Estimating Regional Softwood Lumber Supply in the United States Using Seemingly Unrelated Regression

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Abstract

In this article, we present estimates of regional softwood lumber supply functions in the United States using annual time series data for 1959 to 2009. Seemingly unrelated regression is used in a profit maximization framework to model softwood lumber supply as a function of lumber and stumpage prices, lagged supply, wage rate, and interest rate for the eastern and western United States. The effects of listing the northern spotted owl (*Strix occidentalis caurina*) as a threatened species and the US–Canada softwood lumber trade dispute are controlled for in empirical estimation. Results show that regional lumber supply is quite inelastic to lumber price and that stumpage price and bank prime rate negatively influence regional lumber supply. Results also suggest that present market supplies of softwood lumber have potential expansionary influence on future supplies, that listing of the northern spotted owl in 1990 reduced the lumber supply in the western region during subsequent years, that the US–Canada softwood lumber trade dispute/agreements favored regional lumber production in the United States during the period from 1996 to 2005, and that supply has declined during the recent period of economic recession.

One of the most interesting issues in forest economics is concerned with the nature and extent of the market for timber (Uri and Boyd 1990). The forest product market in the United States is dominated by lumber. The estimated total lumber consumption and production in the United States in 2005 were 11.2 billion cubic feet and 7.9 billion cubic feet, respectively (Howard 2007). In that year, lumber consumption represented about 52 percent of the total forest products consumed, and lumber production represented about 47 percent of the total forest products produced. Softwood lumber has the largest share in the US lumber market. In 2005, 73 percent of the total lumber produced and 83 percent of the total lumber consumed was softwood lumber (Howard 2007). In the same year, softwood lumber imports to the United States were 3.6 billion cubic feet, or about 97 percent of the total lumber imports. Softwood lumber is mainly used in the housing construction sector in the United States. Examining the softwood lumber market is thus of significant importance to economic studies in forestry.

The market for timber and softwood lumber has been widely investigated. For example, Hamilton (1970) estimated aggregate supply of National Forest timber. Supply elasticity specific to the California pine region was estimated by Frazier (1967). Robinson (1974) studied the markets for Douglas-fir (*Pseudotsuga menziesii*) and southern pine (such as *Pinus taeda, Pinus echinata,* and *Pinus palustris*) lumber. Luppold (1984) examined the US hardwood lumber market. Adams and Haynes (1980) were the first to estimate regional softwood lumber supply and demand functions under the Timber Assessment Market Model (TAMM). Regional estimates of aggregate lumber supply and demand functions, however, remain rare. Given the possible economic linkages between different regions in the country, simultaneous estimation of regional supply and demand using updated information is also lacking in the literature.

We examine the supply side of the softwood lumber market in the United States at regional levels. Supply functions for softwood lumber are estimated for two regions of the United States: the eastern (USE) and the western (USW) United States. The USW includes Alaska, Arizona,

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California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming. The USE includes the remaining states in both the southern and northern United States. The regional divisions are based on the volume of softwood lumber supply. The USW has traditionally been the largest softwood lumber producing region (Howard 2007). Although the share of the southern United States has steadily increased since listing of the northern spotted owl (*Strix occidentalis caurina*) as a threatened species in 1990, the average softwood lumber production in the USW was about 1.5 times higher than the average production in the southern United States between 1965 and 2005. The average production in the northern United States was less than one-tenth of that in the USW during the same time period. Thus, instead of treating the northern United States as a separate softwood lumber producing region, the southern and northern United States are combined to form the USE.

The softwood lumber market in both the USE and the USW are likely to be subject to spillovers from economy-wide or worldwide shocks contemporaneously. Thus, the supply equations of the two regions may be linked by the fact that their disturbances are correlated. For this reason, we use Zellner's (1962) seemingly unrelated regression (SUR) model to estimate the supply coefficients of the two regions. Regional supply functions are estimated using a profit maximization framework and time series data for 51 years, from 1959 to 2009. Price elasticities of supply are estimated with respect to both output and input prices. We also examine the effects of listing the northern spotted owl as a threatened species and the US–Canada softwood lumber trade disputes/agreements on regional supply of softwood lumber in the United States.

Methods

Theoretical and econometric model

The softwood lumber industry is assumed to be competitive. This is a realistic assumption given that softwood lumber is a commodity, that the number of softwood lumber mills in the United States is large (735 in 1997 and 522 in 2002; US Bureau of the Census 1999, 2005), and that no single producer or a group of producers has been able to lead the market. In this assumed setting, producers intend to maximize their profits given the prices of lumber and inputs. The profit (π) function for firm j in region i at time t can be written as

$$\pi_{ijt}(P_{it}, \mathrm{W}_{it}) = \underset{Q_{ijt}, L_{ijt}}{\mathrm{Max}}(P_{it}Q_{ijt} - \mathrm{W}_{it}\mathrm{L}_{ijt}) \qquad (1)$$

where P is the price of softwood lumber, Q is the amount of softwood lumber produced, W is a $1 \times K_j$ vector of input prices, L is a $K_j \times 1$ vector of inputs, and K is the number of inputs. Assuming that the profit function is convex in P and W and applying the Hotelling's lemma, the supply curve of the jth firm in the ith region (Q_{ij}) is derived by differentiating the profit function with respect to the market price. As expressed in the following equation, each firm's supply is a function of the market price of lumber and all inputs used in production:

$$\partial\pi_{ijt}/\partial P_{it} = Q_{ij}(P_{it}, \mathrm{W}_{it}) \qquad (2)$$

If all firms in a region maintain a similar production function and face the same prices, the supply function for region i can be found by aggregating the N individual firms' supply functions. Thus,

$$Q_i(P_{it}, \mathrm{W}_{it}) = \sum_{j=1}^{N} Q_{ij}(P_{it}, \mathrm{W}_{it}) \qquad (3)$$

The theoretical model used here is the above equation, which describes softwood lumber supply as a function of its own market price and the prices of various inputs, such as labor, capital, and stumpage.

Previous studies examining the timber/lumber market have often used ordinary least squares (OLS), the full information technique, and/or two-stage estimation method (Frazier 1967, Robinson 1974, Adams and Haynes 1980, Luppold 1984). Although we were not able to find an application of the SUR in estimation of regional lumber demand/supply equations, use of SUR is common in the forestry and applied economics literature (see, e.g., Alig 1986, Nagubadi et al. 2004, Niquidet 2008) when errors of jointly estimated equations are expected to be contemporaneously correlated. SUR gains efficiency over OLS by taking the cross-equation correlations into account (Pindyck and Rubinfeld 1998, p. 359).

As mentioned, the regional softwood lumber markets in the United States are likely to be subject to direct or indirect effects of economy-wide or worldwide shocks contemporaneously. Thus, we expect the error terms of the two supply equations to be correlated. The SUR model used in this study can be specified by writing the system of two equations as follows:

$$\mathrm{Q}_i = \mathrm{X}_i\beta_i + u_i, \qquad i = \mathrm{USE, USW} \qquad (4)$$

where Q_i is a $T \times 1$ vector, X_i is a $T \times K_i$ matrix of explanatory variables (including output and input prices), β_i is a $K_i \times 1$ vector, u_i is a $T \times 1$ vector, and T is the total number of observations (time periods) for each region. The model can be written in a more general form as

$$\mathrm{Q} = \mathrm{X}\beta + \mathrm{u} \qquad (5)$$

where Q is a $2T \times 1$, X is a $2T \times (K_{\mathrm{USE}} + K_{\mathrm{USE}})$, β is a $(K_{\mathrm{USE}} + K_{\mathrm{USW}}) \times 1$, and u is a $2T \times 1$ matrix. SUR assumes no autocorrelation within equations. However, cross-equation correlation exists. Thus, $E(\mathrm{u}_{\mathrm{USE}}\mathrm{u}'_{\mathrm{USE}}) = \sigma_{\mathrm{USE,USW}}\mathrm{I}$, where $\sigma_{\mathrm{USE,USW}}$ is the covariance of disturbances between the USE and USW equations, contemporaneously, and I is an $T \times T$ identity matrix. The most efficient estimation of Equation 5 is obtained by generalized least squares (Pindyck and Rubinfeld 1998, p. 375).

Empirical specification and variables

The regional softwood lumber supply functions are estimated using a linear SUR model. The following two equations (i = USE, USW) are empirically estimated:

$$\begin{aligned}\log(Quantity\_Supplied_{it}) &= \psi_{0i} + \psi_{1i}\log(Price_{it}) \\ &+ \psi_{2i}Stumpage\_Price_{i(t-1)} + \psi_{3i}Interest\_Rate_{it} \\ &+ \psi_{4i}Wage\_Rate_{it} + \psi_{5i}\log(Quantity\_Supplied_{i(t-1)}) \\ &+ \psi_{6i}Spotted\_Owl_{it} + \psi_{7i}Lumber\_Dispute\_1_{it} \\ &+ \psi_{8i}Lumber\_Dispute\_2_{it} + \psi_{9i}Lumber\_Dispute\_3_{it} \\ &+ \psi_{10i}Lumber\_Dispute\_4_{it} + \varepsilon_{it} \qquad (6)\end{aligned}$$

In Equation 6, ε is an error term. The variables are defined in Table 1.

Table 1.—Variable definitions.

Variable name[a]	Description
$Quantity\_Supplied_{it}$	Softwood lumber production in million board feet (MBF)
$Price_{it}$	Softwood lumber price (US$/MBF)
$Stumpage\_Price_{it}$	Softwood stumpage price (US$/MBF)
$Interest\_Rate_{it}$	Bank prime loan rate
$Wage\_Rate_{it}$	Production worker hourly wage rate
$Spotted\_Owl_{it}$	=1 if $t \geq 1990$; =0 otherwise
$Lumber\_Dispute\_1_{it}$	=1 if $1987 \leq t \leq 1991$; =0 otherwise
$Lumber\_Dispute\_2_{it}$	=1 if $1996 \leq t \leq 2000$; =0 otherwise
$Lumber\_Dispute\_3_{it}$	=1 if $2002 \leq t \leq 2006$; =0 otherwise
$Lumber\_Dispute\_4_{it}$	=1 if $2007 \leq t \leq 2009$; =0 otherwise

[a] Subscripts denote region i and year t, respectively.

Higher output price encourages producers to increase their production. Softwood lumber price is thus expected to have a positive influence on supply. Stumpage is a major input in lumber production. Stumpage price has been used as an explanatory variable in previous lumber supply studies (Robinson 1974, Adams and Haynes 1980, Luppold 1984). We use lagged stumpage price as an explanatory variable, because it takes several months for standing timber to be cut and transported to mills and because timber sale contracts typically last for a few months to a year. Wage and interest rates have also been used in previous literature to explain variations in lumber supply (Luppold 1984). Coefficients of all input price variables are expected to have negative signs.

To introduce a distributed lag structure (Nerlove 1958), lagged supply is included in the model as an independent variable. A distributed lag structure assumes that the effects of the explanatory variables on softwood lumber supply are distributed over time. Compared with static models, dynamic models with lagged dependent variables explain the data better, provide more reasonable coefficient estimates, and suffer less from the problem of autocorrelation. Another motivation for using lagged supply as an independent variable is that it has the potential to influence current supply, because high sales in the previous year encourage producers to stay in business and expand capacity (Leuschner 1973). A positive relationship is hypothesized between the current and previous year's supply.

The northern spotted owl was listed as threatened under the US Endangered Species Act (ESA) on June 26, 1990. The listing of the northern spotted owl is expected to have caused a decline in lumber production through reduced annual harvests from public forests in the USW. The coefficient of *Spotted_Owl* is thus expected to have a negative sign.

The dispute over softwood lumber trade between the United States and Canada has received significant attention in the media, in discussions of international organizations, and in the academic literature during the past several decades (Zhang 2001, 2007; Yin and Baek 2004; Abboushi 2010). In this article, we attempt to capture the effects of four distinguishable periods of this dispute on softwood lumber supply in the United States using dummy variables (Table 1). *Lumber_Dispute_1* (1987 to 1991) accounts for the effect of the 1986 Memorandum of Understanding (MOU) between the two countries, which was signed in the last days of 1986 and required the Canadian Provinces to impose a 15 percent tax on their lumber exports to the United States (Zhang 2007). This MOU lasted for about 5 years. *Lumber_Dispute_2* (1996 to 2000) measures the effect of the 1996 Softwood Lumber Agreement (SLA) that stipulated an annual, duty-free quota of 14.7 billion board feet of lumber export by Canada, with increasingly prohibitive tax rates for higher quantities (Zhang 2007). *Lumber_Dispute_3* (2002 to 2006) measures various levels of tariff, including countervailing duty and antidumping duty imposed by the United States on imports of Canadian softwood lumber between March 2002 and September 2006 (Zhang 2007). Finally, *Lumber_Dispute_4* accounts for the effect of 2006 SLA, which imposed export taxes and quantitative restrictions on Canadian lumber exports to the United States (Zhang 2007). All four dummy variables on the US–Canada trade dispute/agreements are expected to have positive influences on regional lumber supply in the United States, because the time periods and policies represented by these variables are considered to be favorable to the US producers. However, the last dummy variable (*Lumber_Dispute_4*) is more of a measure of the recent severe economic recession in the United States. As Figure 1 shows, softwood lumber production simply collapsed during this period, falling to its lowest point in the last half-century in both US regions.

Data

Data used in the econometric estimation of regional supply equations were obtained from various sources and are summarized in Table 2. All prices and interest rates are deflated to the base year 1982 using the Producer Price Index for all commodities (Bureau of Labor Statistics 2010). Average softwood lumber production and prices of softwood lumber and stumpage were higher in the USW over the study period (1959 to 2009).

Regional softwood lumber production data for 1958 to 1994 were obtained from Darius Adams (Department of Forestry, Oregon State University, Corvallis, personal communication, November 2003). The data set provided annual production data for nine regions: Pacific Northwest (PNW), Pacific Northeast (PNE), Pacific Southwest (PSW), Northern Rocky Mountains (NRM), Southern Rocky Mountains (SRM), North Central (NC), Northeast (NE), South Central (SC) and Southeast (SE). Production in the USE is estimated as the sum of the production levels in the NC, NE, SC, and SE regions. Production in the USW is estimated as the sum of the production levels in the PNW, PNE, PSW, NRM, and SRM regions. Production data for 1995 to 2009 were obtained from Random Lengths (RL; 1999, 2005, 2009). Sum of the RL data for the South (SO) and North (NO) are used to estimate production in the USE. The 2009 value for the NO region was missing. Therefore, this missing value was extrapolated using the spline method (SAS Institute Inc. 1999). RL data for the West (Coast and Inland) are used as production in the USW.

Regional softwood lumber price data for 1959 to 1994 were obtained from Darius Adams (personal communication, November 2003). The data set provided annual price data for seven regions: PNW, PNE, PSW, NRM, SRM, NO, and SO. Softwood lumber price in the USE is estimated as the average price of the NO and SO regions. Softwood lumber price in the USW is estimated as the average price of the PNW, PNE, PSW, NRM, and SRM regions. Annual softwood lumber price data for 1995 to 2009 were obtained from RL (1999, 2005, 2009). The Western Spruce-Pine-Fir (S-P-F) composite price is used as the price in the USW. An

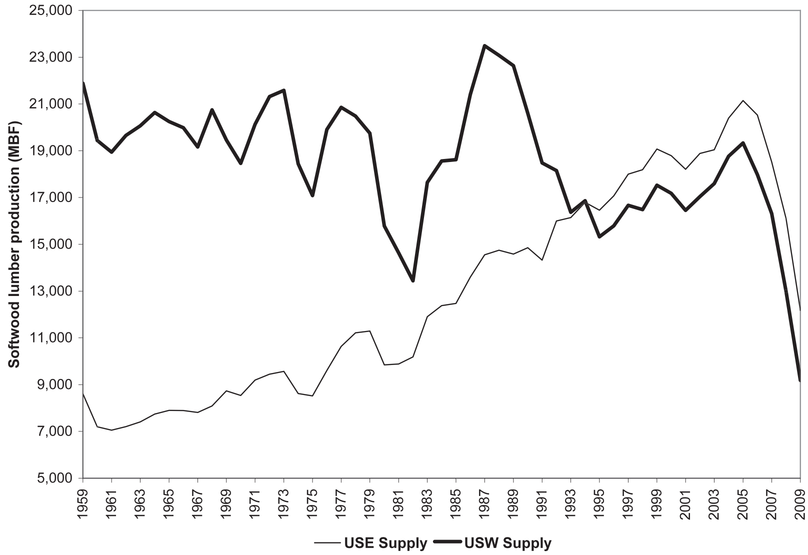

Figure 1.—Regional softwood lumber supply in the United States, 1959 to 2009.

Table 2.—Data summary.

Variable	Mean ± SD	Minimum	Maximum
Quantity_Supplied$_{USE}$	12,884.98 ± 4,396.70	7,051.00	21,145.00
Quantity_Supplied$_{USW}$	18,482.84 ± 2,672.84	9,182.86	23,490.00
Price$_{USE}$	243.45 ± 41.77	144.22	327.98
Price$_{USW}$	265.56 ± 65.72	110.98	419.93
Stumpage_Price$_{USE}$	181.66 ± 70.45	85.47	326.98
Stumpage_Price$_{USW}$	268.84 ± 126.10	78.23	501.14
Interest_Rate	10.77 ± 5.47	1.88	22.34
Wage_Rate	8.04 ± 1.44	5.21	13.44

average of the Southern Pine and Eastern S-P-F composite price is used as the softwood lumber price for the USE.

Annual average softwood stumpage price data for 1959 to 2009 were obtained from the Louisiana Department of Agriculture and Forestry (2007). Average annual softwood stumpage prices in the Northeast for 1961 to 2002 were obtained from Wagner and Sendak (2005). The Northeast stumpage prices over time are highly correlated with the Louisiana stumpage prices (Pearson correlation coefficient = 0.96). For this reason, the Louisiana stumpage prices are used in this study as representative of stumpage prices in the USE. Annual average stumpage price data for the PNW region for 1959 to 2009 were obtained from Jack Lutz (Forest Research Group, Rowley, Massachusetts, personal communication, April 2010). These data are used in this study as stumpage prices in the USW.

Annual average bank prime rates for 1959 to 2009 were obtained from Economagic (2010). The national data are used for both the USE and the USW. National average annual wage rates of production workers in the softwood lumber industry for 1959 to 2005 were collected from the National Bureau of Economic Research's (2009) ''Manufacturing Industry Database'' (Standard Industrial Classification 2421). Data for 2006 to 2008 were obtained from the ''Annual Survey of Manufacturers'' (US Bureau of the Census 2010; North American Industry Classification System 3211). Production worker wages during a year were divided by the number of production worker hours to estimate hourly wages. The missing value for 2009 was extrapolated using the spline method (SAS Institute Inc. 1999).

Results

The SUR estimation results are presented in Table 3. The goodness of fit, as indicated by the R^2 values, is sufficiently

Table 3.—Estimation results of seemingly unrelated regression of regional softwood lumber supply, 1959 to 2009.[a]

Variable	Coefficient ± SE	
	USE	USW
Constant	−0.9991 ± 0.7306	1.9342 ± 0.6374***
log(*Price*$_t$)	0.1897 ± 0.0682***	0.2058 ± 0.0436***
Stumpage_Price$_{t-1}$	−0.0008 ± 0.0003***	−0.0005 ± 0.0001***
Interest_Rate$_t$	−0.0063 ± 0.0029**	−0.0084 ± 0.0028***
Wage_Rate$_t$	0.0044 ± 0.0084	−0.0138 ± 0.0085
Quantity_Supplied$_{t-1}$	1.0164 ± 0.0671***	0.7189 ± 0.0684***
Spotted_Owl$_t$	−0.0149 ± 0.0319	−0.0573 ± 0.0339*
Lumber_Dispute_1$_t$	−0.0286 ± 0.0318	0.0332 ± 0.0292
Lumber_Dispute_2$_t$	0.0425 ± 0.0329	0.0989 ± 0.0315***
Lumber_Dispute_3$_t$	0.0208 ± 0.0356	0.1089 ± 0.0390***
Lumber_Dispute_4$_t$	−0.1620 ± 0.0547***	−0.0944 ± 0.0553*
Durbin *h*	1.0397	0.0772
R^2	0.98	0.90

[a] USE = eastern United States; USW = western United States. Stistical significance is indicated at the 10 percent (*), 5 percent (**), and 1 percent (***) level.

high. We tested for the efficiency gain in SUR, compared with OLS, using the Breusch–Pagan test of independence (Breusch and Pagan 1980).[1] The null hypothesis of this test is zero contemporaneous covariance between the errors of the two equations. The test was highly significant, implying the appropriateness of SUR.[2]

The Durbin *h* statistics were calculated instead of Durbin–Watson *d* statistics, because lagged dependent variables are used in the supply equations. The values of Durbin *h* statistics do not suggest the presence of autocorrelation in the supply equations. We also tested for heteroscedasticity and multicollinearity in preliminary analyses. Heteroscedasticity was not found to be a problem based on the White's test. Estimated condition numbers for the two equations were less than 15, implying an absence of harmful effects of multicollinearity (Chatterjee and Price 1991, p. 195).

The price coefficients in the supply equations are statistically significant and have the expected signs. Because both *Price* and *Quantity_Supplied* are used in logarithmic form, the estimated coefficients of *Price* in the two equations, 0.19 for the USE and 0.21 for the USW, are the regional price elasticities of the softwood lumber supply. The estimated price elasticities fall within the range of regional supply elasticities, 0.19 to 0.96, as estimated by Adams and Haynes (1980, 1996) using the TAMM model.

Softwood stumpage price has significant negative influence on the supply in both regions (Table 3). At sample means, estimated elasticity of softwood lumber supply with respect to lagged stumpage price is −0.14 for the USE and −0.13 for the USW. These values are within the range of regional lumber supply elasticities with respect to stumpage price, −0.05 to −0.28, provided by Adams and Haynes (1980). Bank prime loan rate was found to have a significant negative effect on softwood lumber production in both regions. The coefficient of wage rate is not statistically significant for either region. These results may be related to the fact that labor costs are a small portion of lumber production costs. The lagged supply variable is significant and has the hypothesized positive sign in both equations.

Results suggest that listing of the northern spotted owl as a threatened species in 1990 had a significant negative influence on the USW softwood lumber supply during subsequent years (Table 3). Although the coefficient of *Spotted_Owl* is negative for USE, it is not significant. This is probably because northern spotted owls primarily inhabit in the USW. The coefficients of the dummy variables on the US–Canada softwood lumber trade dispute/agreements are consistent in their signs across the two regions. *Lumber_Dispute_1* is not significant for either region. *Lumber_Dispute_2* and *Lumber_Dispute_3* have the expected positive influence on regional lumber supply in the United States. However, these effects are statistically significant only for the USW, which implies that the direct competition between lumber from the USW and Canada is more intense than that between the USE and Canada. The coefficient of *Lumber_Dispute_4* is negative and significant for both regions. As noted earlier, these negative signs can be explained by the fact that the negative influence of the economic recession that started in 2007 has more than offset the positive effects of the 2006 SLA.

[1] This test should not be confused with the widely used Breusch–Pagan test for heteroscedasticity.

[2] Two separate models for the USE and the USW were also estimated using OLS. The OLS price elasticities of supply were slightly higher than the SUR estimates. Other statistically significant slope coefficients estimated using OLS were similar in magnitude and sign to the ones estimated using SUR.

Discussion and Conclusions

The main contribution of this article to the forest economics literature is to provide updated empirical estimates of regional softwood lumber supply coefficients in the United States. Using a profit maximization framework and SUR with time series data from 1959 to 2009, supply functions for the USW and the USE are estimated. A statistically significant relationship between softwood lumber supply and its price is found in both study regions. Supply is quite inelastic in both regions. This means that an increase in price causes a smaller percentage increase in supply. Note that the estimated elasticities should be interpreted as short-run elasticities, because lagged dependent variables are present in the supply equations (Polyakov et al. 2004). Supply is often inelastic in the short term, when it is difficult for firms to increase their capacity.

Stumpage prices and interest rates have a significant negative influence on the supply of softwood lumber in both regions. Sensitivity of softwood lumber supply to changes in lagged stumpage price is very low. No significant impact of wage rate is revealed by the models used in this study, indicating the less labor intensive nature of sawmills. Lagged production levels strongly affect softwood lumber supply, indicating that present market supplies of softwood lumber have potential expansionary influence on future supplies.

Another contribution of this article lies in its relation to significant economic and policy matters. The listing of the northern spotted owl as a threatened species reduced the lumber supply in the USW during subsequent years. The SLA between the United States and Canada in 1996 and the countervailing and antidumping duties on imports from Canada imposed in 2002 have significantly favored softwood lumber production in the USW. These results may shed some light on the political economy related to the ESA and other environmental regulations as well as the US–Canada softwood lumber trade dispute. While southern forest landowners and lumber producers do not like to be restricted by the ESA and other environmental regulations, they might have benefited from the listing of the northern spotted owl as a threatened species. US lumber producers have similarly fought hard to restrict Canadian lumber imports to the United States. Producers in the USW have been successful in capturing the gains from these restrictions because of their more direct competition with Canadian producers. Finally, even with the 2006 SLA favoring domestic production, regional softwood lumber supply in the United States dropped during the recent years of economic recession. This means that the demand side, affected by the housing market and the US economy, can sometimes overwhelm the supply side.

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