An Econometric Study of the Hardwood Sawtimber Stumpage Market in Louisiana

Rajan Parajuli
Daowei Zhang

Abstract

Although the hardwood timber market is an important segment of the forest industry in the United States, little attention has been paid to modeling hardwood stumpage and lumber markets. Based on the annual data series from 1955 to 2014, we estimate simultaneous demand and supply models of the hardwood sawtimber stumpage market in Louisiana. A permanent structural break in 1993 is detected in the hardwood sawtimber stumpage market, and the modified cointegration test and structural vector error correction approach are used to estimate the demand for and supply of hardwood sawtimber stumpage. The results show that own-price elasticity values in both the demand and the supply equations are inelastic in the long run. Hardwood and softwood sawtimber are found to be substitutes. Moreover, the softwood timber market always leads in the feedback adjustment process and can help predict the hardwood timber price in Louisiana.

Mixed hardwood forests account for more than half of the commercial timberland area in the US South. In 2012, hardwood growing stock made up about 58 percent of total timber volume in the US South (Oswalt et al. 2014). While softwood is used primarily in structural residential construction, a variety of end products are usually manufactured from hardwood sawtimber, ranging from high-grade lumber, furniture, and flooring to ungraded pallets (Luppold and Bumgardner 2006).

Fundamental differences exist between softwood and hardwood stumpage markets in terms of their market structure, drivers, and end-use product markets. Unlike softwood stands, which are often even aged and planted, hardwoods can be even- or uneven-aged, mixed-species natural stands. On the demand side, the softwood timber market is relatively homogeneous, which is driven primarily by US housing starts, whereas the hardwood market is rather disaggregated by timber species due to a greater variation in species composition and quality grades. For example, oaks and maples are sold as several individual species types, such as red oak, white oak, hard maple, and soft maple, and their end uses and market prices vary widely (Hardwood Market Report 2016). In terms of hardwood lumber consumption, the furniture industry used to be a dominant lumber consumer in the 1970s, but in recent years, the pallet, kitchen cabinet, and hardwood flooring industry groups, followed by the export market, are major users of hardwood lumber in the United States (Luppold and Bumgardner 2006). Since the 2000s, the export market has been a major determinant of the US hardwood market, as the United States has been the top exporter of hardwood lumber in the world (Luppold and Bumgardner 2015). Hence, both the demand and the supply factors of the hardwood market might behave differently from the softwood timber market.

The purpose of this article is to estimate demand and supply factors of hardwood sawtimber stumpage and to evaluate the impacts of past market and policy events in the hardwood stumpage market. In addition, we investigate the relationship between hardwood and softwood sawtimber markets in Louisiana. We chose to study the hardwood timber market of Louisiana primarily because of the availability of long time-series data, because the Louisiana Department of Agriculture and Forestry (LDAF) reports the continuous data series on timber harvests as well as prices of several forest products that can be traced back to the 1950s (LDAF 2016). None of the other states or timber harvest regions have compiled timber harvest and price data for such a long period of time. Moreover, Louisiana is one of the important timber-producing states in the US South and may be considered a representative timber

The authors are, respectively, Forest Economist, Texas A&M Forest Serv., College Station (rparajuli@tfs.tamu.edu [corresponding author]; and Professor, Auburn Univ., Auburn, Alabama (zhangd1@auburn.edu). This paper was received for publication in May 2016. Article no. 16-00021.

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market in the south-central region. The mixed hardwood species type, particularly oak-gum-cypress, occupies more than 50 percent of the forestland in Louisiana. Based on the annual data from 1955 to 2014, we estimate the simultaneous demand and supply equations using the framework of a vector error correction (VEC) model. Our results show that hardwood sawtimber demand and supply are inelastic and that several market and policy factors significantly affect the hardwood stumpage market in Louisiana.

Compared with the commercially widespread softwoods, very little attention has been paid to modeling the hardwood stumpage and lumber markets. Parajuli and Chang (2015) tabulated previous research studies that have focused mostly on softwood stumpage markets in the United States. These previous studies in the softwood market estimated a wide range of demand and supply coefficients of softwood stumpage and lumber markets, varying with modeling frameworks, geographic coverage, time span, econometric methods, and tree species. Only a few studies have estimated the hardwood stumpage and lumber markets. Lange (1983) developed econometric models to study hardwood lumber and stumpage markets in the eastern United States. Luppold (1984) and Cardellichio and Binkley (1984) conducted econometric studies of the US hardwood lumber market by end-use sectors. Adams and Haynes (1996) reported regional demand and supply elasticity values of hardwood lumber, but they estimated only regional hardwood stumpage supply. Moreover, based on data from 1981 to 1996, Nagubadi and Munn (1998) studied the demand and supply of the hardwood stumpage market in the south-central United States and reported statistically insignificant price elasticity values in the mixed hardwood stumpage market. On a different aspect of hardwood stumpage and lumber markets, Nagubadi et al. (2001) and Luppold and Prestemon (2003) evaluated the market integration for hardwood sawtimber and pulpwood in the south-central United States and hardwood lumber in the Appalachian hardwood region, respectively.

Theoretical Framework

In this article, we follow the theoretical framework devised by previous studies in the stumpage market. Most of the past studies used the firm's profit maximization approach under a perfect competitive market condition to derive demand and supply models of sawtimber and pulpwood stumpage (Newman 1987, Polyakov et al. 2005, Parajuli and Chang 2015). The statewide derived demand for sawtimber stumpage is considered a function of the price of the final good produced from sawtimber and the prices of inputs in the production stage. Moreover, in order to study the relationship between the hardwood and softwood markets, we include the price of softwood sawtimber in the demand equation. On the other hand, the supply model is specified as a function of the price of stumpage, the total volume of hardwood growing stock, and the hardwood pulpwood price as the price of a substitute (Newman 1987). In mathematical form, the aggregate demand and supply models are formulated as

$$qh_t^D = f(phs_t, pss_t, fs_t, r_t) \qquad (1)$$

$$qh_t^S = f(phs_t, hi_t, php_t) \qquad (2)$$

where qh_t^D and qh_t^S are the quantity of hardwood sawtimber demanded and supplied, respectively, in the year t and phs_t is the price of hardwood sawtimber stumpage. In the demand equation, pss_t is the price of softwood sawtimber; fs_t is the price of hardwood lumber, a major final product of sawtimber; and r_t is the interest rate as a proxy of the price of capital. In the supply equation, hi_t is the total hardwood sawtimber inventory, and php_t is the price of hardwood pulpwood, a substitute product of hardwood sawtimber. The market-clearing equilibrium condition suggests that the quantity of sawtimber demanded should be equal to quantity supplied:

$$qh_t^D = qh_t^S = qh_t \qquad (3)$$

In terms of the expected effects of the variables in demand and supply models, the own stumpage price of hardwood sawtimber (phs_t) is expected to be negative in the demand equation and positive in the supply equation. The sign of pss_t in the demand equation is uncertain, as it depends on whether the hardwood and softwood sawtimber are substitutes or complements. The signs of fs_t and hi_t are expected to be positive, whereas the effects of r_t and php_t are uncertain (Parajuli and Chang 2015).

Estimation Method

The early studies in the stumpage and forest products markets used primarily simultaneous equation modeling approaches particularly two-stage least square (2SLS) and three-stage least square (3SLS) methods to estimate the demand and supply equations (Adams and Blackwell 1973, Adams and Haynes 1980, Newman 1987). Using 2SLS and 3SLS methods on time-series data might not be econometrically sound, as these methods do not address the nonstationary properties of time-series data properly. In order to account for the time-series properties of forest products market data, recent studies (Parajuli and Chang 2015, Parajuli et al. 2016, Parajuli and Zhang 2016) used cointegration tests and the multivariate VEC estimation method in forest sector modeling. Because this study also uses 60-year annual time-series data to estimate Equations 1 and 2, we use the Johansen cointegration test and structural VEC model to estimate the simultaneous demand and supply models of hardwood sawtimber in Louisiana.

As long time-series data usually possess several trends and level breaks owing to certain policy and market events, any undetected structural break in time series might result in underrejecting of unit-root tests (Perron 1989), and the conventional Johansen cointegration tests (Johansen 1988, 1995) should be modified to allow for trend and/or level breaks at known points (Johansen et al. 2000). By setting up the year of 1993 as a structural break in the stumpage market, Parajuli and Chang (2015) estimated a system of demand and supply equation of the softwood sawtimber market in Louisiana. In this study, we also consider a structural break in the hardwood stumpage market and estimate the system of demand and supply equations using the modified cointegration approach of Johansen et al. (2000).

The seven-variable system of equations with a structural break can be presented in the p-dimensional unrestricted VEC as (Johansen et al. 2000, Joyeux 2007)

$$\Delta X_t = \alpha \begin{pmatrix} \beta \\ \gamma \end{pmatrix}' \begin{pmatrix} X_{t-1} \\ tD_{t-k} \end{pmatrix} + \mu D_{t-k} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \sum_{i=0}^{k-1} \sum_{j=2}^{q} kj, iI_{j,t-i} + \varepsilon_t \quad (4)$$

where

$$D_t = (1, D_{2,t})'$$

$$D_{2,t} = \begin{cases} 1, \text{for } T^* + 1 \le t \le 2014 \\ 0, \text{otherwise} \end{cases}$$

$$I_{2,t} = \begin{cases} 1, \text{for } t = T^* + 1 \\ 0, \text{otherwise} \end{cases}$$

where Δ is the first difference notation, T^* is the structural break year, $\Gamma_i = -\Sigma_{j=i+1}^{k} \Pi_j$ is a coefficient matrix with a dimension of $p \times q$, μ refers to $p \times 1$ vector of constant terms, D_t represents $p \times q$ deterministic dummy terms, k is the lag length, and ε_t is a vector of IID errors (0, Ω). Also, α refers to the adjustment parameters, which determine the speed of adjustment to disequilibrium; β is the matrix of long-run coefficients; and γ is the long-run estimate associated with the trend break term, tD_{t-k}. The term X_t is the (7×1) vector of variables that enter to both demand and supply equations:

$$X_t = [qh_t, phs_t, pss_t, fs_t, r_t, hi_t, php_t]' \quad t = 1955, 1956, \ldots, 2014 \quad (5)$$

Besides the deterministic variables, we include several dummy variables in Equation 5 to control for the transitory policy and market events that influenced the stumpage market in Louisiana. A *recs*70 dummy variable captures the effects of the 1970s oil shocks and financial crisis, and a *post_recs* dummy represents the recent period for significant changes in industrial product consumption. A dummy variable associated with the great financial crisis of 2008 was included in the initial model, but it was found statistically insignificant in both demand and supply models. Hence, it was dropped from the final model.

As for the point of a structural break in the stumpage market in Louisiana, we follow Parajuli and Chang (2015) and select the year 1993. As seen in Figure 1, the hardwood sawtimber price in Louisiana, right after 1992, has also a distinct break with a sharp upward trend. Besides the federal policy of harvest reductions in the US Pacific Northwest region, the booming export market of hardwood lumber also supports the argument of a structural break in the early 1990s (Luppold and Bumgardner 2006). In addition, substantial changes in the use of hardwood timber occurred in the early 1990s. Figure 2 presents the historical trend of the production of hardwood products from hardwood timber. Until 1990, lumber was the primary output of hardwood timber, but since 1991, pulpwood-based industries have been using more hardwood timber than the hardwood sawmills (Howard and Westby 2013). Hence, we also consider the year 1993 as a permanent structural break in the hardwood sawtimber market while estimating the demand for and supply of hardwood stumpage in Louisiana.

A crucial requirement of the VEC estimation procedure is that all variables should be nonstationary at the level and stationary at the first difference of the data, suggesting an integration of order 1, I(1). A number of statistical tests are available to examine the stationary (unit-root) properties of the time-series data. The Dicky-Fuller generalized least square (DF-GLS) test (Elliott et al. 1996), a more powerful test, is applied to test the stationarity of the individual data series. In addition, the Zivot-Andrews unit-root test (Zivot and Andrews 1992), which corrects the issue of an unknown structural break, is also applied to validate the results of the DF-GLS test as well as to assess the effects of a possible structural break in the unit-root test results. The Zivot-Andrews test allows one endogenous structural break test in trend and/or intercept while performing the unit-root test.

Once the order of integration of each variable is identified, the modified cointegration test is applied to find the number of long-run cointegrating vectors (n) in a system of variables. We take the intercept and linear trend H_l(r) model specification (eq. 3 of Johansen et al. 2000) into account while executing the cointegration test. Johansen et al. (2000) and Joyeux (2007) described the detailed procedure of the cointegration test and VEC estimation in the presence of structural breaks. Giles (2011) provided a simple example to describe the methodological procedure of executing the Johansen et al. (2000) test. We use the built-in program of JMulTi software, which reports the cointegration test statistics and critical values of the modified cointegration test.

In order to estimate two demand and supply models from the X_t vector, the cointegration test should suggest at least two long-run cointegrating vectors (n). Certain normalization restrictions have to be imposed on long-run parameters so that the parameters of cointegrating matrices provide plausible economic interpretations (Johansen and Juselius 1994). If there are n cointegrating equations, at least n^2 restrictions are required to identify the free parameters in the β matrix (Johansen 1995). We impose normalization restrictions on two long-run cointegrating vectors in order to identify the demand and supply equations as specified in Equations 1 and 2. The β matrix is modified with the restrictions as

$$\begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix}' = \begin{bmatrix} 1 & \beta_{21} & \beta_{31} & \beta_{41} & \beta_{51} & 0 & 0 & \beta_{81} \\ \beta_{21} & 1 & 0 & 0 & 0 & \beta_{62} & \beta_{72} & \beta_{82} \end{bmatrix} \quad (6)$$

where β_1 is the demand equation and β_2 is the price (inverse supply) equation (Toppinen 1998, Parajuli and Chang 2015). The inverse supply equation should be transformed in order to derive the supply determinants in the $\beta 2$ vector. We exclude hi_t and php_t from the β_1 vector and pss_t, fs_t, and r_t from β_2. In addition to the seven variables in the X_t vector, we add a trend break term (tD_{t-k}) in both demand and supply equations. The VEC (Eq. 6) with a normalized β matrix is estimated using the maximum likelihood estimation approach.

In addition to the regression relationship between hardwood and softwood sawtimber markets in demand (Eq. 1), we also execute the cointegration test between

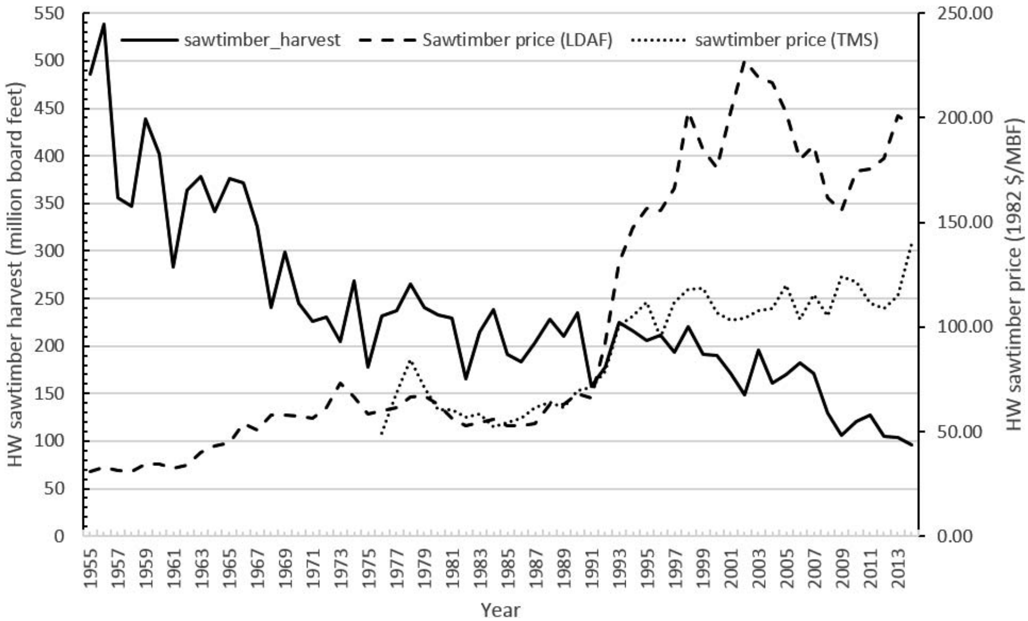

Figure 1.—Hardwood sawtimber stumpage market in Louisiana.

hardwood and softwood sawtimber prices in order to assess the long-run relationship between the two markets. If two price series are cointegrated or a linear combination of two price series is integrated of order zero, it implies that there exists a long-run equilibrium relationship between two markets. In other words, even if both price series follow a random walk, they are affected primarily by similar market forces and policy events.

Data

We obtained annual data from 1955 to 2014 on the annual quantity of hardwood sawtimber harvested (qh_t), hardwood and softwood sawtimber prices (phs_t and pss_t), and hardwood pulpwood price (php_t) from LDAF. Other data sources and their descriptions are presented in Table 1. The data series on Moody's seasoned Baa corporate bond yield as a proxy of the cost of capital is obtained from the US

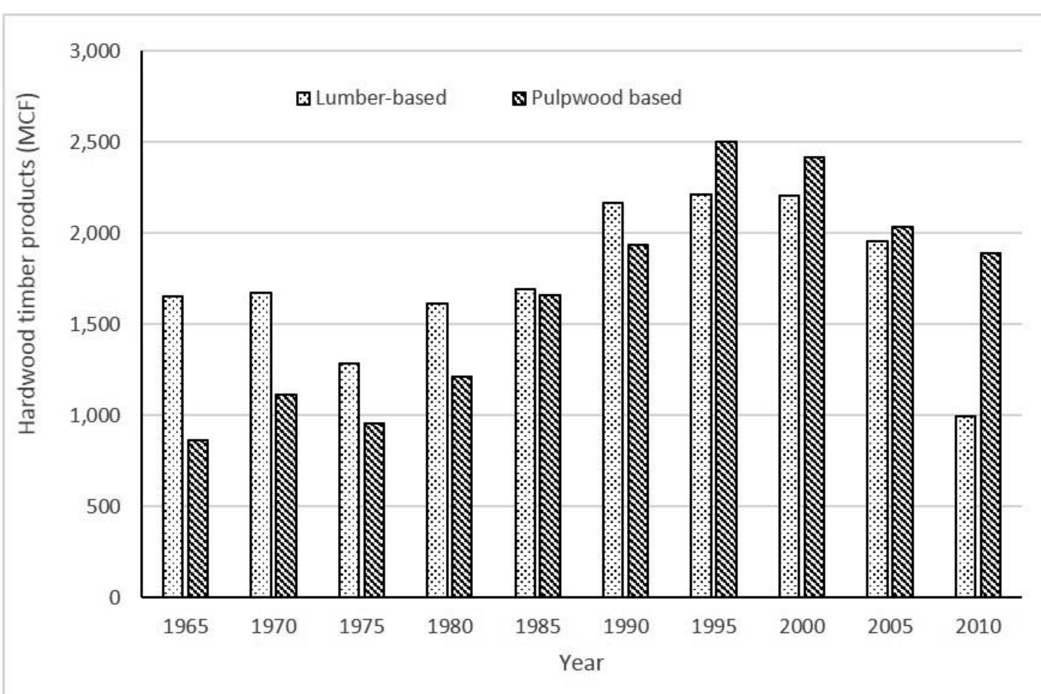

Figure 2.—Production of hardwood timber products (million cubic feet, roundwood equivalent) in the United States (data source: Howard and Westby 2013, table 7a).

Table 1.—Variables and their descriptions and sources.[a]

Variable	Description	Unit	Source
qh_t	Quantity of mixed hardwood sawtimber harvested	MBF	LDAF forestry reports
phs_t	Mixed hardwood sawtimber price	\$/MBF	LDAF forestry reports
pss_t	Softwood sawtimber stumpage price	\$/MBF	LDAF forestry reports
php_t	Mixed hardwood pulpwood price	\$/cord	LDAF forestry reports
fs_t	PPI for hardwood lumber	Index (1982 = 100)	US Bureau of Labor Statistics
hi_t	Net volume of hardwood growing stock	MCF	"Forest Resources of the United States" (various issues)
r_t	Moody's seasoned Baa corporate bond yield	%	US Federal Reserve Bank of St. Louis
*recs*70	Economic recession of 1970s	0 or 1	1 for 1970–1976, 0 otherwise
*d*93	Pacific Northwest federal timber harvest reductions	0 or 1	1 if year > 1993, 0 otherwise
post_recs	Postrecession period	0 or 1	1 if year > 2009, 0 otherwise

[a] MBF = thousand board feet; LDAF = Louisiana Department of Agriculture and Forestry; PPI = producer price index; MCF = million cubic feet.

Federal Reserve Bank of St. Louis. The producer price index for hardwood lumber is used as the lumber price, which is obtained from the US Bureau of Labor Statistics. All prices are deflated to the base year of 1982 using the Bureau of Labor Statistics producer price index for all commodities. Because the inventory data are available for approximately a 10-year interval only, we also use a modified growth drain equation (Parajuli and Chang 2015) to generate annual hardwood growing stock in Louisiana.[1] We obtain hardwood growing stock, annual harvest, and growth rate at inventory years from the various issues of "Forest Resources of the United States" (Waddell et al. 1989; Smith et al. 2001 2004, 2009; Oswalt et al. 2014). Several dummy variables are constructed corresponding with market and policy events to evaluate the effects of these events on demand for and supply of hardwood stumpage in Louisiana (Table 1).

On the other hand, Timber Mart-South (TMS), based on the reports of actual market operations from companies and individuals, also reports quarterly price series of each forest product in southern states since the fourth quarter of 1976 (TMS 2016). We obtained the price series of phs_t from TMS,[2] which can be traced back to only the fourth quarter of 1976. Comparisons of the phs_t data series from two sources show significant disparities and increasingly substantial difference specifically after the early 1990s (Fig. 1). The real phs_t series reported by LDAF appears to be dubious, as it was \$66 per thousand board feet (MBF) in 1991 but was \$157/MBF after 4 years in 1995 and kept rising with a pick of \$228/MBF in 2002. At the same time, the price series reported by TMS was around \$100/MBF. Given this difference in the hardwood sawtimber price data in Louisiana, we replace the LDAF price series by the TMS price data from 1976 on and compile a combined price series for phs_t from both LDAF (1955 to 1975) and TMS (1976 to 2014).

[1] Like Parajuli and Chang (2015), we use different common factors [0,1] to adjust the growth drain equation such that estimated value equals to actual value in the inventory years. The common factor is different for different periods of intervening years. The generated data series of hardwood inventory in Louisiana is available upon request.

[2] We checked the price data difference for pss_t and php_t too, but these two data series from LDAF and TMS are nearly identical.

Table 2 presents the overall summary statistics of the data. The mean quantity of hardwood sawtimber harvest is 236 million board feet (1,000 board feet = 2.36 m^3) with a range of 0.96 million board feet in 2014 to 538 million board feet in 1956. The annual quantity of hardwood sawtimber harvest in Louisiana has substantially declined over the years (Fig. 1). The real price of hardwood sawtimber compiled with the data from LDAF and TMS varies widely from \$31/MBF in 1955 to all-time high of \$140/MBF in 2014. The phs_t price series increased substantially right after 1992, substantiating our intuition of a structural break in the stumpage market in Louisiana. Moreover, compared with the hardwood sawtimber price, the mean softwood sawtimber price is more than double, ranging from \$85 to \$327/MBF.

Results

Table 3 presents the results of DF-GLS and Zivot-Andrews unit-root tests of each variable. All data series but dummy variables representing market and policy events are log transformed. The DF-GLS unit-root test shows that all variables except log-transformed hardwood inventory in Louisiana are nonstationary at the level of the variables. When the unit-root data series are first differenced, all variables turn out to be stationary, suggesting an order of I(1). The Zivot-Andrews test corroborates the findings of the DF-GLS test, revealing that an arbitrary break in trend and intercept does not affect the unit-root properties of any data series in the system. Even though both tests indicate that the hardwood inventory data series is I(0), we include all seven variables in the further analysis, as Johansen (1995) and Toppinen (1998) stated that some stationary variables in the system of I(1) can be incorporated for the cointegration analysis.

Table 4 presents the results of Johansen cointegration tests of the variables and the corresponding critical values at the 5 percent level of significance. Two-lag vector autoregression specification is selected based on Akaike information criteria. The modified cointegration test shows that, with a permanent structural break in 1993, all the variables in the X_t system are cointegrated. The test identifies the two distinct long-run cointegrating vectors in the system, which represent the demand and supply equations of the hardwood sawtimber market. We also execute the Johansen trace and maximum eigenvalue tests in order to compare the results with the modified cointegration

Table 2.—Summary of data used in empirical estimation (before being log transformed): 1955 to 2014.

Variable[a]	No. of observations	Mean	SD	Minimum	Maximum
qh_t	60	236,347.00	94,249.26	95,902.33	538,340.30
phs_t	60	75.32	30.69	31.02	139.91
pss_t	60	168.73	66.14	85.47	326.98
php_t	59	7.26	3.22	4.20	30.32
fs_t	60	113.70	63.49	32.63	241.91
hi_t	60	8,258.19	1,149.74	6,282.00	10,093.00
r_t	60	8.04	2.90	3.53	16.11
*recs*70	60	0.12	0.32	0.00	1.00
*d*93	60	0.37	0.48	0.00	1.00
post_recs	60	0.08	0.28	0.00	1.00

[a] For definitions of the variables, see Table 1.

test. Both tests corroborate the results of the modified cointegration test.

By specifying the two long-run cointegrating ranks in the system, we estimate Equation 4 with the normalized β matrix as in Equation 6. Table 5 presents the long-run coefficients and short-run estimates of dummy variables obtained from the maximum likelihood estimation of the VEC model. The structural break term ($td93_{t-2}$) in the demand equation is found to be statistically significant. The restrictions on the β vector identify both demand and supply equations in the cointegrating vectors. The likelihood ratio test of overidentifying restrictions does not reject the null hypothesis that the overidentifying restrictions on the β vector are valid. The two-lag VEC process clearly corrects the autocorrelation issue, as the Lagrange multiplier test cannot reject the null hypothesis of no autocorrelation. From the estimated vectors, we obtain the elasticity values by transforming the coefficient estimates into the demand and supply coefficients. For example, the elasticity value of hardwood inventory (hi_t) in the supply equation is –6.5/2.36 = –2.75.

Long-run demand and supply models

In the long-run cointegrating demand equation, all the coefficient estimates but the interest rate are found to be statistically significant at the 5 percent level. As expected, own-price elasticity in the demand equation is negative. A 1 percent increase in the price of hardwood sawtimber leads to decrease the hardwood sawtimber demand by 0.85 percent. Further, the softwood sawtimber price is found to have a positive and statistically significant relationship with the sawtimber demand, suggesting that hardwood and softwood sawtimber are substitutes. Contrary to the expectation, the price of hardwood lumber as a proxy of a final good price is found to be negative. The coefficient estimate associated with the interest rate is statistically insignificant. In addition, the structural break term is also found to be not significant in the supply equation.

We obtain the supply model by transforming the estimated inverse supply (price) equation. In the supply equation, the own price is statistically significant and inelastic with a positive value of 0.73. The hardwood inventory is found to have a statistically significant negative elasticity value, which is counterintuitive and not expected. Furthermore, the relationship between the hardwood sawtimber supply and the hardwood pulpwood price is not significant statistically.

Short-run hardwood sawtimber market dynamics

Besides long-run cointegrating estimates, the VEC estimation simultaneously reports estimates of short-run dynamics, coefficient estimates of dummy variables, and speed of adjustments (*ECM*). Table 5 also presents the short-run estimates associated with the dummy variables representing the market and policy events and the adjustment parameters. The market event representing the 1970s economic downturn has significant negative effects

Table 3.—The results of the unit-root tests of individual time series (1955 to 2014).[a]

	DF-GLS test				Zivot-Andrew test[b]			
	Levels		First differenced		Levels		First differenced	
Variable	Lags	DF-GLS	Lags	DF-GLS	Lags	Zandrews	Lags	Zandrews
lqh_t	1	−2.40	1	−7.03*	2	−3.43	1	−9.49*
$lphs_t$	1	−2.53	1	−5.63*	1	−3.81	0	−7.24*
$lpss_t$	1	−1.69	1	−4.53*	1	−3.49	0	−6.47*
$lphp_t$	1	−1.39	1	−4.73*	1	−4.63	2	−7.30*
lfs_t	2	−1.23	1	−6.78*	2	−3.58	1	−8.68*
lhi_t	1	−4.18*			1	−5.62*		
lr_t	1	−0.90	1	−4.89*	2	−3.30	1	−6.54*

[a] Lag lengths were selected based on the Akaike information criterion. * $P < 0.01$. DF-GLS = Dicky-Fuller generalized least square. For definitions of the variables, see the text.

[b] Zivot-Andrews unit-root test allowing for one structural break in both trend and intercept. Critical value at 5 percent is –5.08.

Table 4.—Johansen cointegration rank tests (optimum lags = 2).[a]

Hypothesis		Johansen et al. (2000) test		Johansen cointegration tests (Johansen 1988)			
H0	H1	Likelihood ratio Statistics	5% critical value	Trace statistics	5% critical value	Maximum statistics	5% critical value
$n = 0$	$n > 0$	225.23*	183.13	167.22*	124.24	61.44*	45.28
$n = 1$	$n > 1$	164.30*	146.15	105.78*	94.15	40.89*	39.37
$n = 2$	$n > 2$	110.86	113.02	64.89	68.52	26.22	33.46
$n = 3$	$n > 3$	79.65	83.80	38.66	47.21	20.07	27.07
$n = 4$	$n > 4$	53.87	58.51	18.59	29.68	16.03	20.97
$n = 5$	$n > 5$	29.62	36.39	2.55	15.41	2.12	14.07
$n = 6$	$n > 6$	12.27	18.70	0.44	3.76	0.44	3.76

[a] * $P < 0.01$.

on both hardwood sawtimber harvest and price in Louisiana. During the period from 1970 to 1976, the sawtimber harvest and price were reduced by almost 10 and 8 percent, respectively. Similarly, the dummy variable (d_{93}) has positive influences in the hardwood sawtimber market in Louisiana because it leads to increase in the sawtimber price by around 13 percent. On the other hand, in the period right after the global financial crisis of 2008, the sawtimber harvest in Louisiana dropped by almost 15 percent, but its effect in the sawtimber price is found to be statistically insignificant. Comparing this result with that of the market event in the 1970s, we think that lack of quality hardwood after 2008 may be a reason that sawtimber price does not fall drastically.

In terms of the short-term reactions of both harvest quantity and price toward the long-run disequilibrium in the hardwood market, both harvest quantity and price are highly responsive and adjust any disequilibrium caused by temporary market and policy shocks in the hardwood sawtimber market. In the sawtimber quantity equation, the significant error correction terms of –0.87 and 0.07 suggest that up to 87 percent of the long-run disequilibrium in corrected in each year. In other words, 87 percent of the past year's deviation from long-run equilibrium is corrected, which means it takes around 1.15 (1/0.87) years to adjust any disequilibrium in the long-run market equilibrium. Similarly, up to 48 percent of the deviation due to short-term shocks is corrected each year in the sawtimber price model.

Table 5.—Long-run and short-run coefficient estimates of the vector error correction model (optimum lags = 2).[a]

Variable	Sawtimber demand[b] Coefficient	Sawtimber demand[b] Elasticity	Sawtimber supply[c] Coefficient	Sawtimber supply[c] Elasticity
	Long-run coefficients			
lqh_t	1		−1.37** (0.37)	
$lphs_t$	0.85** (0.16)	−0.85	1	0.73
$lpss_t$	−0.46** (0.12)	0.46		
lfs_t	0.25** (0.06)	−0.25		
lr_t	0.02 (0.08)	−0.02		
lhi_t			−5.00** (0.81)	−3.65
$lphp_t$			−0.31 (0.37)	−0.23
$td93_{t-2}$	−0.002 (0.002)	0.002	−0.02** (0.005)	−0.01
Constant	−14.67	14.67	58.32	42.57
	Short-run coefficients			
$recs70$	−0.10* (0.06)		−0.08* (0.04)	
$d93$	0.08 (0.07)		0.13** (0.05)	
$post\_recs$	−0.15** (0.07)		0.09 (0.06)	
$ECM1_{t-1}$	−0.87** (0.16)		−0.48** (0.12)	
$ECM2_{t-1}$	0.07 (0.07)		−0.16** (0.06)	
R^2	0.60		0.42	

[a] * $P < 0.1$, ** $P < 0.05$. Prefix of l in each variable indicates that the variables are log transformed. Standard errors are presented in parentheses. Likelihood ratio test of overidentifying restrictions: $\chi^2 = 13.05$, $P \geq \chi^2 = 0.22$. Lagrange multiplier test for no autocorrelation at lag 4: $\chi^2 = 49.80$, $P \geq \chi^2 = 0.90$.

[b] Normalized to quantity. $\beta_{11} = 1$; $\beta_{61} = \beta_{71} = 0$.

[c] Normalized to price (i.e., inverse supply). $\beta_{22} = 1$; $\beta_{32} = \beta_{42} = \beta_{52} = 0$.

Cointegration between hardwood and softwood sawtimber prices

Since the unit-root tests in Table 3 depict that both $lphs_t$ and $lpss_t$ price series are I(1), we execute the cointegration tests in a bivariate vector autoregression (VAR) framework to examine whether the hardwood and softwood sawtimber markets have a long cointegrating relation in Louisiana. Table 6 presents the results of both traditional and modified cointegration tests between two price series. Four-lag VAR specification is selected based on the Akaike information criteria. The modified cointegration test with a structural break in 1993 rejects the null hypothesis of no cointegration between two price series at the 5 percent level of significance. The trace and maximum eigenvalue cointegration tests also support the findings of one long-run cointegrating relation. Although hardwood and softwood markets have distinct end uses and products, the long-run cointegration implies that both markets in Louisiana are driven by similar market forces and policy events.

Because we find a cointegration relationship between two prices, we estimate a bivariate VEC model with a structural break that yields the magnitude of the long-run relationship (similar to the β vector in Eq. 4). It reveals that, in the long run, a 1 percent increase in the softwood sawtimber price leads to 1.16 percent increase in the hardwood sawtimber price in Louisiana. Panel C in Table 6 reports estimated feedback adjustment coefficients (α_s), which explain the adjustment process of both prices toward the long-run equilibrium. The adjustment parameters in both hardwood and softwood sawtimber price are found to be statistically significant, indicating that the disequilibrium created by short-term market shocks and news is corrected in both markets. Given the higher magnitude of the feedback adjustment coefficients, the hardwood sawtimber price follows the price movements originating in the softwood sawtimber price. Likewise, Granger causality tests on short-

Table 6.—Cointegration tests of a bivariate vector error correction (VEC) model ($lphs_t$ and $lpss_t$: optimum lags = 4).[a]

		Panel A. Cointegration tests					
		Johansen et al. (2000) test		Johansen (1988) cointegration tests			
H0	H1	Likelihood ratio statistics	5% critical value	Trace statistic	5% critical value	Maximum eigenvalue statistic	5% critical value
$n = 0$	$n > 0$	71.46	58.51	19.45	15.41	18.67	14.07
$n = 1$	$n > 1$	28.99	36.93	0.78	3.76	0.78	3.76

Panel B. Unconstrained long-run cointegration relationship

Variable	Value
$lphs_t$	1
$lpss_t$	1.16* (0.34)
$td93_{t-4}$	0.02* (0.01)
Constant	−9.42

Panel C. Short-run feedback adjustment coefficients

Variable	Value
α_{lphs}	−0.13* (0.03)
α_{lpss}	−0.08* (0.04)

Panel D. Granger causality on VEC model short-run parameters

Hypothesis	Value
H0: $lpss_t$ does not granger cause $lphs_t$	14.68* [0.00]
H0: $lphs_t$ does not granger cause $lpss_t$	4.00 [0.26]

[a] * $P < 0.05$. Standard errors are presented in parentheses; P values are presented in brackets in Panel D. Lagrange multiplier test for no autocorrelation at lag 4: $\chi^2 = 3.57$, $P \geq \chi^2 = 0.94$.

run parameters reveal that the softwood sawtimber price Granger causes the hardwood price, indicating that lagged values of the softwood price help in predicting the hardwood price series. However, the null hypothesis that the hardwood price does not Granger cause the softwood price cannot be rejected at the 5 percent level, suggesting that the hardwood price has no influence on forecasting the softwood sawtimber price in Louisiana.

Discussion

We find that the long-run own-price elasticity values in the demand and supply models of the hardwood sawtimber market are statistically significant with magnitudes of –0.85 and 0.73, respectively. Besides Nagubadi and Munn (1998), who reported statistically insignificant own-price elasticity values of the hardwood stumpage market in the south-central United States, no previous study has reported the hardwood sawtimber demand elasticity values. Adams and Haynes (1996) reported the regional elasticity of 0.41 to 0.48 for private hardwood stumpage supply in the south-central region.

In the competitive market, the final product price of any good is considered to be a major positive demand factor (Newman 1987). Parajuli and Chang (2015) reported a positive impact of the softwood lumber price in the softwood sawtimber demand in Louisiana. We find, however, that the hardwood lumber price is a negative determinant of the hardwood sawtimber demand, which is counterintuitive. It suggests that, in the case of the Louisiana market, the hardwood lumber price is not a major demand driver. If we scrutinize the national consumption trend of hardwood timber products, hardwood lumber was the primary product produced from hardwood timber. Since the early 1990s, however, the pulpwood-based industries have been using the major portion of the hardwood timber in the United States. For example, in 2011, of the 3.3 billion ft^3 of hardwood timber consumed in the United States, only 30 percent was consumed in the form of hardwood lumber, whereas almost 60 percent of the timber was used to produce pulpwood-based products (Howard and Westby 2013). This is probably why we find an unexpected effect of the hardwood lumber price in the demand equation.

In terms of relationship between hardwood and softwood sawtimber markets, we find that two timber types are substitutes. Basically, softwood and hardwood have different end-use markets (Luppold and Bumgardner 2006). This implies a complementary relationship between the two commodity types. Some degree of substitutability, however, exists between the softwood and hardwood timber in terms of flooring and to some extent furniture. On the other hand, as explained earlier, a major portion of hardwood sawtimber is used by the pulpwood industry, where hardwood and softwood pulpwood are more often substitutes. In addition, we find that softwood and hardwood sawtimber prices in Louisiana are cointegrated, meaning that both markets are driven by similar market forces and policy events in the long run. In terms of the dominance of the market, softwood lumber market always leads in the feedback adjustment process and can help predict the hardwood timber price as revealed by the Granger causality test. Compared with the softwood market (Parajuli and Chang 2015), the hardwood timber market is more responsive and adjusts quicker to the long-run disequilibrium as depicted by the estimated short-run error correction coefficients.

Another notable finding of this study is that the hardwood inventory has a statistically significant but negative effect in the hardwood timber supply. As Newman (1987) stated, the standing timber inventory, as a proxy for harvesting costs, should have a positive impact on the timber supply. Two reasons may explain the unexpected sign of the hardwood sawtimber inventory in the supply equation. First, the annual data on inventory are not actually reported numbers. We generate the annual inventory data by using the growth-drain equation, which might not fully capture the year-to-year inventory fluctuations in Louisiana. This is, however, the only way to obtain an annual series of the inventory data (Newman 1987, Liao and Zhang 2008, Parajuli and Chang 2015). Second, even if timber is available for harvest, all hardwood forest stands in Louisiana are not easily accessible due to waterlogged and swampy terrains. The harvesting, logging, and procurement activities are difficult to operate in wetland and coastal areas. In addition, operable inventory might still be limited given the fact that hardwood species grow slow. For example, 3.3 million acres (almost 40%) of the total hardwood timberland area in Louisiana are in the site productivity class of less than 84 ft^3/acre/yr, and of the total hardwood timberland area, oak-gum-cypress forest types make up nearly 50 percent (US Department of Agriculture Forest Service 2016). On the other hand, from the points of view of recreational, wildlife, and other nontimber benefits, there are increasing concerns of conserving the hardwood timber stands, which might have significantly constrained the supply of hardwood timber.

In terms of the policy effects in the hardwood timber market, the structural change of the early 1990s was explained primarily by the induced effects of federal harvest reductions policy in the Pacific Northwest region in order to protect the habitat of the spotted owl. The effects of this federal policy are well documented by several previous studies on timber and lumber markets (Murray and Wear 1998, Sun and Ning 2014, Parajuli and Chang 2015). This study concurs that since its implementation, this federal policy of harvest reductions has had a substantial impact on the national stumpage as well as forest product markets.

On the other hand, given the limited domestic consumption of hardwood products in the United States, the export market for higher-grade hardwood logs and lumber is a vital driver of the hardwood timber market in the United States (Luppold and Bumgardner 2015). The period of the early 1990s has experienced a boom in the exports market of hardwood products and a rise in lumber consumption for flooring, kitchen cabinets, and millwork, which might be another reason for a permanent structural change in the hardwood timber market. Similarly, right after the great financial crisis of 2008, the export market was strong. In 2013, the United States reclaimed its position as the top exporter of hardwood lumber with 17 percent of the total export market share after falling behind to Malaysia and Thailand in 2009 (Luppold and Bumgardner 2015).

Conclusions

In this article, we examine determinants of demand for and supply of hardwood sawtimber stumpage in Louisiana. Based on annual data from 1955 to 2014, we estimate the VEC model in the presence of a structural break and evaluate the impact of market events and policy dummies in the hardwood market. We identify a structural break created by the Pacific Northwest timber harvest reductions in 1993 and implement the modified cointegration test among a system of demand and supply variables. By imposing normalization restrictions on two long-run cointegrating vectors, we estimate the long-run parameters and short-run dynamics of both demand and supply equations simultaneously.

The results show that both stumpage demand and supply are price inelastic, suggesting that market price does not result in substantial hardwood harvest fluctuations. The hardwood species are usually slow-growing species occurring mostly in natural forest stands; hence, the market price cannot solely determine their harvest schedules. It can also be seen in Figure 1 that while the timber price has been constantly increasing, the annual hardwood harvest in Louisiana has a continuous downward trend beginning in the 1960s. Thus, given that both timber price and hardwood inventory have rising trends, the hardwood timber harvests in Louisiana and other southern states should be encouraged. On the other hand, despite being statistically significant, both hardwood lumber price in the demand equation and hardwood inventory have wrong signs, and their effects are counterintuitive. As depicted by estimated short-run dynamics, the Louisiana hardwood market picked up the effects of the economic downturn in the early 1970s, the structural break backed by the federal harvest reduction policy in the Pacific Northwest region, and the rising export market.

Some of the limitations of this study are worth mentioning. The availability of reliable data in any econometric study is a major downfall. The hardwood sawtimber stumpage price reported by LDAF seems dubious after the early 1990s, and we construct a price series by replacing the LDAF data with the TMS data from 1976. Similarly, we generate annual hardwood inventory data by an interpolation approach; hence, caution regarding the interpretation of an inventory estimate should be taken. Finally, using the annual data frequency makes the estimated short-run dynamics less relevant in the context.

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