Exploring the Sources of Productivity Changes for the US Forest Products Industry

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Abstract

This research investigates sources leading to productivity changes for the US forest products industry during the time period from 1997 to 2009 using the contemporaneous and global Malmquist productivity index (MPI) approaches. Under the assumption of variable returns to scale, the global MPI breaks down into new measures of decomposition, such as efficiency change, best practice change, and scale efficiency change. Overall, the productivity change for this industry shows progression in both approaches. The technical and scale efficiency changes are main sources of productivity growth. However, compared with the contemporaneous MPI, the global MPI can reflect the real-world situation in terms of productivity change. Within the US forest products industry, the annual growth rates in housing starts and in real export value significantly affect the productivity growth in the wood product sector. In contrast, the real export value's growth rate is the only notable effect on the pulp and paper sector's productivity growth.

Because the United States plays an important role in terms of abundant forest resources, high consumption, and production of forest products (Howard and McKeever 2011), any stagnation in the US forest products market will ripple out and affect the world forest products markets. During time period 1997 to 2009, US forest products consumption and production peaked in 2005 and 2006 and then declined sharply in 2009. For example, the United States consumed approximately 65 million metric tons of paper and paper board in 2009, a 43 percent decrease from 2006 (American Forest and Paper Association 2009). Between 2006 and 2009, the production of lumber and structural panel products dropped sharply from 92 and 30 million m^3 to 57 and 17 million m^3, respectively. The dramatic crash in new housing construction largely caused the slump in the forest products markets. Annually, new housing construction had consumed a third of US wood products. This consumption peaked at 2,068,000 units in 2005. Since then, it has decreased 273 percent to 554,000 units (National Association of Home Builders 2011).

The steep fall in new housing construction and overall weak US economy slowed forest products demand and created excess production capacity. While some panel, paper, and sawmill companies closed, others remain competitive. For companies remaining in the market, are they more productive even with the ever-changing economic environment? If so, what are the sources of productivity? Finding answers to these questions is worth exploring. Many studies apply the Malmquist productivity index (contemporaneous MPI) introduced by Caves et al. (1982) to explore sources of productivity in various sectors, such as pharmaceutical, hospital, and manufacturing (Färe et al. 1994, Althin 2001, González and Gascón 2004, Maniadakis and Thanassoulis 2004, Lyroudi et al. 2006, Gannon 2008). The contemporaneous MPI is a geometric mean form of two possibly disparate Malmquist indices in adjacent time period t–based Malmquist (M_t) and time period ($t + 1$)–based Malmquist (M_{t+1}). Some researchers maintain that a contemporaneous MPI should obey circular property if it covers a longer period of time (Berg et al. 1992, Shestalova 2003, Pastor and Lovell 2005). Others claim that a contemporaneous MPI with the geometric means of two adjacent opposite signs in productivity changes may lead to inadequate results for an industry going through a large and rapid technology change (Althin 2001, Nin et al. 2003,

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Pastor and Lovell 2005). For this research, we chose to use MPI because it requires neither price information nor a behavioral assumption in its construction. It exclusively uses quantity of information for a formal time-series analysis and allows for performance comparisons of decision making units over time (Malmquist 1953).

Previous studies exploring productivity change for the forest products industry primarily used the contemporaneous MPI (Constantino and Haley 1989, Nyrud and Baardsen 2003, Sowlati and Vahid 2006). However, is it adequate to use a contemporaneous MPI to measure productivity change for the forest products industry? This research investigates the existence of a conflict signal in two adjacent Malmquist productivity indices and the circularity property in measuring productivity change and its components for the US forest products industry. The global MPI developed by Pastor and Lovell (2005) is introduced in order to consider the circularity property and avoid measuring the geometric mean of disparate adjacent period. However, Pastor and Lovell (2005) decompose global MPI into efficiency change indicator and best-practice gap change only under the assumption of constant returns to scale. In contrast, our research follows Ray and Desli's (1997) work in the decomposition of the contemporaneous MPI and provides additional sources of productivity change (i.e., pure technical efficiency change and scale efficiency change) under the assumption of variable returns to scale. Other uncontrolled environment effects, such as the global financial crisis, may cause an unstable national economy (e.g., the sluggish growth demand for housing starts and exports). Since it may also affect the productivity of the US forest products industry, uncontrolled environment factors are discussed as well.

Methods

Variable definitions and data sources

This research evaluates and compares MPIs for the US forest products industry; therefore, mill-level data are inappropriate. Expert judgment as suggested by Banker (1989) captures the real-world situation by determining input and output variables. The Annual Survey of Manufactures (2010) provides the number of production workers, total cost of materials, quantity of electric energy purchased, and capital expenditures as input variables and the value of shipments as an output variable. The value of shipments represents the received or receivable net selling values. The number of production workers, material costs, and electricity energy purchased are the main variable costs for manufacturing products. The capital expenditures refer to the expense of acquiring or upgrading durable assets, such as buildings and machinery.

The forest products industry as depicted in this research consists of the wood products sector (North American Industry Classification System [NAICS] 32111—sawmills and wood preservation; NAICS 32121—veneer, plywood, and engineered wood manufacturing; NAICS 32191—millwork; NAICS 32192—wood container and pallet manufacturing; NAICS 32199—all other wood products manufacturing) and the pulp and paper sector (NAICS 32211—pulp mills, NAICS 32212—paper mills, NAICS 32213—paperboard mills). Data were collected for the 12-year period from 1997 to 2009, compiled by the Annual Survey of Manufactures (2010). During this period, the paper mills ranked first in the US forest products industry with the highest average value of shipments accounting for \$48,525 million of the total US shipments; it has also consumed the most materials (US\$22,779 million), energy (36,282 million kWh), and capital investment (US\$2,674 million). The wood products sector, in general, has had higher employment and lower capital investment than that of the pulp and paper sector. Table 1 provides the descriptive statistics of input and output variables for the eight US forest products subsectors.

Computation and decomposition of the contemporaneous and global MPI

A nonparametric data envelopment analysis (DEA) method is used to measure productivity changes (i.e., contemporaneous and global MPI) for the US forest products industry. The distance functions $D^t(y^{t+1}, x^{t+1})$ and $D^{t+1}(y^t, x^t)$ are obtained by changing time period t to $t + 1$ (see Eq. A2 and A4 in the Appendix). These two mixed-period distance functions measure the input-oriented efficiency in relation to the other period's technology, enabling calculations of the contemporaneous Malmquist index (M^c) and its components. Thus, the geometric mean of the two ratios of input distance functions is similar to Färe et al. (1992), specifically,

$$
\begin{aligned}
M^c &= \left(\frac{D_v^t(y^{t+1},x^{t+1})}{D_v^t(y^t,x^t)} \times \frac{D_v^{t+1}(y^{t+1},x^{t+1})}{D_v^{t+1}(y^t,x^t)}\right)^{1/2} \\
&= \frac{D_v^{t+1}(y^{t+1},x^{t+1})}{D_v^t(y^t,x^t)} \times \left[\frac{D_v^t(y^{t+1},x^{t+1})}{D_v^{t+1}(y^{t+1},x^{t+1})} \times \frac{D_v^t(y^t,x^t)}{D_v^{t+1}(y^t,x^t)}\right]^{1/2} \\
&\quad \times \left(\frac{\dfrac{D_c^{t+1}(y^{t+1},x^{t+1})}{D_v^{t+1}(y^{t+1},x^{t+1})}}{\dfrac{D_c^{t+1}(y^t,x^t)}{D_v^{t+1}(y^t,x^t)}} \times \frac{\dfrac{D_c^{t}(y^{t+1},x^{t+1})}{D_v^{t}(y^{t+1},x^{t+1})}}{\dfrac{D_c^{t}(y^t,x^t)}{D_v^{t}(y^t,x^t)}} \right)^{1/2} \\
&= EC_v \times TC_v \times SEC^c,
\end{aligned} \tag{1}
$$

where the first component in the right-hand side of Equation 1 is the pure technical efficiency change (EC_v), the second component is the technical change (TC_v), and the third component is the scale efficiency change (SEC^c). If this index is less than one, that is, $M^c < 1$, then productivity improves between period t and $t + 1$. Values exceeding one suggest deterioration in productivity.

Obtaining the M^c and its components requires distance function computations for $D_v^t(y^t, x^t)$, $D_c^t(y^t, x^t)$, $D_v^{t+1}(y^{t+1}, x^{t+1})$, $D_c^{t+1}(y^{t+1}, x^{t+1})$, $D_v^t(y^{t+1}, x^{t+1})$, $D_c^t(y^{t+1}, x^{t+1})$, $D_v^{t+1}(y^t, x^t)$, and $D_c^{t+1}(y^t, x^t)$. $TE_v^t(y^t, x^t) = [D_v^t(y^t, x^t)]^{-1} \leq 1$ are measured by solving the linear programming as shown by Färe (1988) in Equation 2:

$$
\begin{aligned}
&[D_v^t(y^t,x^t)]^{-1} = \min \theta \\
\text{s.t.} \quad &\sum_{j=1}^{J} Z_j Y_{jm}^t \geq y_{km}^t \\
&\sum_{j=1}^{J} Z_j x_{jn}^t \geq x_{kn}^t \\
&\sum_{j=1}^{J} Z_j = 1, Z_j \geq 0
\end{aligned} \tag{2}
$$

Table 1.—Descriptive statistics by US forest products industry for the time period 1997 to 2009.[a]

Industry	Output	Inputs			
	Value of shipments (US\$1,000)	No. of production workers	Material costs (US\$1,000)	Electric energy purchased (1,000 kWh)	Capital expenditures (US\$1,000)
Sawmills and wood preservation	27,702,359 (3,618,881)	97,197 (11,761)	19,009,422 (2,536,741)	7,707,360 (959,825)	934,305 (214,001)
Veneer, plywood, and engineered wood manufacturing	21,075,970 (3,580,589)	91,828 (9,983)	12,659,687 (1,909,026)	9,478,341 (1,013,110)	683,808 (159,920)
Millwork	23,735,433 (3,952,172)	124,610 (12,393)	13,723,360 (2,325,038)	3,724,276 (613,092)	608,628 (120,991)
Wood container and pallet manufacturing	5,556,156 (980,663)	44,862 (6,002)	2,976,662 (478,783)	896,496 (166,550)	162,188 (51,012)
All other wood products manufacturing	16,006,511 (2,236,546)	94,812 (14,723)	8,613,028 (1,321,319)	1,803,047 (431,780)	351,465 (99,071)
Pulp mills	3,923,449 (686,493)	6,093 (663)	2,165,587 (432,568)	1,853,041 (177,967)	255,107 (89,256)
Paper mills	48,525,062 (2,606,660)	84,648 (13,991)	22,779,239 (1,745,080)	36,282,351 (2,415,331)	2,674,203 (771,045)
Paperboard mills	22,149,777 (1,768,664)	35,839 (4,274)	11,255,300 (1,010,261)	20,031,009 (1,185,517)	1,105,654 (254,487)

[a] Values in parentheses are standard errors.

where $Z_j (j = 1 \ldots J)$ are intensity variables used to form convex linear combinations of observed inputs and outputs. A similarly defined distance function denoted by $D_v^{t+1}(y^{t+1}, x^{t+1})$ can also be determined using Equation 2 except in time period $t + 1$.

The mixed-period input distance function $D_v^t(y^{t+1}, x^{t+1})$ computes as follows:

$$
\begin{aligned}
&[D_v^t(y^{t+1}, x^{t+1})]^{-1} = \min \theta \\
&\text{s.t.} \quad \sum_{j=1}^{J} Z_j Y_{jm}^t \geq y_{km}^{t+1} \\
&\qquad \sum_{j=1}^{J} Z_j x_{jn}^t \geq x_{kn}^{t+1} \\
&\qquad \sum_{j=1}^{J} Z_j = 1, Z_j \geq 0
\end{aligned}
\tag{3}
$$

Similarly, the distance function $D_v^{t+1}(y^t, x^t)$ is calculated using Equation 3. Omitting the restriction of $\Sigma_{j=1}^J Z_j = 1$ in Equations 2 and 3 obtains $D_c^t(y^t, x^t)$ and $D_c^t(y^{t+1}, x^{t+1})$.

$T^G = conv\{T^1 \cup \ldots \cup T^T\}$ defines a global benchmark technology where construction of a single reference technology requires a full data set in the panel data. The global input distance functions are defined as follows:

$$
D^G(y^t, x^t) = \sup_{\rho} \left\{ \rho : (x^t/\rho, y^t) \in T^G, \rho > 0 \right\}
$$

$$
D^G(y^{t+1}, x^{t+1}) = \sup_{\rho} \left\{ \rho : (x^{t+1}/\rho, y^t) \in T^G, \rho > 0 \right\} \tag{4}
$$

where $D^G(y^t, x^t)$ and $D^G(y^{t+1}, x^{t+1})$ can be the distance functions under assumption of constant returns to scale, that is, $D_c^G(y^t, x^t)$ and $D_c^G(y^{t+1}, x^{t+1})$, or variable returns to scale (VRS), that is, $D_v^G(y^t, x^t)$ and $D_v^G(y^{t+1}, x^{t+1})$.

Under VRS, the global Malmquist productivity index is further decomposed into efficiency change (EC_v), best-practice change (BPC_v), and scale efficiency change (SEC^G) as shown in Equation 5. This new measure of decomposition is structurally identical to Pastor and Lovell (2005) and derives from Ray and Desli (1997):

$$
\begin{aligned}
&M^G(y^{t+1}, x^{t+1}, y^t, x^t) \\
&= \frac{D_v^G(y^{t+1}, x^{t+1})}{D_v^G(y^t, x^t)} \times \frac{SE^G(y^{t+1}, x^{t+1})}{SE^G(y^t, x^t)} \\
&= \frac{D_v^{t+1}(y^{t+1}, x^{t+1})}{D_v^t(y^t, x^t)} \times \left[\frac{D_v^G(y^{t+1}, x^{t+1})/D_v^{t+1}(y^{t+1}, x^{t+1})}{D_v^G(y^t, x^t)/D_v^t(y^t, x^t)} \right] \\
&\quad \times \frac{SE^G(y^{t+1}, x^{t+1})}{SE^G(y^t, x^t)} \\
&= EC_v \times \left[\frac{BPG_v^{G,t+1}(y^{t+1}, x^{t+1})}{BPG_v^{G,t}(y^t, x^t)} \right] \times SEC^G \\
&= EC_v \times BPC_v \times SEC^G
\end{aligned}
\tag{5}
$$

SEC^G is defined as

$$
\frac{SE^G(y^{t+1}, x^{t+1})}{SE^G(y^t, x^t)} = \left[\frac{D_c^G(y^{t+1}, x^{t+1})/D_v^G(y^{t+1}, x^{t+1})}{D_c^G(y^t, x^t)/D_v^G(y^t, x^t)} \right]
$$

$BPG_v^{G,s}$ denotes a best-practice gap between T^G and T^t (the contemporaneous technologies) measured along rays (x^s, y^s), $s = t$, and $t + 1$. BPC_v is the change in $BPG_v^{G,s}$. If $BPC_v > 1$ or $BPC_v < 1$, then technology in period $t + 1$ in the region $[D_v^G(y^{t+1}, x^{t+1})/D_v^{t+1}(y^{t+1}, x^{t+1})]$ is farther away from or closer to the global technology than the technology in period t in the region $[D_v^G(y^t, x^t)/D_v^t(y^t, x^t)]$. Productivity progress, efficiency progress, and scale efficiency progress exist when $M^G(\cdot) < 1$, $EC_v^G < 1$, and $SEC^G < 1$, respectively.

To compute the M^G and its components, the global distance functions $D_v^G(y^t, x^t)$, $D_c^G(y^t, x^t)$, $D_v^G(y^{t+1}, x^{t+1})$, and $D_c^G(y^{t+1}, x^{t+1})$ need to be identified. The $D_v^G(y^t, x^t)$ can be measured as follows:

$$
\begin{aligned}
&[D_v^G(y^t, x^t)]^{-1} = \min_{Z_j^s,\theta} \theta \\
&\text{s.t.} \quad \sum_{s=1}^{t}\sum_{j=1}^{J} Z_j^s y_{jm}^s \geq y_{km}^t \qquad m = 1, \ldots, M \\
&\qquad \sum_{s=1}^{t}\sum_{j=1}^{J} Z_j^s x_{jn}^s \leq \theta x_{kn}^t \qquad n = 1, \ldots, N \\
&\qquad \sum_{s=1}^{t}\sum_{J=1}^{J} Z_j^s = 1, Z_j^s \geq 0 \quad j = 1, \ldots, J, \quad \text{and} \\
&\qquad\qquad s = 1, \ldots t
\end{aligned} \tag{6}
$$

A similarly defined distance function denoted by $D_v^G(y^{t+1}, x^{t+1})$ is also computed as follows:

$$
\begin{aligned}
&[D_v^G(y^{t+1}, x^{t+1})]^{-1} = \min_{Z_j^s,\theta} \theta \\
&\text{s.t.} \quad \sum_{s=1}^{t}\sum_{j=1}^{J} Z_j^s y_{jm}^s \geq y_{km}^{t+1} \qquad m = 1, \ldots, M \\
&\qquad \sum_{s=1}^{t}\sum_{J=1}^{J} Z_j^s x_{jn}^s \leq \theta x_{kn}^{t+1} \qquad n = 1, \ldots, N \\
&\qquad \sum_{s=1}^{t}\sum_{J=1}^{J} Z_j^s = 1, Z_j^s \geq 0 \quad j = 1, \ldots, J, \quad \text{and} \\
&\qquad\qquad s = 1, \ldots, t
\end{aligned} \tag{7}
$$

Likewise, omitting $\Sigma_{s=1}^{t}\Sigma_{J=1}^{J} Z_j^s = 1$ in Equations 6 and 7 obtains $D_c^G(y^t, x^t)$ and $D_c^G(y^{t+1}, x^{t+1})$.

Results and Discussion

Table 2 presents the results of the productivity change for the US forest products industry over time. The average global MPI (M^G) for the forest products industry in the period from 1997 to 2009 is less than one. It signifies a 7.1 percent productivity growth for an industry amid environmental shifts, such as the housing construction crash (Table 2). Closer scrutiny discloses that the growth is mainly from BPC_v (=0.953), followed by scale efficiency change (SEC^G). The efficiency change is almost constant in this time period. The pure technical efficiency change ($EC_v = 1.00$) in Table 2 represents neither progression nor regression for all subsectors of the US forest products industry during the estimation periods. It implies that the efficiency change for the industry is relatively stable over this time period. In other words, BPC_v (technology innovation) accelerates, but efficiency (catching up) remains constant in the forest products industry. Similarly, BPC_v and SEC^G also cause the productivity changes in period 1997 to 2009 for the wood products and pulp and paper sectors by 5.1 and 9.0 percent, respectively. In the wood products sector, the productivity change of millwork ($M^G = 0.886$), contributed by $BPC_v = 0.892$, is the biggest mover among this sector. It suggests that technological innovations induce productivity growth in the millwork sector. On the other hand, the productivity change ($M^G = 0.853$) of paperboard mills has the highest growth in the pulp and paper sector. Similarly, $BPC_v = 0.853$ accounts for the most productivity change in paperboard mills.

Coinciding with the global MPI (M^G), the contemporaneous MPI average ($M^c = 0.988$) also shows progress for the forest products industry (Table 2). Sources of productivity progress are mainly from technical improvements, followed by scale efficiency improvements. Although the wood products sector and pulp and paper sector show productivity progress in this time period, the average productivity growth does not explain all productivity changes in the wood products sector. For instance, subsectors of wood container and pallet manufacturing ($M^c = 1.010$) and all other wood products manufacturing ($M^c = 1.029$) regress during this

Table 2.—Comparison of global and contemporaneous Malmquist productivity index (MPI) for forest products industry for the time period 1997 to 2009.[a]

		Global MPI				Contemporaneous MPI					
Sector	Subsector	M^G	EC_v	BPC_v	SEC^G	M^c	M_t^c	M_{t+1}^c	EC_v	TC_v	SEC^c
Wood products sector	Sawmills and wood preservation	0.989	1.000	0.970	1.020	0.994	0.968	1.020	1.000	1.001	0.993
	Veneer, plywood, and engineered wood manufacturing	0.935	1.000	0.877	1.067	0.973	0.966	0.980	0.996	0.970	1.007
	Millwork	0.886	1.000	0.892	0.994	0.987	0.958	1.018	1.000	0.998	0.990
	Wood container and pallet manufacturing	0.942	1.000	1.000	0.942	1.010	0.993	1.027	1.000	0.998	1.012
	All other wood products manufacturing	0.995	1.000	1.011	0.984	1.029	0.910	1.165	1.000	1.038	0.992
	Mean	0.949	1.000	0.948	1.000	0.999	0.959	1.040	0.999	1.001	0.999
Pulp and paper sector	Pulp mills	0.967	1.000	1.000	0.967	0.868	1.088	0.868	1.000	0.994	0.978
	Paper mills	0.912	1.000	0.919	0.992	0.901	1.039	0.901	1.000	0.963	1.013
	Paperboard mills	0.853	1.000	0.853	1.000	0.931	1.038	0.931	1.000	0.965	1.001
	Mean	0.910	1.000	0.922	0.987	0.900	1.055	0.900	1.000	0.974	0.998
Forest products industry		0.929	1.001	0.953	0.981	0.991	0.941	1.043	1.000	0.991	0.998

[a] M^G = global MPI; EC_v = efficiency change; BPC_v = best-practice change; SEC = scale efficiency change; M^c = contemporaneous MPI; t = time; TC_v = technical change.

time period. This may be because of computation differences in two adjacent MPI. The global MPI provides only a single productivity measurement. In contrast, contemporaneous MPI uses the geometric mean of two adjacent Malmquist indices relaxing the M^c. As a case in point, $M^c =$ 1.010 is computed from productivity progress in M_t^c (=0.993) and regress in M_{t+1}^c (=1.027) for the wood container and pallet manufacturing subsector. As the values of t-based MPI and $(t + 1)$-based MPI severely diverge and deviate, geometric mean of contemporaneous MPI can be uncertain. Global MPI can reflect the real-world situation and avoid the false signals of the contemporaneous MPI. As a case in point, new housing construction dropped from 1999 to 2000 (from 1,675,000 to 1,575,000 units), and this will probably cause regression in industry productivity for the next time period. The global MPI (a single productivity measurement), ($M^G = 1.010$), indeed, shows productivity regression for the time period 2000 to 2001 (see Table 3). However, the value of contemporaneous MPI ($M^c = 0.984$) shows productivity progression, which is computed from two opposite adjacent Malmquist indices, that is, M_t^c (=0.935), indicating productivity progression, and M_{t+1}^c (=1.036), indicating productivity regression.

Table 3 also verifies the global Malmquist index's circularity property by showing the same values ($M^G =$ 0.929) of cumulative productivity index. In addition, the indices of efficiency change, best-practice change, and scale efficiency change are also circular. In comparison, contemporaneous MPI (M^c) cannot satisfy circularity property, nor can its components (i.e., EC_v, TC_v, and SEC^c).

Productivity change scores are found between the range of zero and two. In order to explore uncontrollable factors that may also cause productivity change, the well-defined Tobit regression approach suggested by McCarty and Yaisawarng (1993) is introduced to avoid the restricted effects of the censored dependent variable. The estimated global and contemporaneous MPI are regressed on annual growth rate of housing starts and export value of forest products. The export value of forest products is derived from the US International Trade Commission (2010) and includes sawmills and wood preservation (NAICS 32111); veneer, plywood, and engineered wood manufacturing (NAICS 32121); millwork (NAICS 32191); wood container and pallet manufacturing (NAICS 32192); all other wood products manufacturing (NAICS 32199); pulp mills (NAICS 32211); paper mills (NAICS 32212); and paperboard mills (NAICS 32213). The Tobit model is demonstrated as follows:

$$MPI^{it} = \beta_0 + \beta_1 X_{1t}^i + \beta_2 X_{2t}^i + \varepsilon_i$$

where MPI^{it} is a global or contemporaneous Malmquist index with a range of zero to one, ε_i is the error term, X_{1t}^i is the annual growth rate of housing starts (in percentage), and X_{2t}^i is the annual growth rate of real export value of forest products (in percentage; deflated by implicit price deflator, year 2000 = 100). Annual growth rate of housing starts measures the difference of the current year's and following year's house volume divided by current year's housing starts (i.e., the percentage change of current year and following year's housing starts) and is thus expected to be inversely related to global and contemporaneous MPI in the wood product and pulp and paper sectors.

Table 4 shows the coefficient estimates (i.e., β_0, β_1, and β_2) from the Tobit regression. The annual growth rates in the housing starts and in real export value significantly affect the productivity growth in the wood product sector. This implies that housing starts and exports may cause an increase in derived demand for the wood products sector, resulting in productivity growth. In the pulp and paper sector, the annual growth rate in real export value significantly correlates with the global and contemporaneous MPI. In other words, an increase in export value contributes to the productivity growth. The annual growth rate of housing starts, however, is not at 0.01 significant levels.

Conclusions

Both cumulative values of global MPI ($M^G = 0.929$) and contemporaneous MPI ($M^c = 0.991$) show productivity growth for the forest products industry in the period from

Table 3.—Decomposition of global and contemporaneous Malmquist productivity index (MPI) for forest products industry for the time period 1997 to 2009.[a]

Period	Global MPI				Contemporaneous MPI					
	M^G	EC_v	BPC_v	SEC^G	M^c	M_t^c	M_{t+1}^c	EC_v	TC_v	SEC^c
1997–1998	0.995	1.001	0.993	1.000	0.977	0.958	0.996	1.001	0.978	0.997
1998–1999	0.982	0.998	0.987	0.998	0.969	0.942	0.997	0.998	0.905	1.074
1999–2000	0.992	0.998	0.999	0.995	0.985	0.957	1.014	0.998	1.031	0.958
2000–2001	1.010	1.012	0.991	1.007	0.984	0.935	1.036	1.012	0.994	0.978
2001–2002	0.970	0.988	0.992	0.990	0.961	0.921	1.004	0.988	0.977	0.996
2002–2003	0.978	0.998	0.983	0.997	0.983	0.925	1.044	0.998	0.961	1.025
2003–2004	0.994	1.000	0.997	0.997	0.990	0.945	1.037	1.000	0.951	1.041
2004–2005	0.997	1.012	0.988	0.997	0.974	0.937	1.013	1.012	0.944	1.020
2005–2006	0.991	0.995	0.996	1.000	0.999	0.941	1.062	0.995	1.039	0.967
2006–2007	1.041	1.004	1.032	1.005	1.060	0.991	1.133	1.004	1.085	0.973
2007–2008	0.992	1.010	0.986	0.996	0.987	0.939	1.038	1.010	1.018	0.961
2008–2009	0.985	0.979	1.009	0.997	0.993	0.918	1.075	0.979	1.017	0.997
Cumulative value	0.929	1.001	0.953	0.981	0.991	0.941	1.043	1.000	0.991	0.998
1997–2009	0.929	1.001	0.953	0.981						

[a] M^G = global MPI; EC_v = efficiency change; BPC_v = best-practice change; SEC = scale efficiency change; M^c = contemporaneous MPI; t = time; TC_v = technical change.

Table 4.—Parameter estimates from the Tobit model for global and contemporaneous Malmquist productivity index (MPI).[a]

Explanatory variable	Global MPI		Contemporaneous MPI	
	Wood products sector	Pulp and paper sector	Wood products sector	Pulp and paper sector
Annual growth rate of housing starts (β_1)	−3.321** (1.410)	−3.201 NS (1.809)	−3.298** (1.418)	−3.143 NS (1.761)
Annual growth rate of real export value (β_2)	−4.323*** (1.338)	−4.401** (1.731)	−4.238*** (1.359)	−4.250*** (1.673)
Constant term (β_0)	0.885*** (0.089)	0.884*** (0.120)	0.891** (0.094)	0.857*** (0.115)

[a] Values in parentheses are standard errors. ** = significance level of 0.05; *** = significance level of 0.01; NS = not significant.

1997 to 2009. Under variable returns to scale, the main source of productivity growth is technical improvement. Unlike contemporaneous MPI, the global MPI and its components satisfy the circular property and provide a single productivity index for the forest products industry. It also reflects the real-world situation when measuring productivity change within a year, for example, the productivity regression in the time period 1999 to 2000.

This research also demonstrates significant correlation between uncontrollable factors and productivity growth. The annual growth rates of housing starts and real export value increase productivity in the wood product sector; that is, derived demand appears to cause productivity progress. Similarly, the annual growth rate of real export value is found to have significant relationship with the global and contemporaneous MPIs in the pulp and paper sector. Furthermore, the increase in exports may also contribute to the productivity growth in the pulp and paper sector.

Appendix

The reference technology is defined at each period t, $t = 1, \ldots, T$, to be the set of all feasible input and output vectors. Let $j = 1, \ldots, J$ production units and t, $t = 1, \ldots, T$ time periods. In time period t, the kth unit employs amounts $x^t_{kn} \in R^n_+$, where input n ($n = 1, \ldots, N$) produces amount $y^t_{km} \in R^m_+$ of output m ($m = 1, \ldots, M$). Then the technology of period t is set T^t, where $T^t(y^t) = \{(x^t, y^t){:}x^t \text{ can produce } y^t\}$ with $\lambda T^t = T^t$, $t = 1, \ldots, T$, and $\lambda > 0$. Assume that $T^t(y^t)$ is a closed, bounded, convex set and satisfies strong disposability of inputs and outputs. The input distance function (Shephard 1953, Färe et al. 1992) is defined at time t as

$$D^t(y^t, x^t) = \sup_\rho \{\rho : (x^t/\rho) \in T^t(y^t), \rho > 0\} \qquad \text{(A1)}$$

$D^t(y^t, x^t)$ is the distance function under constant returns to scale, namely, $D^t_c(y^t, x^t)$, or variable returns to scale, namely, $D^t_v(y^t, x^t)$. If $(y^t, x^t) \in T^t(y^t)$, then $D^t(y^t, x^t) \geq 1$, and $D^t(y^t, x^t) = 1$ if and only if (y^t, x^t) is on the boundary. The input distance function is the reciprocal of the Farrell's (1957) input-oriented measure of efficiency, which calculates technical efficiency (TE) at time period t, that is,

$$TE^t(y^t, x^t) = \frac{1}{D^t(y^t, x^t)} \leq 1 \qquad \text{(A2)}$$

A similarly defined distance function denoted by $D^{t+1}(y^{t+1}, x^{t+1})$ also determines efficiency in time period $t + 1$, namely,

$$TE^{t+1}(y^{t+1}, x^{t+1}) = \frac{1}{D^{t+1}(y^{t+1}, x^{t+1})} \qquad \text{(A3)}$$

Two mixed-period input distance functions, $D^{t+1}(y^{t+1}, x^{t+1})$ and $D^{t+1}(y^t, x^t)$, are defined as follows:

$$D^t(y^{t+1}, x^{t+1}) = \sup_\rho \{\rho : (x^{t+1}/\rho) \in T^t(y^{t+1}), \rho > 0\}$$

and

$$D^{t+1}(y^t, x^t) = \sup_\rho \{\rho : (x^t/\rho) \in T^{t+1}(y^t), \rho > 0\} \qquad \text{(A4)}$$

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