Applied Mathematical Sciences, Vol. 2, 2008, no. 17, 799 - 816

Productivity Changes of the Wood Product Manufacturing Sector in the U.S.

Saba Vahid

Department of Forest Resources Management
University of British Columbia
4219 – 2424 Main Mall
Vancouver, BC, V6T-1Z4, Canada
saba_v@interchange.ubc.ca

Taraneh Sowlati*

Department of Wood Science
University of British Columbia
2931 – 2424 Main Mall
Vancouver, BC, V6T-1Z4, Canada
taraneh.sowlati@ubc.ca

Abstract

The wood product manufacturing is one of the important manufacturing industries in the United States. Similar to other manufacturing industries, it has been facing many challenges including an increasing competition from offshore producers. Productivity growth is required to improve its competitive position. This study focuses on the productivity changes of the manufacturing industries in the U.S. from 1997 to 2002. The results showed 5% increase in productivity of the whole sector on average over the study period, while the productivity of the wood product manufacturing decreased by 1% over the same period. The efficiency decline of the industry was the main contributor to the decline of its productivity. The recent declines in investments on capital and training and education of workforce in wood manufacturing industry could be among the factors affected its productivity and if this trend continues, it would affect the productivity and consequently the competitive position of the industry more negatively.

Keywords: Data Envelopment Analysis, productivity change, wood industry, Malmquist productivity index, wood products manufacturing sector

---

* Corresponding author

1. Introduction

The United States is the world's largest producer of manufactured goods. When all benchmarks were taken into account, the U.S. manufacturing sector has achieved the best performance rating among those of the G7 countries [1]. The manufacturing sector has long been the driving engine of the U.S. economic prosperity and growth. It encourages innovation by promoting Research and Development (R&D), investments in machinery and equipment, and labor training. Manufacturing activities generate additional demand for goods and services of other sectors. In 2004, for every dollar of manufactured goods, $1.37 worth of additional products and services was needed to support that demand [2]. The great impact of the manufacturing sector on the U.S. economy is also clear by looking at its GDP contribution; the sector currently accounts for more than 14% of the GDP. Moreover, it generates 11% of the employment in the whole economy [3]. While the manufacturing sector is vital to the U.S. economic health, it has been facing several challenges in recent years.

Although the United States is one of the world's largest exporters of the manufactured goods with more than $669 billion dollars worth of exports in 2004, its share of total world's exports declined from 12% in 2001 to 9% in 2004 [2]. This decline was the result of the decline in manufacturing production after the recession and the decline in the value of US dollar.

The sector 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 [3]. Apart from the current recession, U.S. manufacturers have been facing other challenges. 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 [3].

Another major challenge facing the U.S. manufacturers is the shortage of skilled labor. Considering the advances in manufacturing technologies, there is an increasing need for highly skilled and technically competent employees who can utilize the new technologies and support advanced production processes. It has been argued that the demographic shift in the U.S. resulted in retirement of skilled workers from the "baby boom", and immigration would be the major source of obtaining skilled workforce by 2020. More than 80% of the manufacturers have stated the lack of qualified job applicants as a challenge, even during serious layoff periods after the recession [4].

The wood product manufacturing is one of the important manufacturing industries in the United States. It had a total shipments of more than $103 billion, employed over half a million people [5], and accounted for approximately $5 billion of exports in 2004 [6]. However, the U.S. wood industry has been facing various challenges, such as changing consumer preferences, land fragmentation, species and stand changes, and environmental issues [7]. In addition, similar to other manufacturing industries, the wood industry has been facing increasing competition from offshore producers. Emerging wood exporting countries, such as China and South American countries, have been increasing their exports to the U.S., and therefore, have made the situation difficult for domestic producers [8]. Therefore, it's important for this industry, as well as the whole manufacturing sector, to improve their competitive position in both domestic and global markets.

Productivity growth is one of the key determinants of global competitiveness in the long term. It increases the living standards of nations by increasing the real incomes. Consequently, productivity growth makes it possible to invest in education, health care, social security, environmental improvements, and poverty reduction programs among others [9].

Traditionally, labour productivity levels have been used for comparison purposes [10], [11]. Although labour productivity generally moves in the same direction as the total factor productivity, it only includes the effect of one input (labour) and, therefore, cannot provide a complete measure. The total factor productivity (TFP) measures incorporate multiple production factors in the analysis in order to generate a more accurate picture of the productivity change.

Both parametric and non-parametric TFP productivity analyses have been previously conducted on the manufacturing industries in the U.S. and worldwide. These studies have either compared different industries together in one or more countries (for example, [12], [13], [14]) or focused on a specific industry [15], [16]. Parametric approaches require a functional form to relate the inputs and outputs of the production technology (e.g. Translog or Cobb-Douglas) which is sometimes difficult to decide on. Non-parametric approaches, on the other hand, relax this assumption and are more flexible [17].

In a number of studies, U.S. manufacturing industries have been compared to those of other countries and in many cases it had one of the highest productivity growth rates. Arcelus and Arozena [12] used Malmquist index for measuring the sectoral productivity across 14 OECD[1] countries from 1970 to 1990. The TFP results showed that the U.S. manufacturing sector had the highest growth among other countries in the study. Maudos et al. [13] compared the productivity changes of 23 OECD countries during the period from 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. Using index numbers, Malley et al. [14] presented comparative measures of TFP at the sectoral level for manufacturing industries in the G7 economies from 1971 to 1995. They also found that the U.S. had the highest TFP levels and that other countries showed a slow convergence towards the U.S. performance level.

Considering the importance of the manufacturing sector and mainly the wood product industry in the U.S. and the challenges they have been facing recently, this research has been designed to study the performance of manufacturing sub-sectors by measuring their productivity changes from 1997 to 2002 The Malmquist Productivity Index (MPI) was selected to measure the productivity changes since it can be decomposed into productivity components (namely, efficiency change and frontier shift) to provide

[1] Organisation for Economic Co-operation and Development

further insight. In this research Data Envelopment Analysis (DEA), a non-parametric approach, was used to measure the distance functions required for calculating the MPI.

2. Malmquist Productivity Index (MPI)

The Malmquist productivity index, which is an index for measuring the Total Factor Productivity (TFP) change of a unit between two time periods, was originally developed by Caves et al. [18] based on Malmquist input and output quantity indices introduced by Malmquist [19]. It does not require any price data and can be decomposed into productivity change components: efficiency change (catch-up effect) and frontier shift (technical change), as it is shown in equation (1). The efficiency change is the change over time in the efficiency of each unit individually, while the frontier shift is the change of the best practice frontier over time typically due to changes in "technology". The term "technology" has a more general meaning here and it refers not only to the manufacturing technology and machinery but also to policies, regulations, and business environment that affect the productivity of a unit. When the productivity of a unit improves over time, this can be the result of a frontier shift (all units had access to better technology, therefore, the best practice frontier moved upward) or an efficiency change (the efficiency of the unit increased, therefore, it got closer to the frontier) [17]. The efficiency change may be further decomposed into technical efficiency change and scale efficiency change.

$$\text{MPI} = \text{efficiency change} \times \text{frontier shift} \tag{1}$$

The Malmquist productivity index can be calculated using distance functions. Distance functions can represent a multi input-multi output technology without any behavioral assumptions such as cost minimization or profit maximization. They can be estimated using either parametric (Stochastic Frontier Analysis) or non-parametric methods (Data Envelopment Analysis). Therefore, the Malmquist productivity index may be parametric or non-parametric depending on the method that is chosen for estimating the distance functions. Fare et al. [20] used DEA to estimate the distance functions of a Malmquist productivity index.

Assume there are n units ($j=1,\ldots n$) using m inputs ($X_j \in R^m$) to produce s outputs ($Y_j \in R^s$). The notations $(X_j, Y_j)^1$ and $(X_j, Y_j)^2$ represent unit j in periods 1 and 2, respectively. The efficiency change of unit j between time periods 2 and 1 can be written as equation (2).

$$\text{efficiency change} = \frac{\text{distance of } (X_j, Y_j)^2 \text{ from the frontier of period 2}}{\text{distance of } (X_j, Y_j)^1 \text{ from the frontier of period 1}} = \frac{D^2(X_j, Y_j)^2}{D^1(X_j, Y_j)^1} \tag{2}$$

To calculate the frontier shift of unit j from period 1 to period 2, the distance of $(X_j, Y_j)^1$ from the frontiers of period 1 and period 2 can be considered as shown in equation (3) or the distance of $(X_j, Y_j)^2$ from the same two frontiers can be measured as in equation (4). Therefore, the frontier shift is expressed as the geometric mean of (3) and (4).

$$\text{frontier shift} = \frac{D^1(Xj,Yj)^1}{D^2(Xj,Yj)^1} \tag{3}$$

$$\text{frontier shift} = \frac{D^1(Xj,Yj)^2}{D^2(Xj,Yj)^2} \tag{4}$$

$$\text{frontier shift} = \left[\frac{D^1(Xj,Yj)^1}{D^2(Xj,Yj)^1} \times \frac{D^1(Xj,Yj)^2}{D^2(Xj,Yj)^2}\right]^{1/2} \tag{5}$$

The Malmquist productivity index is then expressed as (6). A value of more than one for MPI and each of its components means that a progress has occurred, while a value of less than one represents a regress. A value of one indicates that no change has occurred in the level of productivity or its components.

$$\text{MPI} = \left[\frac{D^1(Xj,Yj)^2}{D^1(Xj,Yj)^1} \times \frac{D^2(Xj,Yj)^2}{D^2(Xj,Yj)^1}\right]^{1/2} \tag{6}$$

In this research, DEA is used to estimate the distance functions of the MPI and its components because of its flexibility compared to the parametric approach. Data Envelopment Analysis is a non-parametric method to measure the relative efficiency of a set of comparable units, usually referred to as decision making units (DMUs). It involves the use of linear programming methods to construct a piece-wise frontier over the data. The frontier consists of best practice performers and efficiency measures are calculated relative to this frontier. DEA was introduced by Charnes, Cooper and Rhodes [21] based on Farrell's work [22] on frontier estimation using piece-wise linear approach. The DEA model developed by Charnes et al., called the CCR model, has a constant returns-to-scale (CRS) frontier which means that a proportional increase in inputs results in a proportionate increase in outputs. The CCR output-oriented model for n units using m inputs ($X \in R^{m\times n}$) to produce s outputs ($Y \in R^{s\times n}$) is as follow [23]:

$$\begin{aligned} &\max\ z_o = \phi \\ &s.t. \qquad \phi Y_o - Y\lambda \le 0 \\ &\qquad\quad\ \ X\lambda - X_o \le 0 \\ &\qquad\quad\ \ \lambda \ge 0 \end{aligned} \tag{7}$$

In equation (7), X_o and Y_o are the input and output vectors of the unit under evaluation (DMU_o), respectively, and ϕ represents the proportional increase required in outputs of DMU_o to make it efficient (ϕ is equal to one for efficient units). Therefore, $1/\phi$ is the efficiency score of DMU_o and its value is between zero and one. If the unit under evaluation is inefficient, then an efficient target can be determined for it using λ (the radial increase of ϕ in outputs of DMU_o produces an efficient target point ($X_o\,\lambda,\ Y_o\,\lambda$) on the efficient frontier). In an output-oriented model, the improvement of an inefficient unit is through the proportional augmentation of its outputs, while in an input-oriented model, the improvement is done by the proportional reduction of inputs.

The CCR model compares a unit with all the other units in the sample regardless of their scale size, therefore, the efficiency score from the CCR model represents the aggregate efficiency. Banker et al. [24] accounted for the scale size in the DEA model by adding a convexity constraint ($\vec{1}\lambda = 1$) to the previous model. In their model, the BCC model (8), each DMU is compared with units in its own scale size, therefore, the technical efficiency score is measured. The efficient frontier in a BCC model is variable returns-to-scale (VRS), it means that a proportional increase in inputs results in other than proportional increase in outputs.

$$\begin{aligned} \max\ & z_o = \phi \\ s.t.\quad & \phi Y_o - Y\lambda \le 0 \\ & X\lambda - X_o \le 0 \\ & \vec{1}\lambda = 0 \\ & \lambda \ge 0 \end{aligned} \tag{8}$$

The efficiency score of a unit ($1/\phi$) from DEA models is used to estimate the distance functions. 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 (7). Grifell-Tatje and Lovell [25] 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 accurately under VRS assumption. 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 [17]. The CRS assumption is, therefore, still suggested by many researchers and is utilized in this research. Additionally, a non-radial DEA model developed by Tone [26] was used instead of the original CCR model. This model, called Slack-Based Measure (SBM) of efficiency, was chosen to consider the effect of slack variables – non-radial input excess (output shortfall) – and to provide a more realistic picture of the changes in the efficiency. The mathematical programming problem for finding the SBM efficiency is shown in (8), which is basically a DEA model with a modified objective function [26].

$$\begin{aligned} \min\quad & \rho = \frac{1 - \dfrac{s^-}{mX_o}}{1 + \dfrac{s^+}{sY_o}} \\ \text{s.t.}\quad & X_{\mathbf{o}} = X\lambda + s^- \\ & Y_{\mathbf{o}} = Y\lambda - s^+ \\ & \lambda, s^-, s^+ \ge 0 \end{aligned} \tag{9}$$

The vectors $s^- \in R^m$ and $s^+ \in R^s$ are input *excess* and output *shortfall*, respectively, they are also called *slacks*. ρ is a slack based index defined using s^- and s^+, it can be shown that $0<\rho\le 1$ [26]. Readers may refer to Tone [26] for more details on the SBM model.

3. Data

The data for this research were extracted from the U.S. Census Bureau [5], [27] 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 North American Industrial Classification System (NAICS). Based on NAICS, the manufacturing sector is divided into 21 industries. The study period was selected to be from 1997 to 2002 because of the data availability. For time periods before 1997, the industries were classified based on the Standard Industrial Classification (SIC) and, therefore, the analysis could not include the data from previous years. Based on NAICS, the wood product manufacturing industry includes “sawmilling and wood preservation”, “veneer, plywood and engineered wood products” and “other wood products” such as millwork, etc. It excludes “wood furniture” and “pulp and paper” industries.

In order to measure the productivity change of the manufacturing industries a DEA production model including the main performance factors was developed. These factors were selected from the original data set provided by the Census Bureau. As it is shown in Figure 1, the DEA model included three inputs (number of employees, cost of materials, and cost of energy) and one output (total shipments).

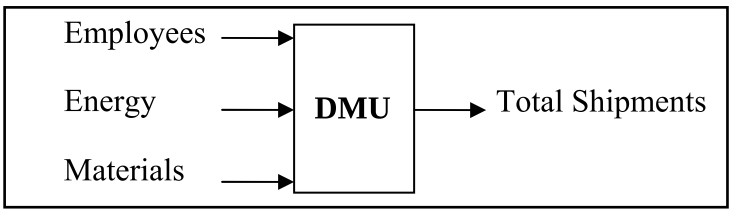

Figure 1. Production model for the U.S. manufacturing industries

The costs and shipment revenues were in current dollar values, available at the industry level for each of the 21 manufacturing industries in each year. Therefore, a deflator was needed to make dollar values comparable across time. Since the data were at the industry level, Producer Price Index (PPI) was selected for deflation. PPI measures the changes in the prices of the manufactured goods and includes only 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 [28]. PPI 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 1.

Table 1. Summary statistics for the U.S. manufacturing sector data

	Inputs			Output
	Employees	**Energy**	**Material**	**Total revenues**
Maximum	**1,886,700**	**12.13**	**321.05**	**527.15**
Minimum	**44,728**	**0.04**	**2.49**	**4.71**
Average	**775,253**	**2.55**	**75.91**	**145.04**
Standard Deviation	**528,199**	**2.49**	**70.65**	**123.81**

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

4. Analyses and Results

The productivity changes of the manufacturing industries in the U.S. were measured using the Malmquist Productivity Index. The change was then decomposed into the efficiency change and the frontier shift in order to further identify the sources of the productivity change. A non-oriented and non-radial (slack-based) DEA model with the CRS assumption was used to estimate the required distance functions. The fixed-base period approach, in which productivity change is measured relative to a fixed base year, was selected. This provided a better picture of how the performance of the industries had changed during the study period compared to their initial position. The *DEA-Solver Pro 4.0* software was used to run the DEA models. The summary results for the U.S. manufacturing industries are presented in Table 2. Note again that all values are relative to year 1997.

Table 2. Malmquist analysis summary for the U.S. manufacturing industries

		Productivity change	**Efficiency change**	**Frontier shift**
1997-2002	Manufacturing sector (Average)	1.05	0.96	1.10
	Transportation equipment manufacturing	1.23	1.23	0.99
	Wood products manufacturing	0.99	0.91	1.09
	Computer & electronic product manufacturing	0.81	0.81	1.00

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 of 1.23 and the lowest change was that of the computer and electronic product manufacturing with an MPI value of 0.81. The detailed results for MPI and its components are shown in Appendix A.

The results for the wood product manufacturing in the U.S. indicated that it had a TFP change below the average of the whole sector during the period from 1997 to 2002 - an MPI value of 0.99. Based on the TFP change, the wood industry was ranked 18th out of 21 industries. However, it had a higher rank based on the frontier shift (10th) compared to the efficiency change (16th).

Figure 2 compares the TFP change of the wood product manufacturing with the transportation industry (highest TFP change) and the computer and electronic products manufacturing (lowest TFP change) and the average for all industries. It is observed that the TFP change gap between the best performer and the wood product manufacturing was wide in the beginning of the period and started to decrease as a result of the decline in the TFP of the transportation industry.

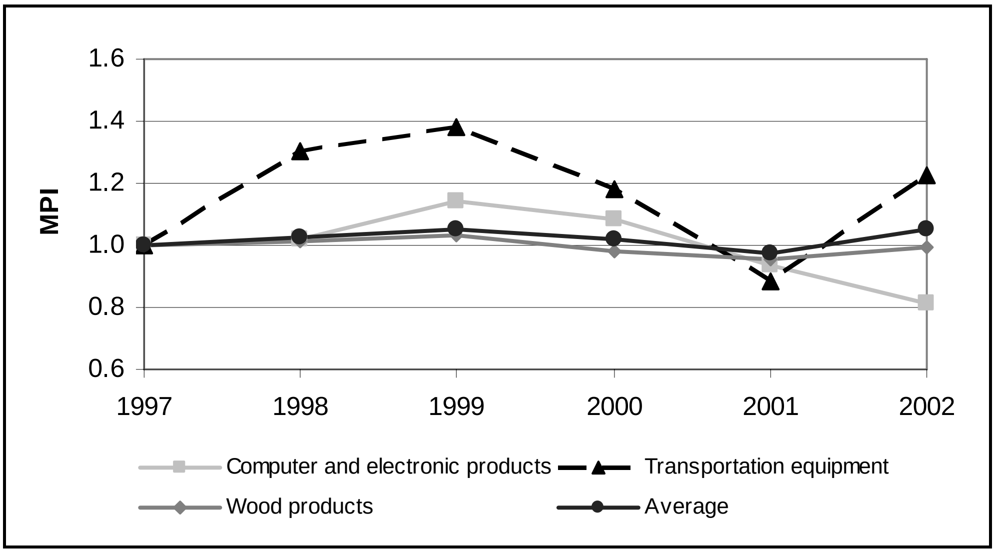

Figure 2. MPI changes for selected American manufacturing industries (1997=1.0)

For the wood product manufacturing , changes in the productivity components are shown in Figure 3. The declining frontier shift effect after 1999 can be attributed to the economic recession.

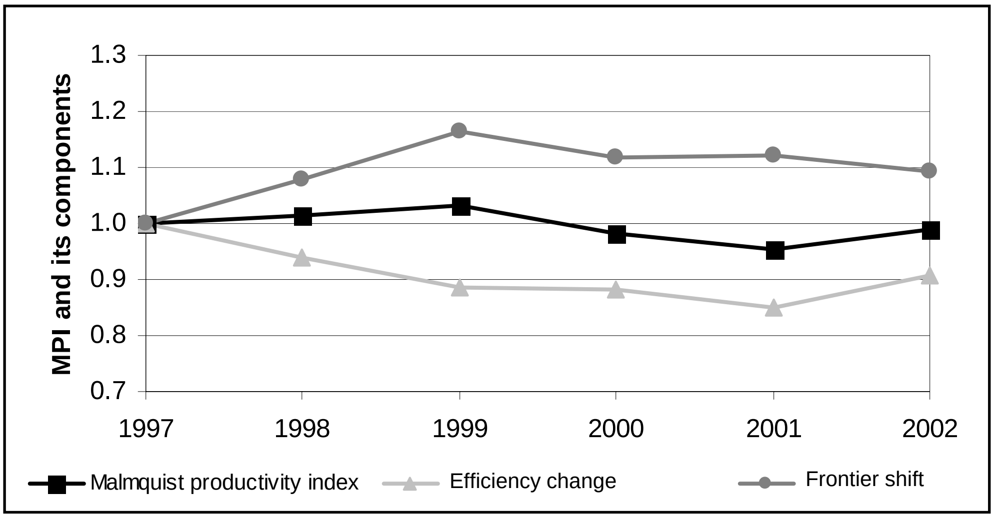

Figure 3. Productivity change components for the American wood products manufacturing (1997=1.0)

5. Discussion

Based on the results, the manufacturing sector in the U.S. showed a total productivity growth of 5% over the study period. This matches with the results of some previous studies. Maudos et al. [13] reported a 0.74% annual productivity growth for the U.S. business sector as a whole from 1975 to 1990. Gu and Ho [29] measured the manufacturing sector's TFP change over the period of 1979 to 1995 and found a similar result (approximately 0.8% per year), an estimate that is close to our result. Also, based on another study by Sharpe [30], the labor productivity of the whole business sector grew by approximately 5.0% from 1997 to 2002.

It is useful to observe the trends of TFP for industries with highest and lowest TFP. A sharp decrease in TFP is seen for the transportation industry in 2001, but the industry bounced back in 2002 with a growth in TFP. 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, 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 [5], [27]. 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 [31].

The decline in TFP of the computer and electronic product industry is not surprising since the high tech industries were affected the most by the recession. The main part of the business investment during the late 1990s was on computers and information technology [32]. In the late 1990's, firms overspent in obtaining new technologies and capacity to meet the high demand for their products. Gordon [33] listed the factors that enhanced the demand for technology products during this period of the *new economy*. Some of these factors are 1) telecom industry deregulation that led to the creation of new firms, each demanding large amounts of equipment to build communication networks; 2) the need to replace computers in order to run a new generation of software starting with Windows 95; and 3) the one-time invention of the World Wide Web. 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 [5], [27].

The results of this study indicated that the wood product manufacturing 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.

There have been various studies on identifying the determinants of productivity growth. Some suggested factors were investment in machinery and equipment, investment in human capital, innovation, openness to trade, and research and development efforts [34], [35], [9]. Because the data on all factors were not available, the two main factors - physical and human capital - 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 efficiency [34], [35]. Rao et al. [9] showed that there is a strong positive correlation between machinery and equipment investment and productivity. Investments in infrastructure are also argued to have an effect on productivity [35]. In the U.S., the real value of the total capital investments in the wood industry decreased from \$2.25 billion in 1997 to \$1.81 billion in 2002 [5], [27]. This could have been a factor leading to the decline in TFP of wood products manufacturing in the US.

Human capital is another important factor in productivity growth. In a study on a large sample of establishments in the U.S., Black and Lynch [36] showed that an increase of 10% in average education level (approximately one more year of schooling) would result in 8.5% increase in manufacturing productivity. Having access to a skilled labour force is more likely to result in new technology (through product or process innovation) and productivity improvements [34], [37], [30]. There have been concerns about the level of education and skills of manufacturing sector's workforce [3]. For wood industry, one of the main concerns in recent years has been the lack of skilled labor and the level of recruitment in wood engineering programs [38]. It has been argued that the declining trend of programs that deliver wood engineering education and the number of engaged students could negatively impact the wood products industry [39]. Although the employees may still be able to work with the existing machinery and equipment, low levels of education may prevent them from working efficiently with new equipments. This, consequently, could stop the industry from obtaining new technologies and creating new ideas. In the long run, this would affect the productivity by decreasing both the frontier shift and efficiency change rates.

6. Conclusion

The results of this study provided a picture of the relative performance of different manufacturing industries in the U.S. during an important period of time, including both growth and recession. The productivity of wood industry could be improved by investing more in both physical and human capital. Efficiency decline was the major source of TFP decline in the wood products manufacturing. Some possible ways for improving this component of productivity change are to implement better management techniques, invest more on training and education of the workforce, and improve input utilization patterns.

It should be noted that the results of this study were based on the production factors included in the model and the available data. Data availability limited the study by preventing the inclusion of data from a longer period. Additionally, although the industries are different in nature, the distance functions in the Malmquist productivity index were calculated using a non-parametric CRS model including all industries. This comparison can be justified since the industries operated in the same country and in a similar economic environment. Besides, similar comparisons among different manufacturing industries have been done previously in the literature.

References

[1] CME: Canadian Manufacturers and Exporters. (2004). Manufacturing challenges in Canada. Retrieved Dec. 11, 2006 from http://cme-mec.ca/mfg2020/Challengespdf.pdf

[2] J., Popkin & K. Kobe, (2006). U.S. manufacturing innovation at risk. National Association of Manufacturers. Retrieved June 28, 2006 from http://www.nam.org/s_nam/bin.asp?CID=202515&DID=236300&DOC=FILE.PDF

[3] U.S. Department of Commerce. (2004). Manufacturing in America: a comprehensive strategy to address the challenges to U.S. manufacturers. Retrieved October 10, 2005 from http://www.ita.doc.gov/media/Publications/pdf/manuam0104final.pdf

[4] National Association of Manufacturers. (2003). Keeping America Competitive: How a talent shortage threatens U.S. manufacturing: Part I. National Association of Manufacturers and Deloitte & Touche. Retrieved June 28, 2006 from http://www.nam.org/s_nam/bin.asp?CID=84&DID=226411&DOC=FILE.PDF

[5] U.S. Census Bureau. (2005). Statistics for industry groups and industries: 2003. Retrieved August 3, 2005 from http://www.census.gov/prod/ec02/am0331gs1.pdf

[6] U.S. Census Bureau. (2006). U.S. International trade statistics. Retrieved April 10, 2006 from http://censtats.census.gov/naic3_6/naics3_6.shtml

[7] S. J. Milauskas, The Wood Education Center, Forest Products Journal, 2005, Vol. 55 (11), 4-9.

[8] FAOSTAT. (2005). Forest products database, Food and Agriculture Organization of the United Nations (FAO). Retrieved April 5, 2005 from http://faostat.fao.org/faostat/collections?subset=forestry&Language=English

[9] S. Rao, J. Tang, W. Wang, The importance of skills for innovation and productivity. International Productivity Monitor, 2002, 4, 15-26. Retrieved March 20, 2006 from http://www.csls.ca/ipm/ipm4.asp

[10] K. Hitomi, Efficiency analysis of Japan's industry and manufacturing. Technovation, 2004, 24 (9), 741-748.

[11] K. Hitomi, Historical trends and the present state of the US industry and manufacturing, Technovation, 2005, 25 (6), 673-681.

[12] F. J. Arcelus, P. Arozena, Measuring sectoral productivity across time and across countries. European Journal of Operational Research, 1999, 119 (2), 254-266.

[13] J. Maudos, M. Pastor, L. Serrano, Total factor productivity measurement and human capital in OECD countries. Economics Letters, 1999, 63 (1), 39-44.

[14] J. Malley, A. Muscatelli, U. Woitek, Some new international comparisons of productivity performance at the sectoral level. Journal of the Royal Statistical Society: Series A (Statistics in Society), 2003, 166 (1), 85-104.

[15] P. Chandra, W. W. Cooper, S. Li, A. Rahman, Using DEA to evaluate 29 Canadian textile companies–considering returns to scale. International Journal of Production Economics, 1998, 54 (2), 129-141.

[16] J. Ma, D. G. Evans, R. J. Fuller, S. F. Stewart, Technical efficiency and productivity change of China's iron and steel industry. International Journal of Production Economics, 2002, 76 (3), 293-312.

[17] T. Coelli, D. S. P. Rao, G. E. Battese, An introduction to efficiency and productivity analysis. 1998, Norwell, MA: Kluwer Academic Publishers.

[18] D. W. Caves, L. R. Christensen, W. E. Diewert, The economic theory of index numbers and the measurement of input, output, and productivity. Econometrica, 1982, 50 (6), 1393-1414.

[19] S. Malmquist, Index numbers and indifference surfaces. Trabajos De Estadistica, 1953, 4, 209-242.

[20] R. Fare, S. Grosskopf, P. Roos, Malmquist productivity indexes: A survey of theory and practice. In R. Fare, S. Grosskopf & R. R. Russell (Eds.), Index numbers: Essays in honor of Sten Malmquist (pp. 127-190), 1997, Boston, MA: Kluwer Academic Publishers.

[21] A. Charnes, W. Cooper, E. Rhodes, Measuring the efficiency of decision making units. European Journal of Operational Research, 1978, 2(6):429-444.

[22] M. J. Farrell,. The measurement of productive efficiency. Journal of the Royal Statistical Society. 1957, 120:253- 282.

[23] A. Charnes, W. Cooper, A. Y. Lewin, L. M. Seiford, Data Envelopment Analysis: Theory, Methodology and Applications, 1994, Kluwer Academic Publishers. Norwell. MA.

[24] R. D. Banker, A. Charnes, W. Cooper, Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science, 1984, 30(9):1078-1092.

[25] E. Grifell-Tatje, C. Lovell, A note on the Malmquist productivity index. Economics Letters, 1995, 47 (2), 169-175.

[26] K. Tone, A slack-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, 2001, 130 (3), 498-509.

[27] U.S. Census Bureau. (2003). Statistics for industry groups and industries: 2001. Retrieved June 20, 2005, from http://www.census.gov/prod/2003pubs/m01as-1.pdf

[28] U.S. Bureau of Labour Statistics. (2005). Producer Prices. In BLS handbook of methods (chapter 14). Retrieved June 20, 2005 from http://www.bls.gov/opub/hom/
homch14_a.htm

[29] W. Gu, M. S. Ho, (2000). A Comparison of Productivity Growth in Manufacturing between Canada and the United States, 1961-95. Retrieved April 20, 2006 from http://www.ksg.harvard.edu/cbg/ptep/HO_GU.pdf

[30] A. Sharpe, (2003). Why Are Americans More Productive Than Canadians? (Research report No. 2003-03). Ottawa, ON: The Centre for the Study of Living Standards. Retrieved April 08, 2006, from http://www.csls.ca/reports/10-03-03_can-us.pdf

[31] D. S. Langdon, T. M. McMenamin, T. J. Krolik, (2002). U.S. labour market in 2001: economy enters a recession. Monthly Labour Review, *125*(2), 3-33. Retrieved September 8, 2005, from
http://www.stats.bls.gov/opub/mlr/2002/02/art1full.pdf

[32] Federal Reserve Bank of San Francisco. (2003). Growth in the Post-Bubble Economy. Retrieved August 10, 2005, from http://www.frbsf.org/publications/economics/letter/2003/el2003-17.html

[33] R. J. Gordon, (2003). Hi-tech innovation and productivity growth: Does supply create its own demand? (Working paper No. 9437). Cambridge, MA: National Bureau of Economic Research.

[34] R. G. Harris, (1999). Determinants of Canadian productivity growth: Issues and prospects (Discussion paper No. 8). Ottawa, ON: Industry Canada.

[35] R. Mahadevan, (2002). New currents in productivity analysis: Where to now? (Productivity series No. 31). Tokyo, Japan: Asian Productivity Organization. Retrieved September 20, 2004, form http://www.apo-tokyo.org/00e-books/IS-08_NewCurrents/06.NewCurrents.pdf

[36] S. E. Black, L. M. Lynch, Human-capital investments and productivity. The American Economic review, 1999, 86 (2), 263-267.

[37] S. Rao, A. Ahmad, W. Horsman, P. Kaptein-Russell, The Importance of Innovation for Productivity. International Productivity Monitor, 2001, 2, 11-18. retrieved April 01, 2006 from http://www.csls.ca/ipm/2/rao-e.pdf

[38] R. Gupta, V. Gopu, (2005). Wood Engineering Education – Trends and Challenges. Proc. of the Structures Congress, April 20-24, 2005; New York City, New York. Reterived March 20, 2006 from http://woodscience.oregonstate.edu/faculty/gupta/pdf/Gopu.pdf

[39] B. M. Testa, R. Gupta, (2004). *Ivory towers - the status of wood design education in American universities. Engineered Wood Journal (APA - The Engineered Wood Association), Spring 2004,* 20-22. retrieved March 20, 2006 from http://woodscience.oregonstate.edu/faculty/gupta/pdf/Testa%20article.pdf

Appendix A. Malmquist Productivity Index results – U.S.

Table A-1. MPI results for U.S. manufacturing industries

Manufacturing Industry	Malmquist productivity index (MPI)				
	1998	1999	2000	2001	2002
Beverage and Tobacco Product Manufacturing (NAICS 312)	1.10	1.20	1.13	1.13	1.09
Chemical Manufacturing (NAICS 325)	1.02	1.00	0.96	0.95	1.04
Clothing Manufacturing (NAICS 315)	1.01	1.03	1.00	0.97	1.17
Computer and Electronic Product Manufacturing (NAICS 334)	1.02	1.14	1.08	0.93	0.81
Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)	1.04	1.05	1.05	1.00	1.05
Fabricated Metal Product Manufacturing (NAICS 332)	1.01	1.01	0.99	0.97	1.03
Food Manufacturing (NAICS 311)	1.02	1.02	0.98	0.95	1.01
Furniture and Related Product Manufacturing (NAICS 337)	1.04	1.06	1.04	1.03	1.11
Leather and Allied Product Manufacturing (NAICS 316)	1.00	0.99	0.94	0.93	0.96
Machinery Manufacturing (NAICS 333)	1.02	1.01	1.00	0.95	1.02
Miscellaneous Manufacturing (NAICS 339)	0.99	1.00	1.00	0.99	1.22
Non-Metallic Mineral Product Manufacturing (NAICS 327)	1.02	1.04	1.00	0.98	1.02
Paper Manufacturing (NAICS 322)	1.03	1.04	1.04	1.01	1.07
Petroleum and Coal Products Manufacturing (NAICS 324)	0.81	0.92	1.12	1.03	1.04
Plastics and Rubber Products Manufacturing (NAICS 326)	1.03	1.04	1.00	0.98	1.03
Primary Metal Manufacturing (NAICS 331)	1.01	0.99	0.95	0.92	0.97
Printing and Related Support Activities (NAICS 323)	1.02	1.06	1.03	1.00	1.17
Textile Mills (NAICS 313)	1.01	1.01	1.00	0.99	1.03
Textile Product Mills (NAICS 314)	0.99	1.02	0.96	0.95	1.05
Transportation Equipment Manufacturing (NAICS 336)	1.30	1.38	1.18	0.89	1.23
Wood Product Manufacturing (NAICS 321)	1.01	1.03	0.98	0.95	0.99
Average	**1.02**	**1.05**	**1.02**	**0.98**	**1.05**

All of the indices are relative to the base year, 1997.

Table A-2. Efficiency change for U.S. manufacturing industries

Manufacturing Industry	Efficiency change (Catch-up effect)				
	1998	1999	2000	2001	2002
Beverage and Tobacco Product Manufacturing (NAICS 312)	1.05	1.07	1.05	1.14	1.06
Chemical Manufacturing (NAICS 325)	0.95	0.86	0.86	0.83	0.93
Clothing Manufacturing (NAICS 315)	0.93	0.88	0.90	0.89	1.10
Computer and Electronic Product Manufacturing (NAICS 334)	0.97	0.97	1.00	0.99	0.81
Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)	0.96	0.91	0.95	0.91	0.97
Fabricated Metal Product Manufacturing (NAICS 332)	0.94	0.87	0.89	0.86	0.94
Food Manufacturing (NAICS 311)	0.94	0.88	0.88	0.85	0.93
Furniture and Related Product Manufacturing (NAICS 337)	0.96	0.91	0.94	0.93	1.04
Leather and Allied Product Manufacturing (NAICS 316)	0.92	0.85	0.85	0.85	0.90
Machinery Manufacturing (NAICS 333)	0.94	0.88	0.91	0.87	0.95
Miscellaneous Manufacturing (NAICS 339)	0.98	0.63	0.66	0.66	0.99
Non-Metallic Mineral Product Manufacturing (NAICS 327)	0.95	0.88	0.88	0.84	0.90
Paper Manufacturing (NAICS 322)	0.95	0.89	0.92	0.87	0.95
Petroleum and Coal Products Manufacturing (NAICS 324)	0.84	0.89	1.13	1.05	1.03
Plastics and Rubber Products Manufacturing (NAICS 326)	0.95	0.89	0.89	0.86	0.94
Primary Metal Manufacturing (NAICS 331)	0.94	0.85	0.84	0.79	0.86
Printing and Related Support Activities (NAICS 323)	0.78	0.74	0.76	0.73	0.79
Textile Mills (NAICS 313)	0.94	0.87	0.88	0.86	0.93
Textile Product Mills (NAICS 314)	0.92	0.88	0.86	0.86	0.98
Transportation Equipment Manufacturing (NAICS 336)	1.18	1.20	0.99	0.98	1.23
Wood Product Manufacturing (NAICS 321)	0.94	0.89	0.88	0.85	0.91
Average	**0.95**	**0.89**	**0.90**	**0.88**	**0.96**

All of the indices are relative to the base year, 1997.

Table A-3. Frontier shift effect for U.S. manufacturing industries

Manufacturing Industry	Frontier shift effect (technical change)				
	1998	**1999**	**2000**	**2001**	**2002**
Beverage and Tobacco Product Manufacturing (NAICS 312)	1.06	1.12	1.08	0.99	1.03
Chemical Manufacturing (NAICS 325)	1.08	1.16	1.12	1.15	1.12
Clothing Manufacturing (NAICS 315)	1.08	1.16	1.11	1.10	1.06
Computer and Electronic Product Manufacturing (NAICS 334)	1.05	1.17	1.08	0.95	1.00
Electrical Equipment, Appliance and Component Manufacturing (NAICS 335)	1.08	1.16	1.11	1.10	1.08
Fabricated Metal Product Manufacturing (NAICS 332)	1.08	1.17	1.12	1.13	1.09
Food Manufacturing (NAICS 311)	1.08	1.16	1.11	1.12	1.09
Furniture and Related Product Manufacturing (NAICS 337)	1.08	1.16	1.11	1.10	1.07
Leather and Allied Product Manufacturing (NAICS 316)	1.08	1.16	1.11	1.09	1.07
Machinery Manufacturing (NAICS 333)	1.08	1.16	1.10	1.09	1.07
Miscellaneous Manufacturing (NAICS 339)	1.01	1.59	1.52	1.51	1.24
Non-Metallic Mineral Product Manufacturing (NAICS 327)	1.08	1.18	1.14	1.17	1.13
Paper Manufacturing (NAICS 322)	1.08	1.17	1.13	1.16	1.12
Petroleum and Coal Products Manufacturing (NAICS 324)	0.96	1.03	0.99	0.98	1.01
Plastics and Rubber Products Manufacturing (NAICS 326)	1.08	1.17	1.13	1.14	1.10
Primary Metal Manufacturing (NAICS 331)	1.08	1.17	1.13	1.16	1.13
Printing and Related Support Activities (NAICS 323)	1.30	1.44	1.36	1.36	1.49
Textile Mills (NAICS 313)	1.08	1.17	1.13	1.15	1.11
Textile Product Mills (NAICS 314)	1.08	1.16	1.11	1.11	1.08
Transportation Equipment Manufacturing (NAICS 336)	1.10	1.15	1.19	0.91	0.99
Wood Product Manufacturing (NAICS 321)	1.08	1.16	1.12	1.12	1.09
Average	**1.08**	**1.19**	**1.14**	**1.12**	**1.10**

All of the indices are relative to the base year, 1997.

Received: October 3, 2007