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A stochastic frontier analysis of technical progress, efficiency change and productivity growth in the Pacific Northwest sawmill industry ☆

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ABSTRACT

Stochastic frontier analysis was employed to investigate technical efficiency and productivity growth in the sawmilling industry of the U.S. Pacific Northwest over the period 1968–2002. The results of our analysis indicate that productivity growth was strong over the 30-year study period, due almost exclusively to technical progress. The model developed in this analysis was used to examine the cause of employment declines in the sawmilling industry between 1988 and 1994. We found that that 62% of the decline was due to changes in output and non-labor input factors and 38% was due to technical change alone.

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Beginning in the late 1980s and continuing into the 21st century, the sawmill industry of Oregon and Washington (hereinafter Northwest) underwent substantial reductions in employment and is believed to have experienced significant technical change as well, resulting in productivity growth (Helvoigt et al., 2003). Much of the information regarding technical change and productivity growth has been anecdotal, however, and to the best of the authors' knowledge has not been empirically validated. In this paper, we employ a stochastic frontier production function (SFPF) to estimate technical change[1], efficiency change[2], and productivity growth[3] for the Northwest sawmill industry. We also compute output elasticities, scale efficiency, and Morishima elasticities of substitution between input factors.

Although its relative importance in the Oregon and Washington economies has slowly declined over the past decades, the forest product industry in the Northwest remains a major source of employment and economic output. Because of its historic and continued significance to the economy and culture of the Northwest and its special role in some communities, it is important to understand how the structure of the sawmilling industry has changed. The results of this analysis provide some insights.

Our approach departs from past studies of the sawmill industry in the Northwest and other North American regions in several ways. First, the SFPF allows the direct estimation of technical efficiency[4] at a point in time, as well as technical and efficiency change through time. This allows comparison of the aggregate position of lumber producers in one region to the best practices frontier of lumber producers in the entire Northwest. Second, most past studies have assumed lumber producers to be successful cost minimizers or profit maximizers and have employed cost or profit functions (see Stier and Bengston, 1992 for a review of studies). Implicit in these approaches is the assumption that any deviation from minimum cost or maximum profit is random noise. In contrast, the SFPF estimates both the frontier of the industry production function and measures the technical efficiency of each producer relative to the frontier. It does not require the assumption that producers are acting in an economically optimal fashion. Third, unlike past studies that have employed CES production functions (Greeber and White, 1982; Stier, 1982), this study employs the flexible translog production function and gives explicit attention to regularity (curvature) conditions for the estimated function.

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[1] Technical change is a measure of the shift in the production frontier over time.

[2] Efficiency change is a measure of the change in the relative distance of a production unit from the (expanding or contracting) production frontier.

[3] Productivity growth, by which we mean total factor productivity, is a measure of growth in output over time relative to all factors of production.

[4] Technical Efficiency is a measure of a production unit's operations relative to the industry's production (technical) frontier. A unit that operates on the industry's production frontier is said to be technically efficient. A production unit that operates beneath the industry's production frontier is said to operate with some degree of technical inefficiency, which can be estimated using frontier estimation methods such as SFPF.

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SFPF estimates the industry's technical frontier based on the performance of the most efficient (i.e., most productive) production units (Kumbhakar and Lovell, 2000). Measures of the technical efficiency of each unit are then estimated based on the distance of the unit from the frontier. Estimates of productivity and/or technical efficiency derived from SFA are therefore relative, not absolute, measures.

1. Stochastic frontier analysis of the forest products industry

Only a few studies of the wood product industry have employed stochastic frontier analysis and none (to our knowledge) have been conducted specifically for the sawmill industry. Carter and Cubbage (1995) estimate a stochastic frontier production function using firm-level data from the southern U.S. pulpwood harvesting industry, examining technical efficiency and rates of technical change. To explain the sources of technical inefficiency, a separate second stage analysis is conducted, entailing regression of the estimated technical efficiency measures on characteristics of the pulpwood producers (including owner age, years of experience, and number of employees).

The Carter and Cubbage (1995) analysis has two important limitations. First, only labor and capital inputs are considered. Other inputs, including energy, supplies, and particularly stumpage, are not considered because there were no data. Second, the specification and estimation of the stochastic production function is done under the assumption that the technical inefficiency effects are independently and identically distributed with one-sided errors. In the second stage model, however, the inefficiency effects are assumed to be a function of firm-specific factors, thus contradicting the assumption in the stochastic production frontier model of independently and identically distributed inefficiency effects.

Siry and Newman (2001) study the efficiency of Polish state timber production and management policies for three years 1993–1995, using 40 forest districts to compose the panel. Output is measured as the volume of timber sales. Inputs include forestland area, growing stock volume, permanent and temporary forest workers, administrative employees, roads and equipment, and, as a measure of privatization, the share of external costs to total operating costs. Because some output elasticity estimates are negative and statistically significant. The estimated production function violates the properties of monotonicity and quasiconcavity. The study does not examine technical or productivity change over the three-year study period, nor does it include time in the production function.

Yin (2000) analyzes the productive efficiency of global producers of bleached softwood kraft pulp using firm-level data. The study employs SFPF, estimating both a translog stochastic production frontier and a translog stochastic cost frontier on a cross-section of 102 producers for the single year 1996. The estimated technical efficiency of every producer is above 99%, indicating essentially no variation in relative technical efficiency. The author surmises that the lack of variation could be due to the nature of the production process, the data generating process, and the SFPF method.

2. Theoretical model

The stochastic frontier production function was developed independently by Aigner, Lovell, and Schmidt (1977), and Meesen and Van den Broeck (1977). Battese and Coelli (1995) show that the stochastic frontier production function can be specified for panel data as:

$$Y_{it} = e^{x_{it}\beta + V_{it} - U_{it}}, \tag{1}$$

where Y_{it} denotes the output for the ith unit ($i = 1,\ldots, N$) in the tth time period ($t = 1,\ldots, T$), x_{it} is a $(1\times k)$ vector of input quantities used by the ith unit in the tth time period, β is a $(k\times 1)$ vector of coefficients to be estimated, and V_{it} and U_{it} are the components of the disturbance term assumed to be independent. The first component, V_{it}, is a random variable that accounts for measurement error and other random factors and can be positive or negative. The second component, U_{it}, is a non-negative random variable that measures the deviation from the efficient frontier of the ith observation. The model is called a stochastic frontier production function because the output values are bounded from above by the stochastic variable $e^{(x_{it}\beta + v_{it})}$ (Coelli et al., 1998 p185).

Kumbhakar, Ghosh, and McGuckin (1991), and Reifschneider and Stevenson (1991) propose models for cross-sectional data that simultaneously estimate the stochastic production function and an explicit model of the inefficiency effects associated with the stochastic production function. Battese and Coelli (1995) extend these ideas to panel data models, allowing for both the estimation of technical change (in the stochastic production function) and the estimation of time-varying inefficiency effects (Battese and Coelli, 1995). The inefficiency effects specification for the panel data model is as follows:

$$U_{it} = z_{it}\delta + W_{it}, \tag{2}$$

where U_{it} is the estimated one-sided inefficiency for the ith unit in time period t, z_{it} is a vector of characteristics intended to explain the inefficiency of the ith unit in time period t, δ is a vector of coefficients estimated in the inefficiency model, and W_{it} is defined by the truncation of the normal distribution with zero mean and variance σ^2.

The stochastic production function and inefficiency effects model are estimated simultaneously using maximum likelihood methods. The estimates of technical efficiency for the ith unit in time period t are given by

$$TE_{it} = e^{-u_{it}} = e^{-z_{it}\delta - w_{it}}. \tag{3}$$

The stochastic frontier production function has some recognized shortcomings. Perhaps the most often cited criticism is that there is no *a priori* reason to choose one distributional assumption for the u_{it} over another. Typically, the inefficiency effects component of the composed error term is assumed to be distributed *half-normal* or *exponential*, both of which are single-parameter distributions. Green (1997) found little difference in the parameter estimates and the estimated u_i's between models estimated with either of these distributions. Another criticism of more practical importance is the choice of functional form for technology. There are numerous choices varying from the restrictive, such as the Cobb–Douglas or CES, to the flexible, such as the translog. Theory often provides little guidance in the choice of functional form, and this lack of guidance may explain why the majority of published studies, including the present one, use the flexible translog.

3. Empirical model

In this study, we consider each of the nine lumber producing regions shown in Fig. 1 as a production unit. Although the theoretical structure of production analysis was initially developed for individual firms or public agencies, it has proved valuable, and is used extensively, in the study of aggregates of micro-level units and even macroeconomic processes (e.g., Färe et al., 1994). Hailu and Veeman (2003), for example, use Canadian provinces in a production efficiency study of logging in boreal regions, and Puig-Junoy (1998) uses countries as production units in an analysis of the efficiency of health care provision in the OECD. There is no exact aggregation process to combine plant-level production functions to the coarser regional scale except in special (and highly limited) circumstances. Summing up output and input use across firms in a region will reduce the relative variability of the aggregates. In the SFPF context this may act to “lower” the efficient frontier and raise the average efficiency of the aggregates relative to what might be found with micro-level data.

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