Productivity in the Sawmilling Industries of the United States and Canada: A Nonparametric Analysis

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ABSTRACT.

We use the nonparametric programming approach to estimate technical efficiency and total factor productivity (TFP) growth of sawmill industries in the U.S. and Canada between 1963 and 2001. The results show that Canadian sawmill industry is more efficient than the U.S. counterpart during the whole study period. The weighted annual productivity growth of sawmill industry is 2.5% for the U.S. and 1.3% for Canada. Regional differences in technical efficiency and TFP growth exist. All regions are shown to have a trend of moving towards the industry frontier.

Key Words: Nonparametric programming approach, Malmquist productivity index, sawmill industry
Introduction

Productivity measures the efficiency with which inputs are transformed into outputs. Higher productivity occurs when larger quantities of outputs are produced with given amount of inputs. Among various techniques to estimate the performance of industries, total factor productivity (TFP) provides a simple yet comprehensive measurement. TFP, the ratio of an index of aggregate output to an index of aggregate input, is a measure taking into account the contribution of all inputs.

Productivity comparisons in the North American sawmilling industries have been of concern for decades as they play an important role in regional resource allocation and relative competitiveness among regional counterparts. Although costs of inputs affect relative competitiveness in the short run, competitiveness in the long run will be determined by technical efficiency and productivity growth. While many studies have been devoted to the productivity growth of the sawmill industry in the U.S and Canada, the results are mixed. Some studies suggest that there has been little or no technical progress in Canada, and productivity growth in the Canadian sawmill industry is lower than the U.S. counterpart (Ghebremichael et al. 1990, Abt et al. 1994, Nagubadi and Zhang 2004). At one extreme, Meil and Nautiyal (1988) reported negative TFP growth for all four Canadian regions over 1950-1983. On the other hand, Gu and Ho (2000) estimated that TFP growth of lumber & wood products industry increased by 0.62% per year in Canada while decreasing by 0.21% annually in the U.S. between 1961 and 1995.

Different approaches adopted by these studies may contribute to the differences in the results. Often, either an index approach or an econometric model is used to estimate productivity growth and technical change. Both approaches assume that all firms in the industries operate efficiently, which may not be the case in the reality, and some specific forms of cost or profit functions have to be assumed in the first place for econometric analysis.

As a more flexible approach, a nonparametric programming approach has been used extensively recently in the area of agricultural and industrial productivity analysis (e.g., Granderson and Linvill 1997, Preckel et al. 1997, Arnade 1998, Yin 2000, Hailu and Veeman 2001, Nin et al. 2003). This method, proposed by Färe et al. (1994) involves estimating an input or output based Malmquist index. Compared to other methods, the nonparametric programming approach has the advantage of imposing no a priori restrictions on the functional form of the underlying technology and allowing for inefficiency in production (Varian 1984). This approach also has the attribute of being capable of decomposing productivity growth into two parts: changes in technical efficiency over time, and shifts in technology over time. Until recently, however, the nonparametric programming approach has rarely been used in sawmill productivity analysis. Nyrud and Baardsen’s (2003) analysis of Norwegian sawmill productivity is one of the few exceptions.

This study attempts to expand the analytic scope of the technical efficiency and productivity trends of sawmill industries in the North America by using the nonparametric programming approach. In doing so, answers to the following questions can be obtained: Which state/province, region or country is on average the most efficient in sawmill production in the North America? What is the pattern of TFP growth for each state/province, region or country? Decomposition of
productivity growth can also shed a light on the sources of the growth (shift in production frontier, or movement towards or away from the production frontier), which assists policy makers and managers make decisions. The next section reviews distance function and the nonparametric Malmquist index used in this study. Section III describes the data. Section IV presents the results. Section V concludes and provides suggestions for future research.

**Methodology: Distance Function and the Malmquist Productivity Indices**

As in Caves et al. (1982), the productivity change of the sawmilling industry over time is estimated as the geometric mean of two output-based Malmquist productivity indices, which are developed based on distance functions. Suppose that for each time period \( t = 1, \ldots, T \), the feasible production set of the industry is:

\[
S^t = \{ (x^t, y^t) : \text{\textit{x}^t can produce \textit{y}^t} \} \tag{1}
\]

Where, \( x^t \in \mathbb{R}^N_+ \) and \( y^t \in \mathbb{R}^M_+ \) are input and output quantity vectors from N and M dimensional real number spaces, respectively. \( S^t \) is assumed to be closed, bounded, convex and to satisfy strong disposability\(^1\) of outputs and inputs.

Following Shepherd (1970), the output-based distance function at \( t \) is defined as the reciprocal of the maximum proportional expansion of output vector \( y^t \) given input \( x^t \):

\[
D_0^t(x^t, y^t) = \inf \left\{ \theta : (x^t, \theta y^t) \in S^t \right\} = \left( \sup \left\{ \theta : (x^t, \theta y^t) \in S^t \right\} \right)^{-1}. \tag{2}
\]

The distance function measures how far the production function being interested is from the frontier of the whole industry in period \( t \). Figure 1 shows the case of two outputs \( (y_1, y_2) \), the frontier at \( t \) is developed by production unit \( B, C, \) and \( D \). For production unit \( A \), the distance function at \( t \) can be expressed as \( D_0^t(x^t, y^t) = \frac{OA^t}{OP^t} \). And its distance function in \( t+1 \) is \( \frac{OA^{t+1}}{OP^{t+1}} \). \( D_0^t(x^t, y^t) \) is equal to 1 when production unit is on the frontier, or technically efficient. Accordingly, \( D_0^t(x^t, y^t) \) is less than 1 when production is technically inefficient. The greater it is, the closer is the production unit to the efficient frontier. The distance function provides a complete characterization of the production technology.
"D^t_0(x', y')" can be obtained by solving the following linear programming model:

\[
\text{Maximize } (D^t_0(x', y'))^{-1} = \theta^t_k.
\]

Subject to:

\[
\sum_{k=1}^{K} \lambda_k y_{km} \geq y_{k'm} \theta^t_k \quad m = 1, \ldots, M
\]

\[
\sum_{k=1}^{K} \lambda_k x_{kn} \leq x_{k'n} \quad n = 1, \ldots, N
\]

\[
\lambda_k \geq 0 \quad k = 1, \ldots, K
\]

where, \(m\) indexes outputs; \(n\) indexes inputs; \(k\) indexes production regions (\(k'\) is a particular region being interested); \(\lambda_k\) is the weight on the \(k\)th region data; \(\theta^t_k\) is the efficiency index, or the reciprocal of the distance function for region \(k'\). The inequalities for inputs and outputs make free disposability possible. Non-negativity of \(\lambda_k\) allows the model to exhibit constant returns to scale.

In the same way, the distance from the production point in \(t\) relative to the frontier in \(t+1\) can be defined as \(D^{t+1}_0(x', y')(Oe)\) in Fig. 1. Based on Caves et al. (1982), Färe et al. (1994) suggest the use a Malmquist index \((M_0)\) to indicate productivity growth. That is:
Improvement in productivity yields the Färe Malmquist index greater than 1 while deterioration in performance over time is associated with the index less than 1. Furthermore, $M_0$ is shown to be decomposed into an efficiency change component and a technical change component. Equation [6] is equivalent to:

$$
M_0 = \left[ \frac{D_0(x^{t+1}, y^{t+1})}{D_0(x^t, y^t)} \times \frac{D_0(x^t, y^{t+1})}{D_0(x^{t+1}, y^t)} \right]^{\frac{1}{2}}
$$

[6]

where, the first part on the right hand side is defined as efficiency change (EFFCH) or “catch up”, which measures the change in how far the observed production unit is from the potential production frontier between period $t$ and period $t+1$. The second part is defined as technical change (TECH) or “innovation”, which captures the shift in technology between two periods. In Figure 1, EFFCH is $\frac{OA^{t+1}}{OP^{t+1}} / \frac{OA^t}{OP^t}$, and TECH is $\frac{OP^{t+1}}{Of} / \frac{OP^t}{Oe}$ for $A$.

Data

A time-series dataset of sawmills and planing mills covering 1963-2001 for 26 states in the U.S. and 8 provinces in Canada was used. In 2001, selected states accounted for 96.8% of softwood lumber production and 93.2% of hardwood lumber production in the U.S. And selected Canadian provinces accounted for about 99% of both national softwood and hardwood lumber production. Since state-level lumber production data prior to 1963 are not available, the study period was selected from 1963-2001. For purpose of regional comparison, selected states of the U.S. were classified into three regions (West, South and North). Canadian provinces were classified into British Columbia, Ontario, Quebec and Others mainly based on their shares of lumber production.

Main data sources for the U.S are the Annual Survey of Manufactures (ASM) and the Census of Manufacturing (CM). Data for Canada are from the Annual Census of Manufactures (ACM), principal statistics from the Canadian Forest Service, and the CANSIM II database. In 1997, the new industry classification system, North American Classification System (NAICS), was introduced and replaced the Standard Industrial Classification (SIC) system. For this study, we used the industry definition based on the 1987 SIC system. A bridge between SIC and NAICS was constructed based on value of shipments, number of employees, and annual payrolls in 1997. All principal production data in NAICS were converted based on Table 1.

Table 1. Concordance between SIC242 and NAICS for the U.S. used in this study

<table>
<thead>
<tr>
<th>NAICS</th>
<th>Value of Shipment (%)</th>
<th># of Employee (%)</th>
<th>Annual Payroll (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3211</td>
<td>85</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>3219</td>
<td>19</td>
<td>16</td>
<td>15</td>
</tr>
</tbody>
</table>
Five inputs and three outputs were used to estimate the Malmquist index. The construction of each variable is described as follows.

**Labor Inputs**

Manufacturing-related labor is measured in terms of hours worked for the American states and in terms of hours-paid for the Canadian provinces, which includes paid vacation. Labor not related to manufacturing is measured in terms of the number of employees who are not production workers.

**Capital Input**

Capital stock in 1997 constant U.S. dollars was estimated by using the perpetual inventory method (PIM). As in Ahn and Abt (2003), investment on plants and structures was depreciated over 28 years, and machinery and equipment was depreciated over 16 years. Annual capital stock estimates for different asset types were aggregated as a total capital stock for each state/province. Following BLS (1983), we chose decay parameter of 0.5 for equipment, and 0.75 for structure.

**The U.S.** We retrieved the end of year investment data on different assets by state from CM and ASM to year 1954. We estimated the investment data of SIC 242 prior to 1954 by using estimates of national non-residential fixed assets by types from Bureau of Economic Analysis for SIC 24, the average proportion of capital investment of SIC 242 in SIC 24, and each state’s average share in total national capital investment in SIC 242 during 1954-1957.

**Canada.** Annual capital and repair expenditure data are available for three provinces (QC, ON, and BC) during 1970-2001. Other provinces’ investment during the same period were estimated by national sawmill industry flows and stocks of fixed non-residential capital, and each province’s average share of national industry added value. For all provinces, capital investment data for 1935-1969 were constructed by multiplying national industry fixed capital flows and each province’s average share of national industry added value from 1961 to 2001.

**Energy Input**

**The U.S.** Since energy quantity data are not available, approximations were made by using energy cost and a weighted aggregate energy price index. Cost of energy includes purchased fuels and electricity assembled from ASM, CM, and the U.S. Census Bureau’s publication, “Fuels and electric Energy Consumed”.

**Canada.** Quantities of purchased fuels and electricity are from Catalogues 35-204, 35-250, and Catalogue 57-208 for years 1963-1984. For years 1985-2001, provincial industry energy cost is available from the Canadian Forest Service.

**Wood Input**

**The U.S.** Quantities of wood inputs were derived by non-energy material costs and the weighted price of delivered hardwood and softwood sawtimber. Softwood and hardwood sawtimber prices
by states for the South over 1977-2001 were collected from Timber Mart South. Southern region average prices were used to estimate prices for the states in the West and the North. The sum of southern-pine sawlog selling price by Louisiana private owners and logging and haul cost was used to estimate industry delivered softwood log price for 1963-1976\(^6\) (Ulrich 1988). The sum of oak sawlog selling price by Louisiana private owners and logging and haul cost was used to estimate industry delivered hardwood log price for 1963-1976. Softwood and hardwood delivered sawtimber prices were aggregated by using state softwood and hardwood production as weights to estimate the weighted price index of wood input.

**Canada.** Quantities of wood materials were collected from Statistics Canada, Catalogues 35-204, 35-250, and Catalogue 57-208, for the years 1963 to 1984. Softwood and hardwood sawtimber were treated as homogeneous, and aggregated by volume in terms of thousand board feet, Scribner. For years thereafter, the quantities were estimated by provincial industry materials cost and a price index. The price index was based on the price data of 1963-1984 and extended to the following years by using industry raw materials price index from Statistics Canada, CANSIM, table 330-0006 and Catalogue no. 62-011-XPB. [http://www.statcan.ca/english/IPS/Data/.htm](http://www.statcan.ca/english/IPS/Data/.htm)

**Softwood and Hardwood Lumber Outputs**

For the U.S., softwood and hardwood lumber production for each state was collected from lumber production and the mill stock section of current industrial reports by the census annually. For Canada, production data from 1963-1984 were collected from Canadian Forestry Statistics. Missing data were interpolated by using the average growth rate of state/province production in the previous 5 years.

**Woodchips**

*The U.S.* The quantity of woodchips was estimated based on annual value of shipments and average chip price. Annual state level value of shipment data for woodchips were constructed by the product of industry value of shipments and the share of woodchips in total value of shipments at the national level. Chip price was approximated by the average value of softwood chips exported from four customs districts provided by the Pacific Northwest Research Station.\(^7\)

*Canada.* The quantity of woodchips for five provinces (NS, NB, QC, ON and BC) over 1963-1980 is available from Canadian Forestry Statistics. Missing data for each province were estimated by annual national woodchips quantity, and annual proportion of woodchips in the industry value of shipments for total products.

**Results and Discussions**

Outputs or inputs from different states/provinces under the same category were assumed to be homogeneous. Also, each state/province was treated as a production unit as a whole. Technology is assumed to be constant return to scale for the Malmquist index estimation and further decompositions.
Technical Efficiency

Over the 39 years, some states/provinces stayed on the frontier more often than others, especially for BC, SK in Canada and ID, MT, OR, and WV in the U.S. (80% or more of time). Among them, Oregon was the only state which remained on the frontier during the whole period. However, other states/provinces such as NS, AR, NC, TN, and TX were on the frontier for less than 20% of time. Interestingly, they are all southern states. Among them, North Carolina was the only state which had been on the frontier less than 5% of the whole study period.

There are some apparent geographic patterns of distribution of efficient units. The weighted arithmetic means (WAM$^k$) of the percentage of time for each region and country on the industry frontier were calculated. Compared to the U.S., the Canadian sawmill industry was more likely to be efficient. During 1963-2001, Canadian sawmills stayed on the industry frontier 74% of time while American sawmills stayed on the frontier 56% of time. Over the whole study period, the U.S. West (81% of the time) and the North (47%) were more likely to be on the frontier than the U.S. South (30%).

It should be noted that the technical efficiency performance for the selected states/provinces varied with different periods of time. Some states/provinces performed efficiently during most of time during the early periods but the performance gradually deteriorated in the later periods, such as BC, MB, NB in Canada, and GA, MI, PA, WI in the U.S. Some other states/provinces were off the efficiency frontier most of time in the early periods but the performance gradually improved in the later periods, such as AB and ON in Canada, and AL, FL, IN, LA, ME, MS, TX, WA in the U.S., most of which are in the U.S. South. In the latest ten years, Canadian province AB as well as American states FL, ID, ME, MT, OR, and WV formed the “best practice” frontier. Although most other western states remained on the frontier, CA apparently moved off from the frontier after the late 1980s.

For most Canadian provinces, the 1980s was a period with the highest rate of technical efficiency. However, on the other hand, the 1990s was a period during which most of Canadian provinces moved off the industry frontier, especially for BC and Quebec, the largest two softwood production provinces in Canada. Meanwhile, more and more the U.S. southern states moved towards and stayed on the efficient production frontier, especially in the latest 10 years.

It should be noted that being more efficient does not imply higher well-being. It only means that states/provinces with higher efficiency scores have exploited their resources relatively better than others in the sample with similar proportional combinations of inputs.

Färe Malmquist Productivity Index and Components

Table 2 provides a summary of the Färe productivity growth index and its decomposition into efficiency and technological change for 1964-2001.
### Table 2. Färe Productivity Index, Efficiency Change, and Technical Change for 1964-2001

<table>
<thead>
<tr>
<th>Province/State</th>
<th>Färe Index ($M_0$)</th>
<th>Efficiency Change (EFFCH)</th>
<th>Technical Change (TECH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Canada:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia</td>
<td>1.014</td>
<td>1.001</td>
<td>1.012</td>
</tr>
<tr>
<td>Ontario</td>
<td>1.016</td>
<td>1.002</td>
<td>1.016</td>
</tr>
<tr>
<td>Quebec</td>
<td>0.996</td>
<td>1.001</td>
<td>0.999</td>
</tr>
<tr>
<td>Others</td>
<td>1.028</td>
<td>1.004</td>
<td>1.025</td>
</tr>
<tr>
<td>Alberta</td>
<td>1.051</td>
<td>1.001</td>
<td>1.048</td>
</tr>
<tr>
<td>Manitoba</td>
<td>1.004</td>
<td>0.990</td>
<td>1.009</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>1.009</td>
<td>0.999</td>
<td>1.009</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>1.013</td>
<td>1.022</td>
<td>1.005</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>1.024</td>
<td>1.002</td>
<td>1.020</td>
</tr>
<tr>
<td><strong>United States:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>1.025</td>
<td>1.001</td>
<td>1.024</td>
</tr>
<tr>
<td>Indiana</td>
<td>1.009</td>
<td>0.988</td>
<td>1.018</td>
</tr>
<tr>
<td>Maine</td>
<td>1.037</td>
<td>1.011</td>
<td>1.027</td>
</tr>
<tr>
<td>Michigan</td>
<td>0.996</td>
<td>1.000</td>
<td>0.998</td>
</tr>
<tr>
<td>Missouri</td>
<td>1.024</td>
<td>1.002</td>
<td>1.021</td>
</tr>
<tr>
<td>New York</td>
<td>1.055</td>
<td>1.007</td>
<td>1.040</td>
</tr>
<tr>
<td>Ohio</td>
<td>1.051</td>
<td>0.993</td>
<td>1.061</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>1.008</td>
<td>0.997</td>
<td>1.013</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>1.006</td>
<td>0.994</td>
<td>1.022</td>
</tr>
<tr>
<td>West Virginia</td>
<td>1.043</td>
<td>1.004</td>
<td>1.041</td>
</tr>
<tr>
<td><strong>South:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alabama</td>
<td>1.026</td>
<td>1.004</td>
<td>1.020</td>
</tr>
<tr>
<td>Arkansas</td>
<td>1.035</td>
<td>1.004</td>
<td>1.028</td>
</tr>
<tr>
<td>Florida</td>
<td>1.034</td>
<td>1.003</td>
<td>1.030</td>
</tr>
<tr>
<td>Georgia</td>
<td>1.009</td>
<td>0.999</td>
<td>1.010</td>
</tr>
<tr>
<td>Kentucky</td>
<td>1.050</td>
<td>1.002</td>
<td>1.043</td>
</tr>
<tr>
<td>Louisiana</td>
<td>1.027</td>
<td>1.003</td>
<td>1.021</td>
</tr>
<tr>
<td>Mississippi</td>
<td>1.021</td>
<td>1.002</td>
<td>1.021</td>
</tr>
<tr>
<td>North Carolina</td>
<td>1.032</td>
<td>1.003</td>
<td>1.028</td>
</tr>
<tr>
<td>South Carolina</td>
<td>1.029</td>
<td>1.003</td>
<td>1.026</td>
</tr>
<tr>
<td>Tennessee</td>
<td>1.040</td>
<td>1.003</td>
<td>1.034</td>
</tr>
<tr>
<td>Texas</td>
<td>1.003</td>
<td>0.999</td>
<td>1.006</td>
</tr>
<tr>
<td>Virginia</td>
<td>1.021</td>
<td>1.002</td>
<td>1.020</td>
</tr>
<tr>
<td><strong>West:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>California</td>
<td>1.021</td>
<td>0.995</td>
<td>1.028</td>
</tr>
<tr>
<td>Idaho</td>
<td>1.023</td>
<td>1.000</td>
<td>1.023</td>
</tr>
<tr>
<td>Montana</td>
<td>1.025</td>
<td>1.000</td>
<td>1.024</td>
</tr>
<tr>
<td>Oregon</td>
<td>1.030</td>
<td>1.000</td>
<td>1.030</td>
</tr>
<tr>
<td>Washington</td>
<td>1.019</td>
<td>1.001</td>
<td>1.017</td>
</tr>
</tbody>
</table>

Most of these states/provinces experienced progress in productivity during the period. The weighted arithmetic means were estimated for each region and country. During 1964-2001, the weighted annual productivity growth of sawmill industry for the U.S. was 2.5%, indicating modest progress. During the same period, Canadian sawmill industry was shown to have a lower growth rate of 1.3%. In the U.S., all regions experienced comparable productivity growth (around 2.5% annually). Michigan was the only U.S. state experiencing regress during the whole period. Most Canadian provinces experienced progress over 1964-2001, Quebec being an exception.
All regions were shown to have positive efficiency change, indicating a trend of moving towards the industry frontier. Differences in productivity growth is mainly attributable to the difference in technical change for Canada and the U.S. during the whole study period (1.2% for Canada and 2.4% for the U.S.).

Sawmill productivity growth experienced ups and downs in the subperiods for both countries and all regions. Most regions experienced regress during the 1970s and progress during all other decades. Before the 1980s, Canada possessed a higher rate of growth (or lower rate of regress) than the U.S. However, the U.S. outperformed Canada after the 1980s (annual rate of growth was 5.0% for the U.S. vs. 2.2% for Canada during 1980s, and 3.2% for the U.S. vs. 0.4% for Canada during 1990s). The U.S. South experienced the highest annual growth rate during the 1980s (6.1%), which contributed to the country’s growth significantly. Although the North possessed the highest growth rate during 1960s, the growth rate declined during the subsequent periods. As for Canada, Ontario was the only province which experienced productivity progress during all four time periods. On the other hand, Quebec experienced regress during most of the time, except the 1980s.

Figure 2 shows the cumulated Färe index for the U.S. and Canada during the same period using 1963 as the base year. The cumulated index was calculated as sequential multiplicative sums of weighted annual Färe index values. Apparently, the gap in TFP growth between the U.S. and Canada has widened since the 1990s.

![Figure 2. Cumulated Färe productivity indices for the U.S. and Canada, 1963-2001 (Base=1963)](image)

**Conclusion**

This study used nonparametric programming approach to estimate technical performance and productivity trends of sawmill industries in the North America for the first time. The results showed that the U.S. sawmill industry was more likely to be on the industry frontier than the Canadian counterpart during 1990-2001 although the Canadian sawmill industries were more
likely to be efficient than the U.S. counterpart before 1990. This suggested that alleged higher productivity by Canada may not be true for 1990-2001.

During 1964-2001, the weighted annual productivity growth of sawmill industry for the U.S. was 2.5%, indicating progress. During the same period, Canadian sawmill industry was shown to have a lower growth rate of 1.3%. Difference in productivity growth was mainly due to the difference in technical change.

This study suggested that there was a trend of gap-widening between two countries’ productivity growth during the late part of the study period. The large difference in annual rate of TFP growth between the U.S. and Canadian sawmilling industries after 1990 led to this widening gap.

It should be noted that this study did not consider the quality difference in inputs and outputs across states and provinces. Meanwhile, there is difference in outputs combinations between the U.S. and Canada. The U.S. has larger proportion of hardwood in total lumber production than Canada. However, the DEA method used in this study did not consider this inherent difference between these two countries as well as among regions.

**Endnotes**

[1] Which means if \((x', y') \in S', \) then \((\bar{x}', \bar{y}') \in S'\) for all \((\bar{x}', \bar{y}')\) such that \(\bar{x}' \geq x'\) and \(\bar{y}' \geq y'.\)


[3] Selected U.S. western states: California (CA), Idaho (ID), Montana (MT), Oregon (OR), Washington (WA). Selected U.S. northern states: Indiana (IN), Maine (ME), Michigan (MI), Missouri (MO), New York (NY), Ohio (OH), Pennsylvania (PA), Wisconsin (WI), West Virginia (WV). Selected U.S. southern states: Alabama (AL), Arkansas (AR), Florida (FL), Georgia (GA), Kentucky (KY), Louisiana (LA), Mississippi (MS), North Carolina (NC), South Carolina (SC), Tennessee (TN), Texas (TX), Virginia (VA).

[4] Alberta (AB), British Columbia (BC), Manitoba (MB), New Brunswick (NB), Nova Scotia (NS), Ontario (ON), Quebec (QC) and Saskatchewan (SK).

[5] Employee number, production hours and production worker number are converted based on the concordance of # of employee. Employee wages and production worker wages are converted based on the concordance of annual payroll. All others are converted based on the concordance of value of shipment.

[6] Average prices for sawlog sold by private owners in Louisiana, and logging and haul cost were from Ulrich (1988). The original price was in dollars per MBF, Doyle log scale. The conversion factor of 1 Scribner log scale = 1.39 Doyle log scale was used to convert the prices in Doyle log rule to prices in Scribner log rule.


[8] Since each state/province has different share in lumber production, weighted average is a better estimate for regional and national estimate than simple average.

[9] Since each state/province has different share in lumber production, weighted average is a better estimate for regional and national productivity growth than simple average. See Färe and Zelenyuk (2003) for detailed discussion on this point. Volume of lumber
production (sum of softwood and hardwood) is used as weight. In this study, simple averages reports greater productivity progress for both Canada and the U.S.

**Literature**


