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Assessing the lumber manufacturing sector in western Washington

Jean M. Daniels *

Research Forester USDA Forest Service, Pacific Northwest Research Station, 620 SW Main St., Portland, Oregon, 97205, USA

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ABSTRACT

The production structure of the lumber manufacturing sector in western Washington was investigated using a translog cost function with capital. labor, and sawlog inputs. Analyses were performed with a panel data set of biennial observations from 1972 to 2002 on a cross section of sixteen western Washington counties. Production structure was examined using Allen and Morishima partial elasticities of substitution, own- and cross-price factor demand elasticities, and total factor productivity decomposed into scale effects and technical change effects. Allen and Morishima substitution elasticities agreed that capital and labor were most easily substituted inputs. Own-price elasticity at the regional level showed that capital demand was the most responsive to changes in own-price while log demand was least. Demand for logs was virtually unresponsive to changes in capital and labor price, suggesting that producers had little flexibility to reduce total costs by substituting away from log inputs. Total factor productivity increased by 1.54% every two years on average; productivity gains in the industry were dominated by scale effects. Hicks-neutral technological change was rejected; technical change bias was sawlog-saving, capital-using, and labor-neutral Results suggest that policies influencing log costs had the greatest impact on sawmill viability.

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1. Introduction and background

In 2007, sawmills in Washington produced 4.76 billion board feet of lumber, adding 1.75 billion dollars to the state economy and providing 6218 documented jobs (Western Wood Products Association, 2008). With 85% of statewide production, lumber manufacturing has remained particularly viable in western Washington.[1] despite macroeconomic uncertainty, regulatory constraint, and competition from foreign and other domestic producers (Mittelhammer et al., 2005). Trends in lumber production are of particular interest because sawmills are a traditional source of jobs and economic prosperity in rural areas with few other employment opportunities.

There are many reasons for a comprehensive economic analysis of the western Washington lumber industry. After a period of dramatic of lumber output and capacity expansion in western Washington mills, lumber demand collapsed as the 2007 sub-prime mortgage crisis curtailed housing markets nationally. Predicting the impact of this nationwide slow-down on production inputs is problematic; input demand characteristics of lumber producers in western Washington have not been examined since 1995 (Stevens). Widespread adoption of labor-saving technology and consolidation of capacity and production into fewer large-scale mills located near urban manufacturing centers and transportation corridors raises concerns for fural employment and community stability. Yet, substitution characteristics between labor and capital investment are unknown. Overall sawmill costs are largely attributed to raw materials (Fig. 1), implying an inelastic relationship between sawlog demand and price that remains unquantified.[2] Last, studies show that investment in technology increases productivity; yet this claim has not been evaluated for mills in western Washington (Mittelhammer et al., 2005; Helvoigt, 2006).

This study differs from previous studies in several ways. This is the only known study of lumber manufacturing in western Washington performed since the mid-1990s. The data set contains biennial observations from 1972 to 2002, spanning three decades with known market perturbations. This is the first study using a translog flexible cost function model and the first to estimate total factor productivity in western Washington. Previous studies have used Allen elasticity of substitution to explain input substitution in the industry. Blackorby and Russell (1989) showed that with more than one factor input, Morishima substitution elasticities (MES) are the appropriate measure of elasticity of substitution. This is the first study to estimate MES for western Washington.

Table 1 lists lumber production studies performed in the U.S. since 1980 with area of study, functional form, inputs. outputs, data sample, and technology variable indicated. Only one previous study focused specifically on the western Washington lumber industry (Stevens, 1995). Stevens data set induded biennial observations from 1980 to

* Tel.: +1 503 808 2004; fax: +1 503 808 2033.
E-mail address: jdaniels@fs.fed.us.

[1] Western Washington is composed of the 19 counties lying west of the Cascade Mountain crest.

[2] Fig. 1 shows a declining share of sawlog costs after 1996; this is largely a function of the loss of export premiums following the Asian Financial Crisis of 1997 (Daniels, 2005).

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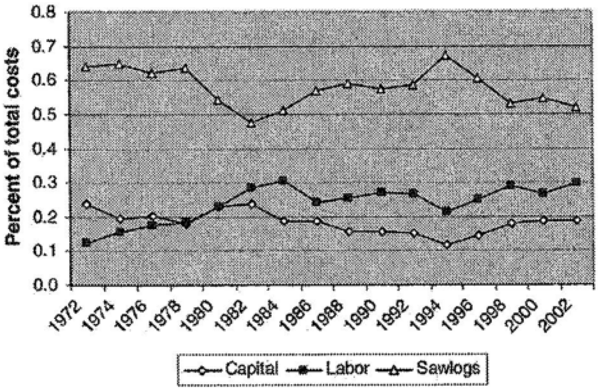

Fig. 1. Input cost shares in western Washington sawmills, 1972–2002.

1988, a recessionary period with negative profits and many mill closures. With only five time-series points and 16 cross-sectional county groups, he acknowledged that parameter estimates could benefit from additional time-series observations. Mittelhammer, et al. (2005) examined methods to explicitly model technical change in the lumber industry at the state level. The most recent observation was eighteen years ago as the author's objective was to examine the industry before the spotted-owl controversy of the early 1990s. The remaining studies examined lumber production at a regional or national scale. All but two of these studies is over a decade old, and none include data more recent than 1996. Six studies employed a translog cost function approach, including the most recent (McQueen and Potter-Witter, 2006). Results from these studies appear in Tables 7 and 8.

This study uses a trans log flexible cost function approach to analyze the production structure and input substitution of the lumber manufacturing sector in western Washington with biennial data from 1972 to 2002. The total cost function is estimated simultaneously with cost-share equations using three inputs: labor, logs, and capital. Output is an aggregate of softwood and hardwood lumber production; residues were omitted owing to data inconsistencies.[3] Measures used to assess economic performance are Allen and Morishima partial elasticities of substitution, own- and cross-price elasticities of factor demand, and total factor productivity, decomposed into scale and technical change effects. The next section summarizes the theoretical and empirical model, followed by data sources. Remaining sections present analysis results and conclusions.

2. Theoretical and empirical model

Lumber production can be modeled using a production function representing the relationship between inputs and outputs:

$$Y = f(K, L, S; T),$$

where Yis lumber output (thousand board feet, lumber tally), K is capital (dollars), L is labor (total manhours), S is sawlogs (thousand board feet, Scribner log rule), and T is a time trend representing technology (years). The dual relationship between production and costs motivates the use of a corresponding cost function[4]:

$$C = f(Y, P_K, P_L, P_S, T),$$

where C is total cost, Y is lumber output, P_K, P_L and Ps are capital, labor, and sawlog price, respectively, and T is a time trend. Assumptions imposed on producer and market behavior a *priori* are: mills produce a single output and minimize costs, mills purchase or rent cost-minimizing levels of production inputs, markets are competitive, and output and input prices are exogenous.

Awell-behaved cost function is concave in input prices. The principal minors of the Hessian matrix of second-order partial derivatives are negative semidefinite and symmetric, meaning $f_{x_1 x_2} = f_{x_2 x_1}$ (Silberberg and Suen, 2001). Factor demand functions must be non-negative to ensure the cost function is monotonic in both Y and P, and the cost function must be homogeneous of degree one with respect to input prices. These curvature properties are maintained hypotheses about the geometry of the function that can be tested or imposed *a priori* (Chambers, 1988).

A translog cost functional form was selected for flexibility with respect to restrictions. returns to scale, elasticities of substitution, and technical change (Berndt and Christensen, 1973).5 After imposing linear homogeneity with respect to input prices and symmetry of cross-partial coefficients using the restrictions:

$$\sum_i \beta_i = 1, \quad \sum_i \beta_{ij} = \sum_i \beta_{iY} = \sum_i \beta_{iT} = 0, \quad \beta_{ij} = \beta_{ji}, \quad i,j = L, S, K$$

and appending the model to include a first-and second-order autocorrelation term $(\varphi_1, \varphi_2)^6$; the translog cost function became:

$$\begin{aligned} \ln C = {} & \ln\alpha_0 + \alpha_Y \ln(Y) + \alpha_L \ln\left(\frac{P_L}{P_K}\right) + \alpha_S \ln\left(\frac{P_S}{P_K}\right) + \frac{1}{2}\left[\beta_{LL} \ln\left(\frac{P_L}{P_K}\right)^2\right] \\ & + \beta_{LS} \ln\left(\frac{P_L}{P_K}\right) \ln\left(\frac{P_S}{P_K}\right) + \frac{1}{2}\left[\beta_{SS} \ln\left(\frac{P_S}{P_K}\right)^2\right] + \beta_{LY} \ln\left(\frac{P_L}{P_K}\right) \ln(Y) \\ & + \beta_{SY} \ln\left(\frac{P_S}{P_K}\right) \ln(Y) + \frac{1}{2}\alpha_{YY} \ln(Y)^2 + \alpha_t T + \frac{1}{2}\alpha_{tt}(T)^2 + \beta_{Lt} \ln\left(\frac{P_L}{P_K}\right) T \\ & + \beta_{St} \ln\left(\frac{P_S}{P_K}\right) T + \beta_{Yt} \ln(Y) T + \varphi_1 + \varphi_2 \end{aligned}$$

with corresponding cost share equations derived using Shepherd's lemma (1953):

$$M_L = \alpha_L + \beta_{LL} \ln\left(\frac{P_L}{P_K}\right) + \beta_{LS} \ln\left(\frac{P_S}{P_K}\right) + \beta_{LY} \ln(Y) + \beta_{Lt} T + \varphi_1 + \varphi_2$$

$$M_S = \alpha_S + \beta_{LS} \ln\left(\frac{P_L}{P_K}\right) + \beta_{SS} \ln\left(\frac{P_S}{P_K}\right) + \beta_{SY} \ln(Y) + \beta_{St} T + \varphi_1 + \varphi_2.$$

These cost share equations are equivalent to factor demand equations; logarithmic differentiation of the translog cost function with respect to input prices yields $\frac{\partial(\ln C)}{\partial(\ln P_i)} = \left(\frac{\partial C}{\partial P_i}\right)\left(\frac{P_i}{C}\right) = \frac{P_i X_i}{C} = M_i, i = L, S, K$ where X_i is

[3] Many researchers have attempted to include wood chips as an output; Latta and Adams (2000) found chip output data lacking for test of jointness in production.

[4] Non-negative, continuous, and twice-differentiable; see Samuelson (1947), Shepherd (1953), or Silberberg and Suen (2001) for more information about duality theory.

[5] The unrestricted three-input translog variable cost function was:

$$\begin{aligned} \ln C = {} & \ln\alpha_0 + \alpha_Y \ln(Y) + \sum_i \beta_i \ln P_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_i \ln P_j + \sum_i \beta_{iY} \ln P_i \ln Y \\ & + \frac{1}{2}\alpha_{YY}(\ln Y)^2 + \alpha_T T + \frac{1}{2}\alpha_{TT}(T)^2 + \sum_i \beta_{iT} \ln P_i T + \beta_{YT} \ln(Y) T. \end{aligned}$$

where C is total variable cost defined as the sum of input costs, $C = \sum_i P_i X_i$, Y is output, i and j are production inputs, and T is technology represented by time.

[6] In accordance with Portmanteau Autocorrelation Tests, 12 lags.

Table 1
U.S. lumber production studies employing duality theory since 1980.

Year	Author	Study area	Data	Function	Functional form	Inputs (quasi-fixed)	Output	Technology
1980	Stier (a)	US	1958–74	Cost	Translog	Capital, labor	Lumber (SIC 242)	Time trend
1980	Stier (b)	US	1950–74	Cost	Translog	Capital, labor, sawlogs	Lumber (SIC 242)	Time trend
1981	Denny, et al.	US	1949–71	Cost	Dynamic normalized quadratic	Energy, labor, materials (capital)	Lumber (SIC 24)	Time trend
1981	Jorgenson and Fraumeni	US	1958–74	Price	Translog	Capital, energy, labor, materials	SIC 24	Time trend
1983	Bible	Oregon NE	1970–80	Cost	Translog	Capital, labor, sawlogs	Lumber	None
1983	Merrifield and Haynes	PNW	1950–76	Production	Translog	Capital services, labor, stumpage	Lumber, plywood (weighted avg)	None
1985	Merrifield and Haynes	PNW east	1950–79	Cost	Translog	Labor, stumpage, rental price structure, rental price equip	Lumber	Time trend
1985	Merrifield and Haynes	PNW west	1950–79	Cost	Translog	Labor, stumpage, rental price structure, rental price equip	Lumber	Time trend
1986	Merrifield and Singleton	PNW	1954–80	Cost	Dynamic normalized quadratic	Labor, stumpage (capital)	Lumber	Time trend
1987	Abt	Appalachian	1963–78	Cost	Translog	Labor, roundwood (capital)	Lumber	Time trend
1987	Abt	Southeast	1963–78	Cost	Translog	Labor, roundwood (capital)	Lumber	Time trend
1987	Abt	West	1963–78	Cost	Translog	Labor, roundwood (capital)	Lumber	Time trend
1988	Constantino and Haley	PNW west	1957–82	Profit	Translog	Labor, sawlogs, (capital, wood quality)	Lumber, chips	Explicitly modeled
1989	Wear	Montana	1958–78	Cost	Normalized quadratic	Capital, labor, stumpage	Lumber, plywood	Time trend
1995	Stevens	Washington west	1980–88	Profit	Normalized quadratic	Energy, sawlogs, unskilled labor (capital stock, skilled labor)	Lumber, chips	Time trend
1997	Bernard, et al.	Northeast	1965–90	Profit	Symmetric normalized quadratic	Aggregates logs, labor, energy as one input (capital stock)	Air dried sftwd lumber, kiln-dried sftwd lumber	Time trend
2005	Mittelhammer, et al.	Washington	1968–90	Profit	Normalized quadratic	Labor, sawlogs (capital stock)	Lumber, chips	Explicity modeled
2006	McQueen and Potter-Witter	Lake States	1963–96	Cost	Translog	Capital, labor, sawlogs	Lumber	Time trend

The benchmark translog cost model was sequentially compared against models of a homothetic and homogeneous cost function, unitary elasticity of substitution, Hicks-neutral technology, and no technical change by applying the following restrictions (McQueen and Potter-Witter, 2006):

- Homothetic cost function: $\beta_{iY}=0$
- Homogeneous cost function: $\beta_{iY}=\alpha_{YY}=0$
- Unitary elasticity of substitution: $\beta_{ij}=0$
- Hicks-neutral technical change: $\beta_{it}=0$ and
- No technical change: $\alpha_t=\alpha_{tt}=\beta_{it}=\beta_{Yt}=0.$

Likelihood ratio tests (LRT) were employed to select between models. Test statistics were compared against chi-square critical values with degrees of freedom equal to the number of model restrictions (Greene, 2003). Allen and Morishima elasticities of substitution, own- and cross-price demand elasticities, total factor growth, and input factor bias were calculated from parameters of the selected model.

Allen partial elasticities of substitution (Allen, 1938) describe the extent that inputs are *technically* substitutes in production. Where M_i is the cost share value for input i, Allen partial elasticities of substitution are[7]:

$$\sigma_{ii}^A = \frac{\beta_{ii} + M_i^2 - M_i}{M_i^2}$$

$$\sigma_{ij}^A = \left(\frac{\beta_{ij}}{M_i M_j}\right) + 1.$$

This measure is symmetric, meaning $\sigma^A_{ji} = \sigma^A_{ij}$. Positive Allen elasticity values imply that inputs are substitutes; values greater than or less than one indicate an elastic or inelastic relationship, respectively.

Own- and cross-price elasticities are factor demand elasticities that reflect changes in input demand resulting from changing input prices. Own $(i = j)$ and cross $(i \neq j)$ price elasticities of factor demand are derived from input cost shares and Allen substitution elasticities:

$$\eta_{ii} = M_i \sigma_{ii}^A$$
$$\eta_{ij} = M_j \sigma_{ij}^A$$
$$\eta_{ji} = M_i \sigma_{ij}^A.$$

Morishima substitution elasticities, unlike Allen elasticities, are not symmetric and are derived from factor demand elasticities:

$$\sigma_{ij}^M = \eta_{ji} - \eta_{ii}$$
$$\sigma_{ji}^M = \eta_{ij} - \eta_{jj}.$$

Total factor productivity (TFP) measures residual output growth not accounted for by growth in factor inputs. The percentage change in TFP is estimated as (Nagubadi and Zhang, 2006):

$$\dot{TFP} = \dot{T} + (1 + \eta_{CY})\dot{Y}.$$

If TFP growth is positive, costs are decreasing over time (given fixed input prices and output), and productivity is increasing. If $\dot{TFP}$ is negative, costs are rising over time.

[7] Elasticity values were calculated at the mean of input cost shares.

Table 2
Likelihood ratio test results for translog restrictions.

Model	No. of restrictions	Determinant residual covariance	Likelihood ratio[a]	Likelihood ratio test statistic	Chi-square 99% critical value	Outcome
Benchmark	0	8.140E−08				
Hicks-neutral technology	2	9.560E−08	1.721E−09	40.360	9.21	Reject
No technical change	5	1.010E−07	1.742E−12	54.152	15.09	Reject
Homothetic	2	2.360E−07	9.614E−59	267.179	9.21	Reject
Homogeneous	3	2.420E−07	4.117E−60	273.480	11.34	Reject
Unitary elasticity of substitution	3	3.000E−07	8.029E−72	327.406	11.34	Reject

[a] The likelihood ratio is calculated as $(\Omega R/\Omega U)^{\wedge -n/2}$ where ΩR and ΩU are determinant residual covariance of the restricted and unrestricted models; n is sample size.

Growth in TFP can be decomposed into technology and scale effects. The first term T is the rate of technical change: it is the negative derivative of the cost function with respect to time:

$$\dot{T} = -\frac{\partial \ln C}{\partial T} = -(\alpha_T + \alpha_{TT}T + \alpha_{YT}\ln Y + \sum \beta_{iT}\ln P_i).$$

The second term $(1-\eta_{CY})\dot{Y}$ represents scale effects, where $\dot{Y}$ is the rate of change in output[8] and η_{CY} is the elasticity of cost with respect to output:

$$\eta_{CY} = \frac{\partial \ln C}{\partial Y} = \alpha_Y + \alpha_{YY}\ln Y + \alpha_{YT}T + \sum_i \beta_{iY}\ln P_i.$$

If the industry exhibits constant return to scale, scale effects equal zero and TFP growth is solely measured by technical change, $\boldsymbol{T}$. Separating TFP into scale effects and technical change effects has questionable validity both when using aggregated industry data and in a time-series setting (Diamond et al., 1978[9]; Criliches and Ringstad, 1971, Baardsen, 2000), yet scale and technical change effects are reported for comparability to earlier studies.

When time is used as a proxy for technology, technical change is Hicks-neutral if the marginal rate of substitution is independent from time. Rejection of Hicks neutrality suggests the presence of input factor bias. Factor bias of the ith input is the coefficient of the interaction term between capital, labor, and saw logs and output: B_{KY}, B_{LY}, B_{SY} (Kant and Nautiyal, 1997). When B_{iY} is less than, equal to, or greater than zero, technical change is input saving, neutral, or using, respectively.

3. Data

Data required for the translog cost function include total sawmill costs, total cost and prices of inputs capital, labor, and logs, and volume of lumber output. Mill-level data for labor quantity, log quantity, and lumber production were available biennially from the Washington Mill Survey (Washington Department of Natural Resources (WADNR),1972-2002a,b). These were aggregated and combined with additional county-level cost and price data constructed from sources described in Appendix A. This study uses biennial data from 1972 to 2002,[10] resulting in a panel data set of 256 observations. Values were adjusted to 1982 dollars using the all-commodity producer price index (PPI).

4. Results

Likelihood ratio tests rejected all model restrictions at the 1% significance level (Table 2). These results are contrary to McQueen and Potter-Witter, who could not reject Hick's neutral technical change in sawmills in the Great Lakes states. Stevens neither tested nor imposed restrictions on his model. Subsequent calculations of elasticities and total factor productivity were based on coefficients from the benchmark model.

Coefficient estimates and standard errors from the translog cost function appear in Table 3. The R-squared value of 0.9805 suggests a good fit between the translog cost model and sawmill data. Of the 23 estimated parameters, 16 were significant at the 1% level and 3 were significant at the 5% level. Three of the six the technology variables were not significant, yet Hicks-neutral and no technical change models were rejected by the likelihood ratio test. Since the translog does not satisfy the conditions for well-behaved cost function globally (Berndt and Wood, 1975), concavity in input prices and strictly positive input demand functions were tested and met for each observation.

Descriptive statistics for capital, labor, and log cost shares are listed in Table 4. Logs accounted for 58% of sawmill costs. Although labor and capital contributions to costs (24 and 18% respectively) were smaller on average, maximum values of 71 and 61% suggest that county-level aggregation of labor and capital costs may dilute impacts observed at the individual mill level.

Allen and Morishima partial elasticities of substitution with associated standard errors appear in Table 5. All inputs were inelastic Allen substitutes with the greatest substitutability between capital

Table 3
Cost function coefficient estimates for the western Washington sawmill industry.

Coefficient	Estimate	Standard error
α_0	10.3454*	5.0082*
α_Y	−0.3839	0.7138
β_L	1.0124	0.1152**
β_S	−0.6051	0.1217**
β_K	0.5927	0.1154**
β_{LL}	0.1007	0.0096**
β_{LS}	−0.0893	0.0086**
β_{LK}	−0.0115	0.0079*
β_{SS}	0.1652	0.0124**
β_{SK}	−0.0759	0.0092**
β_{KK}	0.0874	0.0106**
β_{YL}	−0.0846	0.0102**
β_{YS}	0.1852	0.0102**
β_{YK}	−0.1007	0.0109**
β_{YY}	0.1434	0.0687*
α_t	−0.3032	0.2942
α_{tt}	0.0017	0.0130
β_{LT}	0.0095	0.0037**
β_{ST}	−0.0207	0.0038**
β_{KT}	0.0112	0.0032**
β_{YT}	0.0087	0.0083
φ_1	0.6678	0.0389**
φ_2	0.2355	0.0394**
R-squared	0.9804	
Standard error of regression	0.1318	
Durbin–Watson statistic	2.2340	

** and * indicate significance at the 1% and 5% level, respectively.

[8] Nagubadi and Zhang (2006) derived the rate of change in output from the semi-log equation, $\ln Y = a + bT$. Y is output, T is time in years, a and b are parameters, and the rate of change in Y is estimated as $(e_b - 1)100$.

[9] Also called the Diamond–McFadden impossibility theorem.

[10] Although there are 19 counties in western Washington, Island, San Juan, and Wahkiakum Counties were omitted owing to data inconsistencies.

Table 4
Descriptive statistics for western Washington sawmill input factor cost shares.

	Cost share		
	Capital	Labor	Logs
Mean	0.1839	0.2368	0.5793
Median	0.1629	0.2140	0.5906
Maximum	0.6077	0.7125	0.8554
Minimum	0.0144	0.0505	0.1436
Std. deviation	0.1277	0.1226	0.1255

and labor (0.7369). With substitution elasticity of 0.2876, capital and logs were the most difficult to substitute.

Morishima partial elasticities of substitution were consistent with Allen substitution elasticities. All input combinations were inelastic substitutes. Capital and labor were the strongest Morishima substitutes; labor was somewhat easier to substitute for capital than the converse (Table 5). Morishima elasticities confirm that sawmills were least able to substitute between logs and the other inputs.

Price elasticity results presented in Table 6 show that all input pairs are inelastic substitutes. The own-price elasticities all had the expected negative sign; capital demand was most responsive to own-price changes and log demand the least. The labor-log cross-price elasticity was the largest at 0.2023; a 1% increase in log price increased labor demand by 0.20%. Demand for logs was the least elastic with respect to changes in capital and labor input prices.

When evaluated at the mean values of input variables, total factor productivity in the western Washington lumber industry improved by an average of 1.54% every two years over the study period. After decomposing TFP into scale effects and technical change, it was clear that scale had a far greater impact on TFP than technical change. Overall, the proportion of TFP growth attributable to scale was 1.45%. Output rose by almost 3% every two years and the output elasticity value of 0.51 suggests increasing returns to scale (McQueen and Potter-Witter, 2006). The rate of technical change was estimated at 0.09 per biennium. Hicks-neutral technological change was rejected; technical change bias was sawlog-saving, capital-using, and labor-neutral.

5. Discussion and conclusions

The structure of the western Washington lumber industry can be represented by an unrestricted translog cost function exhibiting nonunitary elasticity of substitution, nonconstant returns to scale, and biased technical change. Restrictions for unitary elasticity of substitution, homogeneity, homotheticity, no technical change, and Hicks-neutral technology were rejected. Input demand was not independent from factor prices or output; the hypothesis that factor shares are independent of prices was strongly rejected. Estimated cost and factor demand functions are well behaved; curvature and positivity requirements were met for each observation.

Sawmill profitability was primarily driven by log costs, which were nearly 58% of sawmill variable production costs on average. Holding output constant, elasticities show that log demand was unresponsive to own- or cross- input prices, with only a modest ability to substitute capital for logs. Thus, the industry was highly sensitive to unexpected changes in log markets. Price elasticities confirm that increasing log prices led to increased demand for capital and reduced demand for labor. Improved lumber recovery resulting from capital investment was achieved at the expense of sawmill workers. This conclusion is intuitive; a mill may layoff workers or postpone investment in facilities when faced with rising costs, but it is impossible to create lumber without wood.

Total factor productivity in western Washington sawmills is comparable to other regions. McQueen and Potter-Witter (2006) found that productivity in the Great Lake states improved by 0.69% annually; Nagubadi and Zhang (2006) estimated TFP growth of 0.54% in Canadian sawmills. However, productivity improvements were dominated by scale effects, rather than technical change, suggesting that mill owners sought to capture cost savings by expanding production. The technical change that did occur was sawlog-saving as producers attempted to mitigate the impact of log costs. One thing is clear; efforts to minimize input costs are a crucial part of producer strategy.

Since log costs exert a critical influence over western Washington's production of lumber, policies that reduce volatility in log prices should be the most beneficial to the industry. Continued access to adequate raw material supply is one way to ensure that sawmills remain solvent Timber harvest has dramatically declined over the study period on all ownership categories (WADNR, 1972-2002b). The greatest declines have been on national forests as a result of federal policy. Unanticipated harvest declines have also occurred on state trust lands, on western Washington tribal lands, on industrial forest lands, and on western Washington non-industrial private lands, largely in response to changing regulations, market conditions, and land conversions. There is concern that harvest from non-industrial lands will continue to decline as landowner preferences shift away from financial gain from harvested timber (McQueen and Potter-Witter, 2006). Lower harvest rates could raise log prices, leading to closure of mills with the least ability to substitute away from wood.

Land conversion and parcelization of forest land holdings also impact log costs. Conversion is greatest close to urban populations and major transportation routes. In these cases development values of land can exceed land expectation values associated with commercial forestry values by 15-20 times (Bradley et al., 2007). Regulatory cost and complexity, social pressure from new residents and, for family forest landowners, generational changes and estate taxes are other motivations to convert. Forest conversion eliminates timber economic benefits and much of the ecological benefit of forest lands. With evidence that the land base of suitable timber in western Washington is shrinking, policies that limit urban expansion are likely to benefit lumber producers.

With skyrocketing fuel prices, another option is to examine policies that reduce transportation costs for delivering logs from the forest to the mill or delivering lumber from the mill to product markets. Since capacity is increasingly being located away from logging sites, mills may benefit from incentives to utilize alternative fuels or modes of transportation, such as water and rail.

Table 5
Elasticities of input substitution for the western Washington sawmill industry.

	Capital	Labor	Logs
Allen substitution elasticities			
Capital		0.7369 (0.1822)	0.2876 (0.0862)
Labor			0.3492 (0.0624)
Morishima substitution elasticities			
Capital		0.4767 (0.0451)	0.3940 (0.1182)
Labor	0.5123 (0.1114)		0.4205 (0.0058)
Logs	0.3022 (0.0895)	0.3379 (0.0546)	

Note: Values in parentheses are approximate standard errors (Binswanger, 1974).

Table 6
Own- and cross-price factor demand elasticities for the western Washington sawmill industry.

	Price of capital	Price of labor	Price of logs
Capital	−0.3411 (0.0574)	0.1745 (0.0432)	0.1666 (0.0499)
Labor	0.1355 (0.0335)	−0.3378 (0.0404)	0.2023 (0.0362)
Logs	0.0529 (0.0159)	0.0827 (0.0148)	−0.1356 (0.0432)

Note: The first row indicates how a 1% change in prices of capital, labor and logs affects demand for capital. The first column indicates the effect of a 1% change in price of capital on demand for the three inputs. Values in parentheses are approximate standard errors.

Table 7
Substitution elasticity results from previous U.S. lumber industry cost function studies.

	Author	Study area	σ^A_{KL}	σ^A_{LS}	σ^A_{KS}	σ^M_{KL}	σ^M_{LK}	σ^M_{LS}	σ^M_{SL}	σ^M_{KS}	σ^M_{SK}
1980	Stier (a)	U.S.	0.105	na	na	na	na	na	na	na	na
1980	Stier (b)	U.S.	0.194	0.360	0.176	na	na	na	na	na	na
1983	Bible	Oregon NE	0.342	0.587	−1.047	na	na	na	na	na	na
1985	Merrifield and Haynes	PNW east	1.810	0.170	−0.450	na	na	na	na	na	na
1985	Merrifield and Haynes	PNW west	1.300	0.070	−0.050	na	na	na	na	na	na
1987	Abt	U.S. Appalachian	na	na	na	na	na	na	na	na	na
1987	Abt	U.S. South	na	na	na	na	na	na	na	na	na
1987	Abt	U.S. West	na	na	na	na	na	na	na	na	na
2006	McQueen and Potter-Witter	Lake States	0.018	0.076	0.530	0.910	0.430	0.450	0.330	0.930	0.610
2009	Current study	Washington west	0.737	0.349	0.288	0.477	0.512	0.421	0.338	0.394	0.302

Table 8
Factor demand elasticity results from previous U.S. lumber industry cost function studies.

	Author	Study area	η_{KK}	η_{LL}	η_{SS}	η_{KL}	η_{LK}	η_{LS}	η_{SL}	η_{KS}	η_{SK}
1980	Stier (a)	U.S.	na	na	na	0.058	0.047	na	na	na	na
1980	Stier (b)	U.S.	−0.243	−0.353	−0.377	−0.086	−0.068	−0.070	−0.040	−0.205	0.071
1983	Bible	Oregon NE	−0.041	−0.155	−0.378	na	na	na	na	na	na
1985	Merrifield and Haynes	PNW east	−0.870	−0.790	0.020	0.600	0.170	0.050	0.050	−0.090	−0.040
1985	Merrifield and Haynes	PNW west	−0.890	−0.510	−0.001	0.350	0.110	0.040	0.010	0.004	−0.006
1987	Abt	U.S. Appalachian	na	−0.110	−0.080	0.110	na	0.110	na	na	−0.100
1987	Abt	U.S. South	na	−0.470	−0.250	−0.010	na	0.470	na	na	−0.030
1987	Abt	U.S. West	na	−0.390	−0.200	0.010	na	0.390	na	na	−0.190
2006	McQueen and Potter-Witter	Lake States	−0.910	−0.420	−0.290	0.006	0.001	0.047	0.026	0.330	0.023
2009	Current study	Washington west	−0.341	−0.338	−0.136	0.174	0.135	0.202	0.083	0.166	0.053

While log costs are critical components of production costs, the costs of taxes and forestry regulations are also important to private forest landowners. Washington has one of the highest tax obligations for owning timberlands and harvesting timber in the U.S. (Perez-Garcia. 2006). Washington's stringent stream buffer requirements for forestry, intended to benefit salmon, impose a significant cost, especially on owners of small forest parcels. High costs can undermine the incentive to sustain land in forestry, jeopardizing access to raw materials required by sawmills.

Given these challenges to sawmill viability, the role of sawmills in generating employment and rural development in western Washington appears to have diminished. However, Lee and Eckert-jennings (2002) found that small- and medium-sized sawmills provided the most stability in employment during periods of both long-term growth and decline in the Washington forest products industry, Improving the operating environment for small mills may be one approach to stabilizing wood-producing communities. Policies such as providing access to limited supplies of state and federal timber, providing favorable credit and taxation, and reducing the disproportionate impacts of environmental regulations on small mills might help create and maintain steady employment opportunities in rural areas (Tables 7 and 8).

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Appendix A

An exhaustive description of the data can be found in Daniels (2007). Total labor cost was annual payroll values by county for Standard Industrial Classification (SIC) code 242 from 1972 to 1996 and NAICS code 3211 from 1998 to 2002 (U.S. Department of Commerce, Bureau of the Census, 1972-2002).11 Industries in SIC 242 and NAICS 3211 do not match exactly; separating wood-preservation facilities from sawmills was not possible at the county level owing to disclosure laws. However, the bias created by this data inconsistency appears to be minimal; state-level data show that wood preservation facilities comprised no more than 9% of NAICS code 3211 between 1998 and 2002. In addition, the 1997 Economic Census declared sales or receipts from NAICS within 3% of SIC sales or receipts (U.S. Department of Commerce, Bureau of the Census, 2000).

Missing payroll values were generated in two ways. If the period immediately prior and immediately following the missing value was reported, the missing value was an average of those two values. If several consecutive years were missing, values were generated using reported data for SIC 24 and NAICS 321 and the number of firms using the ratio (for SIC or NAICS): $\frac{\text{SIC 24 payroll}}{\text{\#SIC 24 firms}} = \frac{\text{SIC 242 payroll}}{\text{\#SIC 242 firms}}$.

Labor quantity is denned as annual mill operating hours (WADNR, 1972-2002a,b). County level wages were calculated by dividing total labor cost by operating hours. The resulting data series contained total biennial labor cost and wages for each county.

The volume (thousand board feet, Scribner log rule) of logs consumed by western Washington lumber manufacturers consists of an all-species log volume from mill data for each county. (WADNR, 1972-2002a).

Three sources were used to construct the log price series. Log prices from 1972 to 1985 were an average of number 1, number 2, number 3, and number 4 domestic grades of Douglas-fir and western hemlock compiled by the Industrial Forestry Association and published annually in Warren (1972-2002). Log prices for 1986 and 1988 were published in the Forest Price Report (National Agricultural Statistics Service (1986-1988)). For each of three sub-regions, Douglas-fir and hemlock-fir prices were averaged over four domestic grades: special mill, number 2, number 3, and number 4. After 1988, prices were available from the Log Lines Price Reporting Service (1989-2002). Monthly prices for Douglas-fir and western hemlock

11 The Census Bureau converted from the SIC system to the North American Industrial Classification System (NAICS) in 1997.

special mill, number 2, number 3, and number 4 grades were averaged to form annual prices. Log Lines reports western Washington log prices at three sub-regional levels.

The total cost of capital was represented by the assessed building values of sawmills responding to the WADNR mill survey (Stevens, 1995). Values were gathered from County Assessor offices and state archive facilities in Olympia, Bellevue, and Bellingham, Washington. Building values were selected to represent capital because building assessments were more consistent across counties than machinery and equipment, introducing a potential downward bias to capital stock values. Missing assessment values were estimated using ordinary least squares to regress county sawmill capacity (available in the mill survey) on available assessed values.

User cost of capital calculations require generating a capital stock series. Initial capital stock values were the 1972 total assessed building value for sawmills in each county. Subsequent stock values were generated using the perpetual inventory method (Christensen and Jorgensen, 1969) modified in two ways. Because appraisers consider depreciation when evaluating properties, no adjustments for depreciation were incorporated into building values. The series was also adjusted for the service life of capital stock assuming a building lifespan of 25 years (Baardsen, 2000). User costs of capital were then constructed using the capital stock series, a discount rate (Moody's AAA Corporate Bond Rate), and county property tax rates (Washington State Department of Revenue, 1972-2002).

Lumber output volume (thousand board feet, lumber tally) was acquired from the mill survey (WADNR,1972-2002a,b). Mill survey data do not specify lumber grade; the series consists of all-species and all-grades of lumber produced by county.

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