineered wood products (EWP); and other wood products. Wood products manufacturing has been operating in a changing business environment. There are many new wood products exporters such as Southeast Asian or South American countries that can offer wood products at very low prices. Trade regulations and trade barriers on commodity products, in both tariff and
non-tariff forms, have also created a difficult situation for the Canadian exporters that traditionally have relied heavily on commodity exports. In response to these changes, the industry is restructuring itself by shifting towards more processed products such as wood panels or engineered wood products. In order to be able to compete in the world markets, Canadian producers need to not only focus on value-added products, but to also offer these products with lower prices than their competitors. Producing quality products at low costs is not possible unless all the processes are carried out with high efficiency and minimum waste.

Considering the importance of the wood industry, it is helpful to monitor its performance and study the changes in its efficiency and productivity levels. It should be noted that the term “wood industry” used here, does not include the pulp and paper or the furniture industry. This research not only looked at the productivity changes of the wood industry relative to other manufacturing industries, but also analyzed the efficiency changes of its three sub-sectors separately. DEA was used to measure the efficiency changes, because of its flexibility and lack of any functional form assumptions.

The TFP index was decomposed to identify the TFP change components: efficiency improvement and frontier shift. Based on the results, both Canada and the U.S. showed a TFP growth in the manufacturing sector over the study period, with the frontier shift as the main growth component. The recession of 2001 had a negative impact on the majority of the industries, although the effect was higher in the U.S.

In Canada, during the period 1994 to 2002, petroleum and coal products manufacturing showed the highest TFP growth with an MPI value of 1.78 for the whole period. This growth could have been a result of the rapid increase in oil prices in the second half of the study period. The prices were almost tripled in less than a year from 1999 to 2000 and continued to increase after that.

Food products manufacturing had the largest decline in TFP with a productivity change of 0.92 (a decline of 0.08). This decline mainly happened after 1998 and this could partially be attributed to a decline in the prices of food products, in Canada and also worldwide. Declining demand from large importers of food, such as China, contributed to this decrease in prices. Lower revenues of the food industry, along with the
increase in the number of employees, resulted in a productivity decline over the study period.

Wood products manufacturing had the second lowest TFP change (0.95) and was below the average throughout the period. The main reason for this decline was the efficiency drop (a catch-up effect of 0.93), while the frontier shift showed improvements (1.04). The catch-up effect and frontier shift were changing in opposite directions during the study period. This could be explained by the fact that the frontier was shifted upwards by some leading industries and, therefore, the distance between wood industry and the frontier increased. Efficiency dropped as a result and it took some time before wood industry started catching up again.

Among the U.S. manufacturing industries, transportation equipment manufacturing showed the highest TFP growth (1.23) from 1997 to 2002. However, it was hit by the recession of 2001 which decreased the demand for transportation equipment such as automobiles. Computer and electronic products manufacturing showed the largest TFP decline (with an MPI value of 0.81) during the study period. This, of course, was because the recession had the strongest negative effect on high-tech industries. Huge investments in computers and information technology did not obtain enough returns because the demand could not keep up with the increasing supply and the market declined.

Similar to the situation in Canada, wood products manufacturing in the U.S. was found to have a below average TFP change (0.99). The catch-up effect (0.91) was identified as the reason for the TFP decline while the frontier shift contributed positively to the TFP change (1.09). Some reasons for this declining TFP in both countries could have been decreasing capital expenditures or the low levels of education of the work force.

These results were helpful in realizing how different industries performed during a time that included both growth and recession periods. The results suggested that the wood industry in both countries needs to invest more in both physical and human capital to improve the TFP growth. Since technical efficiency decline was the major source of
TFP decline in the wood industry, attempts should be made to improve it; for example, better management techniques and input utilization patterns can be helpful.

In order to better understand the performance of the wood products manufacturing, the efficiency changes of its sub-sector were also studied using DEA. The importance of different inputs was incorporated into the model using weight restrictions. An assurance region was selected for imposing the constraints on weights. Based on the findings, all sub-sectors had increased their aggregate efficiency during the study period. Changes in scale and technical efficiencies, however, were different among the sub-sectors. Sawmills and wood preservation was found to be the most efficient sub-sector, on average, and other wood products was identified as the least efficient. The results suggested that technical inefficiency was the major source of aggregate inefficiency. Also, the returns-to-scale results showed that the sub-sectors were mainly operating under decreasing returns-to-scale.

The sawmilling industry was found to have very high technical and scale efficiencies; it was also suggested that mergers and acquisitions may not be the best solution for this sub-sector. The technical efficiency of veneer, plywood and EWP could still be improved and, like sawmills and wood preservation, no scale increase was suggested by the returns-to-scale results. Since other wood products manufacturing had the lowest technical efficiency, a strong focus on improving the input utilization patterns could be a useful strategy. Also, finding ways for enabling the establishments in this sub-sector to invest more in machinery and equipment could help to increase their technical efficiency in the long run. Overall, improving the technical and managerial knowledge in wood industry was suggested to be more important in increasing the efficiency, compared to changes in the scale of operations.

The efficiency results were compared with the partial measures currently used by Statistics Canada. A non-parametric statistical test, Spearman's rank coefficient, was used for this purpose. The results showed that, for sawmills and veneer, plywood, and EWP, no correlation existed (at 1% confidence level) between the partial measures and the DEA technical efficiency scores. Even when the rankings based on two partial measures (shipments per employee and value-added per employee) were compared for
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the sawmills and wood preservation sub-sector, no correlation was found between them. This illustrated the problem with using partial measures that each of them might give a different picture of performance. Using DEA as an alternative approach can be useful in such cases, because multiple inputs and outputs are incorporated into the analysis.

5.2. Limitations

This research has some limitations. Productivity and efficiency results are all relative, therefore, adding extra DMUs (more industries, for example) might change the results. The Malmquist Productivity Results are calculated based on a frontier that was constructed using constant returns-to-scale DEA. This frontier was formed using all the industries with different scales of operations and the results might have not been fair for industries with very small or very large operating scales. The frontier shift could have been affected by the rapid progress of certain industries, and consequently, influenced the productivity change results for other industries.

In the DEA analysis of the wood industry sub-sectors, panel data were used, therefore, the efficiency scores may include the frontier shift effect as well. It was not possible to perform a thorough productivity analysis and decompose the productivity changes into efficiency change and the frontier shift due to the small number of units available in the analysis. Furthermore, DEA models used in this research were all deterministic and could not incorporate variations in the data through stochastic analysis.

Using aggregate data created the problem of including many establishments with different sizes and activities. Based on the NAICS, firms producing similar products are grouped as one industry, however, large variations in the production process, type of products, type of raw materials and energy usage, etc. exist among the firms in one industry or sub-sectors of one industry. For example, other wood products manufacturing includes manufacturing of wooden windows, wooden floors, moulding, etc. Aggregating these firms in one sub-sector makes the results hard to interpret. The same is true when comparing industries with totally different processes, such as transportation equipment manufacturing and food manufacturing. It is, therefore, very important to note that the results cannot be directly applied to the individual establishments, since they are different
from the operational efficiency of individual firms. Alternatively, they can be helpful when making strategic decisions for industries as a whole.

In the NAICS, each company is classified under a certain industry based on its primary activities. It means that when a large company produces different types of products, for example lumber and paper products, based on what was defined as the primary activity, the company would be classified under sawmills and wood preservation sub-sector (under wood products manufacturing) or paper manufacturing industry. Consequently, revenues generated from different products will be included as a part of revenue for that specific industry. This, in turn, may result in overstating or understating the revenue for certain industries. The efficiency and productivity results in this study are based on the NAICS definitions.

It should be mentioned again here that all of the results of this study are based on the included factors, namely: revenue, labour, energy and material cost, and capital investment. Revenue and cost of energy and material are affected by changing prices. This could affect the results by increasing or decreasing the efficiency and productivity values, while in fact no improvement in performance had happened. The obtained results might be different if other factors, such as production volume, could be incorporated into the analysis.

5.3. Future research directions

Future improvements are possible for this research. The efficiency and productivity of individual companies within each industry could have been analyzed separately, if the relevant data were available. In this way, each company could have been compared to other units within the same industry that were performing similar activities. However, comparisons among manufacturing industries have been previously conducted. In this study, in order to make the comparison more acceptable, the productivity change rates were studied rather than the absolute efficiency levels. Also, if the data for wood products manufacturing sub-sectors were available for a longer period, a Malmquist analysis would have been possible that could have taken into account both catch-up and frontier shift effects.
Different directions for the future work are suggested. The productivity analysis of the manufacturing sector in Canada and the U.S. could be repeated with comparable data, so that the results can be quantitatively compared. Also, adding capital investment data to this analysis would represent the production technology better. Another major improvement is adding weight constraints in order to incorporate the importance of different inputs. Accounting for the undesirable outputs and pollution from the wood industry sub-sectors could also give a better evaluation of their performance.

For both manufacturing sectors and wood industry sub-sectors, some factors that could have caused the productivity and efficiency changes were mentioned. However, more comprehensive research could be conducted to better explain the observed variations. Furthermore, using parametric techniques (such as stochastic frontier analysis or deterministic cost/production functions) and comparing the results with the non-parametric methods could provide interesting insights on how the results differ between the two groups of methods.
## Appendix A. Malmquist Productivity Index results – Canada

Table A-1. MPI results for Canadian manufacturing industries

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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>Beverage and Tobacco Product Manufacturing (NAICS 312)</td>
<td>1.00</td>
<td>1.01</td>
<td>1.02</td>
<td>1.00</td>
<td>0.99</td>
<td>1.08</td>
<td>1.05</td>
<td>1.06</td>
</tr>
<tr>
<td>Chemical Manufacturing (NAICS 325)</td>
<td>1.18</td>
<td>1.01</td>
<td>1.03</td>
<td>0.98</td>
<td>1.01</td>
<td>1.18</td>
<td>1.15</td>
<td>1.19</td>
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<td>Clothing Manufacturing (NAICS 315)</td>
<td>1.02</td>
<td>0.98</td>
<td>1.16</td>
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<td>0.99</td>
<td>1.01</td>
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<td>1.05</td>
<td>1.12</td>
<td>1.26</td>
<td>1.39</td>
<td>1.08</td>
<td>1.01</td>
</tr>
<tr>
<td>Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)</td>
<td>1.01</td>
<td>1.04</td>
<td>1.08</td>
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<td>1.08</td>
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<td>1.01</td>
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<td>1.01</td>
<td>1.01</td>
<td>1.02</td>
<td>1.01</td>
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<td>1.01</td>
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<td>1.01</td>
<td>1.03</td>
<td>1.08</td>
<td>1.09</td>
<td>1.06</td>
<td>1.11</td>
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<td>1.03</td>
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<td>1.00</td>
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<td>0.97</td>
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<td>1.06</td>
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<td>0.98</td>
<td>0.95</td>
<td>0.93</td>
<td>0.95</td>
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<td><strong>1.03</strong></td>
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<td><strong>1.01</strong></td>
<td><strong>1.01</strong></td>
<td><strong>1.06</strong></td>
<td><strong>1.10</strong></td>
<td><strong>1.08</strong></td>
<td><strong>1.09</strong></td>
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</table>

*All of the indices are relative to the base year, 1994.*
### Table A-2. Catch-up effect for Canadian manufacturing industries

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<tr>
<th>Manufacturing Industry</th>
<th>Efficiency change (Catch-up effect)</th>
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</thead>
<tbody>
<tr>
<td>Beverage and Tobacco Product Manufacturing (NAICS 312)</td>
<td>0.98</td>
</tr>
<tr>
<td>Chemical Manufacturing (NAICS 325)</td>
<td>1.01</td>
</tr>
<tr>
<td>Clothing Manufacturing (NAICS 315)</td>
<td>1.00</td>
</tr>
<tr>
<td>Computer and Electronic Product Manufacturing (NAICS 334)</td>
<td>1.01</td>
</tr>
<tr>
<td>Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)</td>
<td>0.97</td>
</tr>
<tr>
<td>Fabricated Metal Product Manufacturing (NAICS 332)</td>
<td>0.99</td>
</tr>
<tr>
<td>Food Manufacturing (NAICS 311)</td>
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<tr>
<td>Furniture and Related Product Manufacturing (NAICS 337)</td>
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<tr>
<td>Leather and Allied Product Manufacturing (NAICS 316)</td>
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<tr>
<td>Machinery Manufacturing (NAICS 333)</td>
<td>0.99</td>
</tr>
<tr>
<td>Miscellaneous Manufacturing (NAICS 339)</td>
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</tr>
<tr>
<td>Non-Metallic Mineral Product Manufacturing (NAICS 327)</td>
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<td>Paper Manufacturing (NAICS 322)</td>
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<tr>
<td>Petroleum and Coal Products Manufacturing (NAICS 324)</td>
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<tr>
<td>Plastics and Rubber Products Manufacturing (NAICS 326)</td>
<td>0.95</td>
</tr>
<tr>
<td>Primary Metal Manufacturing (NAICS 331)</td>
<td>1.02</td>
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<tr>
<td>Printing and Related Support Activities (NAICS 323)</td>
<td>0.99</td>
</tr>
<tr>
<td>Textile Mills (NAICS 313)</td>
<td>0.98</td>
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<tr>
<td>Textile Product Mills (NAICS 314)</td>
<td>0.94</td>
</tr>
<tr>
<td>Transportation Equipment Manufacturing (NAICS 336)</td>
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</tr>
<tr>
<td>Wood Product Manufacturing (NAICS 321)</td>
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<td><strong>Average</strong></td>
<td><strong>1.03</strong></td>
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</tbody>
</table>

All of the indices are relative to the base year, 1994.
Table A-3. Frontier shift effect for Canadian manufacturing industries

<table>
<thead>
<tr>
<th>Manufacturing Industry</th>
<th>Technical change (Frontier shift effect)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beverage and Tobacco Product Manufacturing (NAICS 312)</td>
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</tr>
<tr>
<td>Chemical Manufacturing (NAICS 325)</td>
<td>1.17</td>
</tr>
<tr>
<td>Clothing Manufacturing (NAICS 315)</td>
<td>1.02</td>
</tr>
<tr>
<td>Computer and Electronic Product Manufacturing (NAICS 334)</td>
<td>1.02</td>
</tr>
<tr>
<td>Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)</td>
<td>1.04</td>
</tr>
<tr>
<td>Fabricated Metal Product Manufacturing (NAICS 332)</td>
<td>1.04</td>
</tr>
<tr>
<td>Food Manufacturing (NAICS 311)</td>
<td>1.02</td>
</tr>
<tr>
<td>Furniture and Related Product Manufacturing (NAICS 337)</td>
<td>0.89</td>
</tr>
<tr>
<td>Leather and Allied Product Manufacturing (NAICS 316)</td>
<td>1.02</td>
</tr>
<tr>
<td>Machinery Manufacturing (NAICS 333)</td>
<td>1.05</td>
</tr>
<tr>
<td>Miscellaneous Manufacturing (NAICS 339)</td>
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</tr>
<tr>
<td>Non-Metallic Mineral Product Manufacturing (NAICS 327)</td>
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</tr>
<tr>
<td>Paper Manufacturing (NAICS 322)</td>
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<tr>
<td>Petroleum and Coal Products Manufacturing (NAICS 324)</td>
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<tr>
<td>Plastics and Rubber Products Manufacturing (NAICS 326)</td>
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<td>Printing and Related Support Activities (NAICS 323)</td>
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<td>Transportation Equipment Manufacturing (NAICS 336)</td>
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<tr>
<td>Wood Product Manufacturing (NAICS 321)</td>
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</tr>
<tr>
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<td><strong>1.01</strong></td>
</tr>
</tbody>
</table>

*All of the indices are relative to the base year, 1994.*

All of the indices are relative to the base year, 1994.
### Appendix B. Malmquist Productivity Index results – U.S.

#### Table B-1. MPI results for U.S. manufacturing industries

<table>
<thead>
<tr>
<th>Manufacturing Industry</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
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<td>1.20</td>
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</tr>
<tr>
<td>Chemical Manufacturing (NAICS 325)</td>
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<td>1.00</td>
<td>0.96</td>
<td>0.95</td>
<td>1.04</td>
</tr>
<tr>
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<td>1.03</td>
<td>1.00</td>
<td>0.97</td>
<td>1.17</td>
</tr>
<tr>
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<td>1.02</td>
<td>1.14</td>
<td>1.08</td>
<td>0.93</td>
<td>0.81</td>
</tr>
<tr>
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<td>1.04</td>
<td>1.05</td>
<td>1.05</td>
<td>1.00</td>
<td>1.05</td>
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<td>1.01</td>
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<td>0.95</td>
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<td>1.06</td>
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<td>1.11</td>
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<tr>
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<td>0.96</td>
</tr>
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<td>0.99</td>
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<tr>
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<td>0.98</td>
<td>1.02</td>
</tr>
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<td>1.04</td>
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<td>1.07</td>
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<tr>
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<td>0.92</td>
<td>1.12</td>
<td>1.03</td>
<td>1.04</td>
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<tr>
<td>Plastics and Rubber Products Manufacturing (NAICS 326)</td>
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<td>1.04</td>
<td>1.00</td>
<td>0.98</td>
<td>1.03</td>
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<tr>
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<td>0.97</td>
</tr>
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<td>1.03</td>
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<td>1.17</td>
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<td>1.00</td>
<td>0.99</td>
<td>1.03</td>
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</tr>
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<td>0.99</td>
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<td><strong>1.02</strong></td>
<td><strong>0.98</strong></td>
<td><strong>1.05</strong></td>
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*All of the indices are relative to the base year, 1997.*
Table B-2. Catch-up effect for U.S. manufacturing industries

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<th>2000</th>
<th>2001</th>
<th>2002</th>
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<tbody>
<tr>
<td>Beverage and Tobacco Product Manufacturing (NAICS 312)</td>
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<td>0.81</td>
</tr>
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<td>0.91</td>
<td>0.97</td>
</tr>
<tr>
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<td>0.87</td>
<td>0.89</td>
<td>0.86</td>
<td>0.94</td>
</tr>
<tr>
<td>Food Manufacturing (NAICS 311)</td>
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<td>0.88</td>
<td>0.85</td>
<td>0.93</td>
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<tr>
<td>Furniture and Related Product Manufacturing (NAICS 337)</td>
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<td>0.94</td>
<td>0.93</td>
<td>1.04</td>
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<td>0.85</td>
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<td>0.90</td>
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<tr>
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<tr>
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<td>0.91</td>
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<td><strong>0.90</strong></td>
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<td><strong>0.96</strong></td>
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</table>

All of the indices are relative to the base year, 1997.
Table B-3. Frontier shift effect for U.S. manufacturing industries

<table>
<thead>
<tr>
<th>Manufacturing Industry</th>
<th>Technical change (Frontier shift effect)</th>
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<td></td>
<td>1998</td>
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<td>Beverage and Tobacco Product Manufacturing (NAICS 312)</td>
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<td>Computer and Electronic Product Manufacturing (NAICS 334)</td>
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<tr>
<td>Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)</td>
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</tr>
<tr>
<td>Fabricated Metal Product Manufacturing (NAICS 332)</td>
<td>1.08</td>
</tr>
<tr>
<td>Food Manufacturing (NAICS 311)</td>
<td>1.08</td>
</tr>
<tr>
<td>Furniture and Related Product Manufacturing (NAICS 337)</td>
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</tr>
<tr>
<td>Leather and Allied Product Manufacturing (NAICS 316)</td>
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</tr>
<tr>
<td>Machinery Manufacturing (NAICS 333)</td>
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<tr>
<td>Miscellaneous Manufacturing (NAICS 339)</td>
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<tr>
<td>Non-Metallic Mineral Product Manufacturing (NAICS 327)</td>
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<tr>
<td>Paper Manufacturing (NAICS 322)</td>
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</tr>
<tr>
<td>Petroleum and Coal Products Manufacturing (NAICS 324)</td>
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</tr>
<tr>
<td>Plastics and Rubber Products Manufacturing (NAICS 326)</td>
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<tr>
<td>Primary Metal Manufacturing (NAICS 331)</td>
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</tr>
<tr>
<td>Printing and Related Support Activities (NAICS 323)</td>
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<tr>
<td>Textile Mills (NAICS 313)</td>
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<tr>
<td>Textile Product Mills (NAICS 314)</td>
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<tr>
<td>Transportation Equipment Manufacturing (NAICS 336)</td>
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<tr>
<td>Wood Product Manufacturing (NAICS 321)</td>
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</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.08</strong></td>
</tr>
</tbody>
</table>

All of the indices are relative to the base year, 1997.
Appendix C. DEA efficiency results for wood industry sub-sectors - Canada

Table C-1. Technical efficiency (BCC) scores

<table>
<thead>
<tr>
<th>Year</th>
<th>Sawmills and wood preservation</th>
<th>Veneer, plywood and EWP</th>
<th>Other wood products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.96</td>
<td>1.00</td>
<td>0.49</td>
</tr>
<tr>
<td>1995</td>
<td>0.89</td>
<td>0.99</td>
<td>0.45</td>
</tr>
<tr>
<td>1996</td>
<td>0.93</td>
<td>0.87</td>
<td>0.46</td>
</tr>
<tr>
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<td>1.00</td>
<td>0.81</td>
<td>0.46</td>
</tr>
<tr>
<td>1998</td>
<td>0.96</td>
<td>0.89</td>
<td>0.46</td>
</tr>
<tr>
<td>1999</td>
<td>1.00</td>
<td>1.00</td>
<td>0.38</td>
</tr>
<tr>
<td>2000</td>
<td>0.98</td>
<td>0.90</td>
<td>0.54</td>
</tr>
<tr>
<td>2001</td>
<td>0.94</td>
<td>0.85</td>
<td>0.53</td>
</tr>
<tr>
<td>2002</td>
<td>1.00</td>
<td>0.89</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table C-2. Aggregate efficiency (CCR) scores

<table>
<thead>
<tr>
<th>Year</th>
<th>Sawmills and wood preservation</th>
<th>Veneer, plywood and EWP</th>
<th>Other wood products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.91</td>
<td>0.83</td>
<td>0.48</td>
</tr>
<tr>
<td>1995</td>
<td>0.85</td>
<td>0.83</td>
<td>0.45</td>
</tr>
<tr>
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<tr>
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<td>0.75</td>
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<tr>
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<td>0.46</td>
</tr>
<tr>
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<td>1.00</td>
<td>0.38</td>
</tr>
<tr>
<td>2000</td>
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<td>0.90</td>
<td>0.54</td>
</tr>
<tr>
<td>2001</td>
<td>0.91</td>
<td>0.85</td>
<td>0.53</td>
</tr>
<tr>
<td>2002</td>
<td>0.99</td>
<td>0.89</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Table C-3. Scale efficiency scores

<table>
<thead>
<tr>
<th>Year</th>
<th>Sawmills and wood preservation</th>
<th>Veneer, plywood and EWP</th>
<th>Other wood products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.95</td>
<td>0.83</td>
<td>1.00</td>
</tr>
<tr>
<td>1995</td>
<td>0.95</td>
<td>0.84</td>
<td>1.00</td>
</tr>
<tr>
<td>1996</td>
<td>0.94</td>
<td>0.87</td>
<td>0.99</td>
</tr>
<tr>
<td>1997</td>
<td>0.94</td>
<td>0.93</td>
<td>0.99</td>
</tr>
<tr>
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<td>0.93</td>
<td>0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>1999</td>
<td>0.90</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>2000</td>
<td>0.93</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>2001</td>
<td>0.97</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>2002</td>
<td>0.99</td>
<td>1.00</td>
<td>0.99</td>
</tr>
</tbody>
</table>