INTEGRATION OF HARDWOOD STUMPAGE MARKETS IN THE SOUTHCENTRAL UNITED STATES

VENKATARAO NAGUBADI, IAN A. MUNN AND ALIREZA TAHAI*

ABSTRACT

The law of one price is tested using Johansen's simultaneous multivariate cointegration framework and the question of market integration is examined for hardwood pulpwood, mixed hardwood sawtimber, and oak sawtimber in six states (Alabama, Arkansas, Louisiana, Mississippi, Tennessee, and Texas) using quarterly real stumpage prices from 1977 to 1997. The main finding is that the law of one price is not applicable and markets are not fully integrated for any of these hardwood stumpage commodities. The implication is that the six states in this region can not be treated as single market for these commodities. Hardwood pulpwood markets are less integrated than hardwood sawtimber markets. There is evidence for three separated markets for hardwood pulpwood, and for two separated markets for each of mixed hardwood and oak sawtimber.

Keywords: Cointegration, error-correction, hardwood stumpage, law of one price, Southcentral United States.

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INTRODUCTION

The bulkiness of stumpage commodities makes the nature and extent of geographical markets a very important feature in the forestry sector. Spatially separated markets for any commodity can be considered as one market if the prices of that commodity in each market move together over time, and if the prices differ roughly by transaction costs between the markets. The force of arbitrage keeps these prices moving together.

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Approved for publication as Journal Article No. FO-140 of the Forest & Wildlife Research Center, Mississippi State University, Mississippi State, MS 39762, U.S.A. Research funded by the Southern Forest Resource Assessment Consortium (SOFAC) and the USDA Forest Service, Southern Research Station. The authors wish to thank Donald Grebner, Darren Hudson, and Benjamin Blair, for comments on earlier drafts of the paper. An earlier version was presented at the 6th Ulvön Conference on Forest Economics, at Ulvön, Sweden, June 1999.

JOURNAL OF FOREST ECONOMICS, ISSN 1104–6899. Manuscript received 1999-11-18. Revised manuscript accepted 2000-09-07.

In the timber supply modeling literature, timber markets were often implicitly assumed to be integrated at international, national, or regional levels. For example, Dykstra & Kallio (1987) assumed that timber markets were integrated at international levels in their Global Trade Model (GTM). Adams & Haynes (1980) assumed that timber markets were integrated at the national level in their Timber Assessment Market Model (TAMM). McKillop's (1967) supply and demand analysis for forest products, Robinson's (1974) econometric analysis of softwood lumber and stumpage markets, and Luppold's (1984) analysis of hardwood lumber treated the entire U.S. as a single market. Newman's (1987) analysis of softwood stumpage markets treated the southern U.S. as one market. These assumptions hold when the respective timber markets are integrated and the law of one price holds at the assumed levels. However, these assumptions have not been tested with respect to stumpage markets.

If the markets are not well integrated spatially, regional or national aggregation may lose much of the information specific to individual markets. The inferences and conclusions drawn from the analysis of such aggregated markets may not be valid. If markets are not integrated, perfectly competitive conditions may not hold between segmented markets. If imperfect competitive conditions, such as monopolies, monopsonies, oligopolies, or oligopsonies hold, then the conclusions derived under the assumptions of perfectly competitive conditions may not be appropriate for policy analysis. The structure of markets can be understood by studying integration of markets using price analysis.

The degree of integration for spatially separated markets may change over time. For example, Murray & Wear (1998) note lumber markets in the Pacific Northwest (PNW) and U.S. South have undergone structural change since 1989 due to harvest restrictions on federal lands to protect the habitat of an endangered species, northern spotted owl. Lumber markets in these regions, which were functioning as separate markets, have become integrated after the imposition of harvest restrictions.

Recently, cointegration analysis has become a widely used technique for analyzing economic time series data. Cointegration techniques are necessary because of the nonstationary nature of many economic time series. Failure to account for the nonstationarity of data can lead to invalid standard statistical tests and inferences, and may result in spurious regressions (Engle & Granger, 1987). Further developments in the application of cointegration techniques, such as Johansen's (1988, 1995) maximum likelihood procedure of multivariate cointegration analysis, enable researchers to derive new insights into the workings of stumpage markets. Toppinen (1998) demonstrates that cointegration relationships can be incorporated in short-run timber market models to provide essential information on price and quantity determinants and forecasting.

The objectives of this study are to: (1) test the law of one price and the degree of market integration in hardwood stumpage markets simultaneously using Johansen's cointegration methodology; (2) test the law of one price between pairs of states for the hardwood stumpage markets; and (3) investigate how price changes are transmitted between various markets within the region using error correction methods to improve short-run forecasting. The analysis is done with respect to both hardwood pulpwood and sawtimber. Hardwood sawtimber is further disaggregated into mixed hardwood and oak sawtimber.

MARKET INTEGRATION

Markets are integrated if, at equilibrium, the law of one price holds and no arbitrage opportunity exists as a necessary condition for spatial price efficiency. The law of one price is a test for market integration. The analysis of market integration starts by determining if the markets are cross efficient, i.e., is it possible to profit by trading across commodity markets by exploiting price movements in one market to predict price movements in another?

According to Baulch (1997), markets are integrated if prices in different markets move together and their price differential equals the transfer costs that include transportation and transaction costs. If there is an equilibrium relationship between two markets, the prices in these markets cannot diverge by more than a small amount in the long-run (Engle & Granger, 1987). The assumption that product prices in different markets do not behave independently must be tested. This assumption is critical for the concept of market integration (Faminow & Benson, 1990).

The degree and extent of spatial integration has several implications for markets (Thorsen, 1998). It may give important information concerning the competitive strengths and weaknesses of individual markets. Lack of spatial integration may indicate non-optimal resource allocation on a regional level, and it may indicate that welfare gains can be made. Further, strong spatial integration may imply that any policy decision made by significant agents (e.g., industry or government) in any market will directly affect the market agents in all markets involved.

There are very few studies of market integration in U.S. stumpage markets. Yin *et al.* (1998) tested the law of one price in 13 pine pulpwood and sawtimber markets in the southern U.S. using Engle and Granger methodology between pairs of markets and found no evidence for the law of one price. Using Johansen's multivariate cointegration tests, Nagubadi & Munn (1999) found evidence of market integration for hardwood pulpwood but not for pine pulpwood in five states of the Southcentral U.S. In other countries, studies in Finland (Toppinen & Toivonen, 1998), and Denmark (Thorsen, 1998) gave mixed evidence for the law of one price. Murray & Wear (1998), Jung & Doroodian (1994), and Hänninen (1998) tested the law of one price for lumber markets. Buongiorno & Uusivuori (1992), Hänninen *et al.* (1997) investigated market integration for pulp and paper products.

ANALYTICAL FRAMEWORK

Typically, price integration has been tested using simple static, bivariate correlations. This approach has been strongly criticized (Harriss, 1979; Ravallion, 1986). Ravallion (1986) proposed a dynamic model of spatial price differentials to test alternative hypotheses of market integration. However, Ravallion's model did not consider the nonstationary nature of time series price data.

The law of one price, which is the key requirement for market integration, will hold only when market prices are cointegrated. Engle & Granger (1987) developed a test for cointegration by regressing one nonstationary variable on the other nonstationary variable, both variables being integrated of the same order, and testing the error series for stationarity. If the error term is a stationary white noise process, then the two variables are cointegrated and have a long-run equilibrium relationship.

Cointegration requires that the individual series of interest are nonstationary. If a time series has mean and variance which do not depend on time, it is a stationary time series. Stationarity of time series data can be determined by using the augmented Dickey-Fuller (ADF) test, which is given below (Enders, 1995):

$$\Delta X_t = \alpha_0 + \alpha_1 T + \delta X_{t-1} + \sum_{i=1}^{k} \beta_i \Delta X_{t-i} + u_t \tag{1}$$

where Δ is the first difference operator, X_t is the time series variable, T is time trend, α_0, α_1, δ, and β_i are the coefficients, k is the number of lags, and u_t is error term. If the null hypothesis of $\alpha_1 = \delta = 0$ is not rejected, then the null hypothesis of existence of a unit root cannot be rejected and the data are said to be non-stationary. To remove possible residual autocorrelation in the series, the appropriate lag length, k, is chosen based on the Schwarz Bayesian Criterion.

The Engle & Granger (1987) cointegration test has been criticized on the grounds that it is a two step process, and the cointegration is confined to pairwise comparisons which require that one of the two variables be designated as exogenous. Johansen's (1988, 1995) maximum likelihood procedure for cointegration tests identifies cointegrating relationships in a multivariate setting. This procedure does not require that one of the variables be designated as exogenous. In Johansen's methodology for the multivariate cointegration test, the basic statistical model is an unrestricted p-dimensional vector autoregressive (VAR) model of lag order k, as given below:

$$x_t = \mu + \Pi_1 x_{t-1} +,\ldots,+ \Pi_k x_{t-k} + \Phi D_t + \varepsilon_t; \qquad t = 1,\ldots,T. \tag{2}$$

where x_t is a $(p \times 1)$ vector that denotes the t^{th} observation on a set of p variables in levels, μ is a $(p \times 1)$ vector of intercept terms, Π_i, ... , Π_k are $(p \times p)$ matrices of parameters, D_t represents a matrix of non-stochastic variables like seasonal dummies, Φ is a $(p \times 1)$ vector of coefficients for the non-stochastic variables, k is the number of lags, and ε_t is a $(p \times 1)$ vector of normally, independently and identically distributed (NIID) disturbance terms with zero mean and variance-covariance matrix, $\varepsilon_t\varepsilon_t'=\Omega$. The k-th order VAR in levels in the above equation can be reparameterized and reformulated (Johansen, 1995) as an error correction form as follows:

$$\begin{aligned}\Delta x_t = \mu + \Gamma_1 \Delta x_{t-1} +,...,+ \Gamma_{k-1}\Delta x_{t-k+1} \\ + \Pi x_{t-1} + \Phi D_t + \varepsilon_t; \quad t = 1,...,T,\end{aligned} \qquad (3)$$

where

$\Gamma_i = -I + \Pi_i \quad (i = 1, \ldots, k-1),$

$\Pi = -I + \Pi_1 +, \ldots, + \Pi_k,$

where Δ is the first difference operator, Δx_t is a $(p \times 1)$ vector of variables integrated of zero order, i.e., $I(0)$, in the system, $\Gamma_1, \ldots, \Gamma_{k-1}$, and Π are coefficient matrices, and the other symbols as defined in the previous equation. The Γ_i describe the short-run dynamics of the system and Π is the matrix of long-run coefficients. The rank of the long-run matrix, $\Pi=\alpha\beta'$, determines the number of cointegrating vectors in the system. The information about the long-run dynamics of the system is embedded in the matrix β, and the short-run effects of disequilibria are measured by the matrix α. The columns of the matrix β are the cointegration vectors representing the stationary linear combination of variables x_t. The respective columns of matrix α give the weights with which the error correction terms enter each equation, indicating the speed of adjustment to equilibrium.

The likelihood ratio test devised by Johansen (1988) measures the number of cointegration vectors in the data. This test, also called a trace test is used to test the rank of the cointegrating matrix, and is given by,

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{p} \ln\left(1 - \hat{\lambda}_i\right) \qquad (4)$$

where T is the number of observations, $\hat{\lambda}_i$ are the estimated eigenvalues obtained from the estimated Π matrix , and r is the rank indicating the number of cointegration vectors. The rank, r, of matrix Π determines the number of cointegration vectors in the system of variables. The number of cointegration vectors can be thought of as representing constraints that an economic system imposes on the movement of the variables in the VAR model in the long-run (Dickey *et al.*, 1991).

With respect to the number of cointegration vectors, i.e., the rank of Π, there are three possible cases to consider: (a) if the rank of Π is zero, then it contains no long-run information, and a VAR in first differences is the appropriate representation; (b) if the rank of Π is full, x_t is stationary in levels and VAR in levels is the appropriate representation; and (c) if the rank of Π is more than zero and less than the number of variables p, then $\beta' x_t$ is stationary even though x_t is not stationary and an error correction form is the appropriate representation.

If there are p variables in the system, full market integration requires a rank of $p-1$ (Goodwin & Grennes, 1994). Since there are six states in the region, the hypothesis of full market integration can be accepted if the number of cointegrating vectors is five. If the rank of matrix Π, is less than five, the hypothesis of full market integration is rejected. In this case, the degree of market integration is said to be lower and the law of one price does not hold in all six states simultaneously.

The cointegration tests reveal long-run equilibrium relationships between variables and thus indicate long-run market integration. However, short-run market integration can also be tested using error correction models. The error correction representation introduces lagged relationships into the dynamic specification of prices along with the long-run equilibrium relationships in the form of error correction terms. The error correction models can show how quickly price differentials between different markets reach equilibrium values.

Study Area and Data

The geographical region of the study consists of six states in the Southcentral United States: Alabama, Mississippi, and Tennessee — east of the Mississippi River, and Arkansas, Louisiana, and Texas — west of the Mississippi. Tennessee has the largest inventory of growing stock of all hardwood stumpage products in the region followed by Alabama and Mississippi (Table 1). However, removals do not parallel inventories. Alabama leads the other states with

TABLE 1. INVENTORIES AND REMOVALS OF HARDWOOD STUMPAGE COMMODITIES IN THE SOUTHCENTRAL UNITED STATES: 1997.

State	Mixed Hardwood Sawtimber		Oak Sawtimber		Hardwood Pulpwood	
	Inventory (mcf)[a]	Removals (mcf)	Inventory (mcf)	Removals (mcf)	Inventory (mcf)	Removals (mcf)
Alabama	3887.3 (18.6)	177.3 (26.0)	2750.3 (20.0)	150.5 (29.2)	6360.2 (21.5)	250.0 (32.3)
Arkansas	3204.9 (15.4)	74.2 (10.9)	847.3 (6.1)	23.6 (4.6)	4457.8 (15.1)	82.8 (10.7)
Louisiana	3559.7 (17)	130.3 (19.1)	1752.8 (12.7)	80.6 (15.6)	3609.8 (12.2)	109.6 (14.2)
Mississippi	3686.5 (17.7)	159.7 (23.4)	2598.7 (18.9)	141.1 (27.4)	5151.6 (17.5)	202.5 (26.2)
Tennessee	5101.1 (24.6)	93.0 (13.7)	4552.6 (33.0)	71.9 (13.9)	7419.6 (25.1)	53.8 (6.9)
Texas	1434.4 (6.9)	47.2 (6.9)	1275.2 (9.3)	48.1 (9.3)	2528.9 (8.6)	74.9 (9.7)
Total	20873.9 (100)	681.7 (100)	13776.9 (100)	515.8 (100)	29527.9 (100)	773.6 (100)

Source: Calculated from McDill and Brazee (1997). Figures in parentheses are percentages. [a] mcf = million cubic feet.

respect to removals of all hardwood stumpage products followed by Mississippi and Louisiana in that order. Tennessee's share of hardwood pulpwood removals is the smallest in the region.

The hardwood stumpage market in the region is characterized by a very large number of landowners (sellers) on the supply side. These landowners fall into three categories: public, forest industry, and nonindustrial private forest (NIPF). NIPF landowners own 72% of the hardwood growing stock in the region (Powell *et al.*, 1994). Public landowners account for 13%, but much of this is unavailable for harvest (e.g. timber in National Parks and Wilderness Areas). Industrial landowners account for the remainder. Within the NIPF category, there are an estimated 767,000 ownership parcels representing 51.8 million acres, with the average parcel being 67.5 acres (Birch, 1997). On the demand side, the number of mills (buyers) is much smaller,

TABLE 2. STATE-WISE STATISTICS OF SAWMILLS AND PULPMILLS IN THE SOUTHCENTRAL UNITED STATES.

State	Number of sawmills[a]	Hardwood sawlog receipts (mcf)[a]	Number of pulpmills 1998[b]	24-hour Pulping capacity 1998[b] (tons)
Alabama	145	389	16	23628
Arkansas	127	87	8	8343
Louisiana	n.a.	n.a.	11	17520
Mississippi	84	93	7	9425
Tennessee	496	159	5	5935
Texas	n.a.	n.a.	7	8795

[a] Source: Howell, Gober & Nix (1999); Howell & Levins (1998); Stratton, Howell & Romedy (1998); and Stratton & Wright (1999); The sawmill figures include both hardwood and softwood sawmills. [b] Source: Johnson & Steppleton (2000); These numbers include both hardwood and softwood pulpwood. [c] n.a. indicates data not available.

but still substantial. Tennessee has the highest number of sawmills (using both hardwood and softwood sawlogs) followed by Alabama in the region (Table 2). However, the receipts of hardwood sawlogs were highest for Alabama, followed by Tennessee. The number of pulpmills (using both hardwood and softwood pulpwood) is much smaller than the number of sawmills in each of these states. Alabama has the highest number of pulpmills followed by Louisiana in the region. Alabama and Louisiana together control more than 55% of 24-hour pulping capacity in the region.

In this study, Timber Mart-South (TMS, 1977–97) quarterly price data are used. Producer Price Index deflated real stumpage prices in natural logarithmic form are used in this analysis. Figures 1 to 3 show the real prices of hardwood pulpwood, mixed hardwood sawtimber, and oak sawtimber in six states in the Southcentral U.S. Higher prices and volatility in prices were regular features for most stumpage commodities after 1988, possibly due to the impact of harvest restrictions in the Pacific Northwest region.

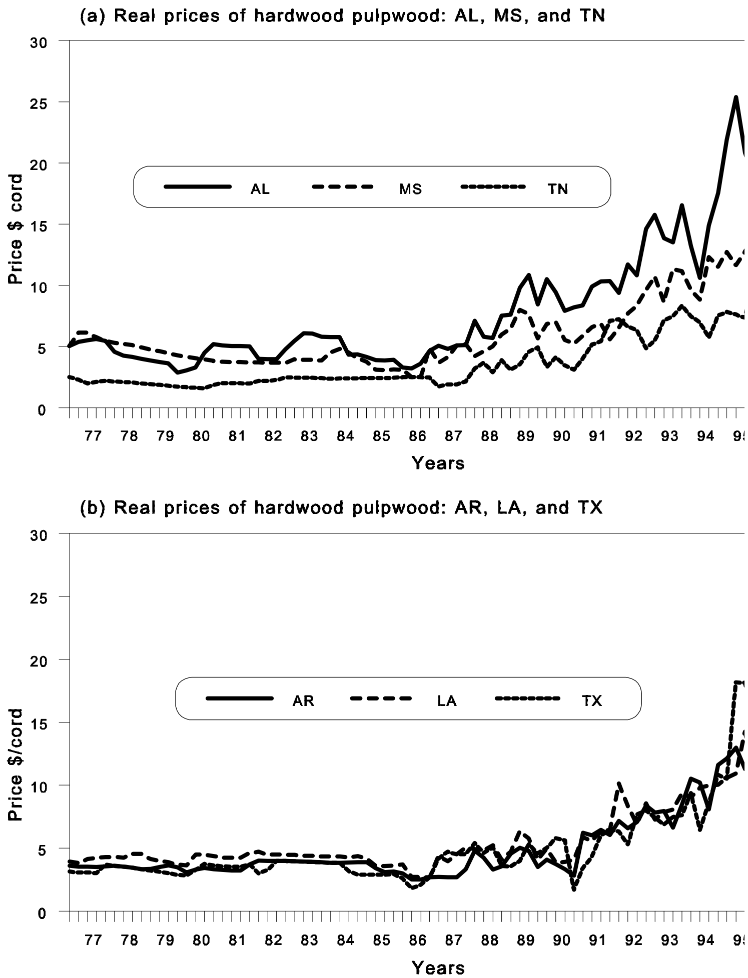

FIGURE 1. REAL HARDWOOD PULPWOOD PRICES IN THE SOUTHCENTRAL U.S.

ESTIMATION RESULTS

ADF Tests for Unit Roots

The first step in the empirical analysis of market integration is the determination of the order of integration of the price series. Lag orders up to six are tested for all price series. In the ADF test, the model with a constant and a time trend is used. The null hypothesis of a unit root is rejected for values of δ in the Equation (1) which are negative and significantly different from zero using significance levels provided by MacKinnon (1991).

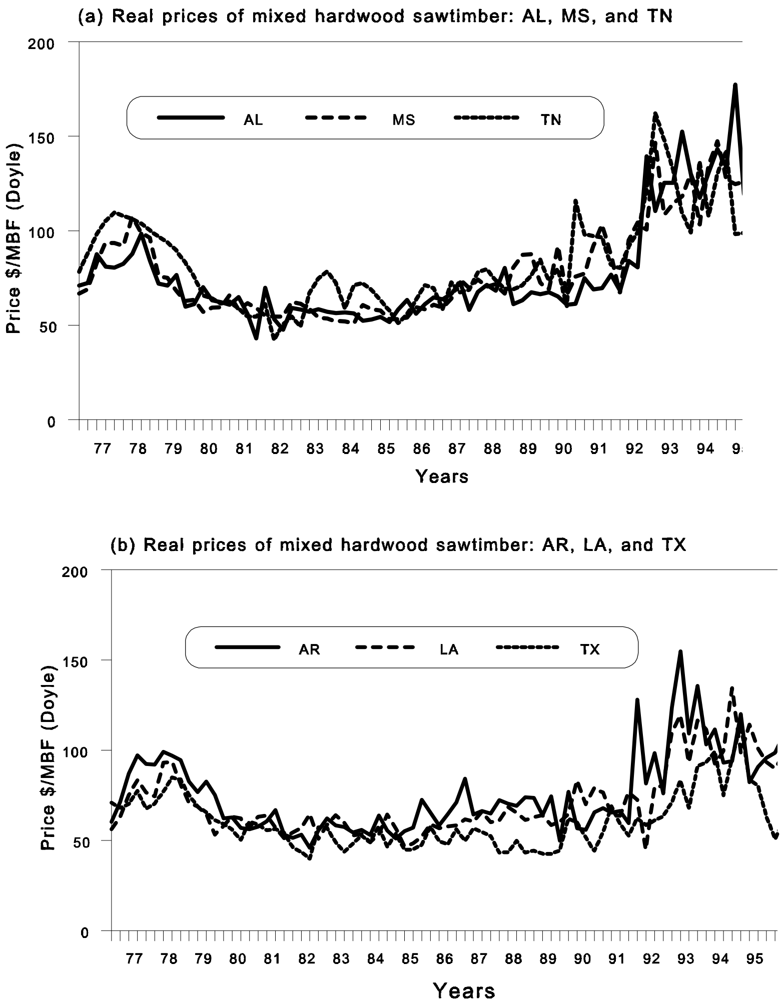

FIGURE 2. REAL MIXED HARDWOOD SAWTIMBER PRICES IN THE SOUTHCENTRAL U.S.

The results of the ADF test for the state price series of hardwood stumpage products in logarithmic form, both for data in levels and first differenced form, are presented in Table 3. For data in level form, the null hypothesis that a unit root exists could not be rejected for any of the stumpage price series in any of the states in the region. This indicates that all the hardwood stumpage price series in the states examined are nonstationary in nature. The ADF tests on the first-differenced price series for all states and products rejected the null hypothesis of existence of unit roots at the 1 % level of probability, except for the mixed hardwood sawtimber price series of Arkan-

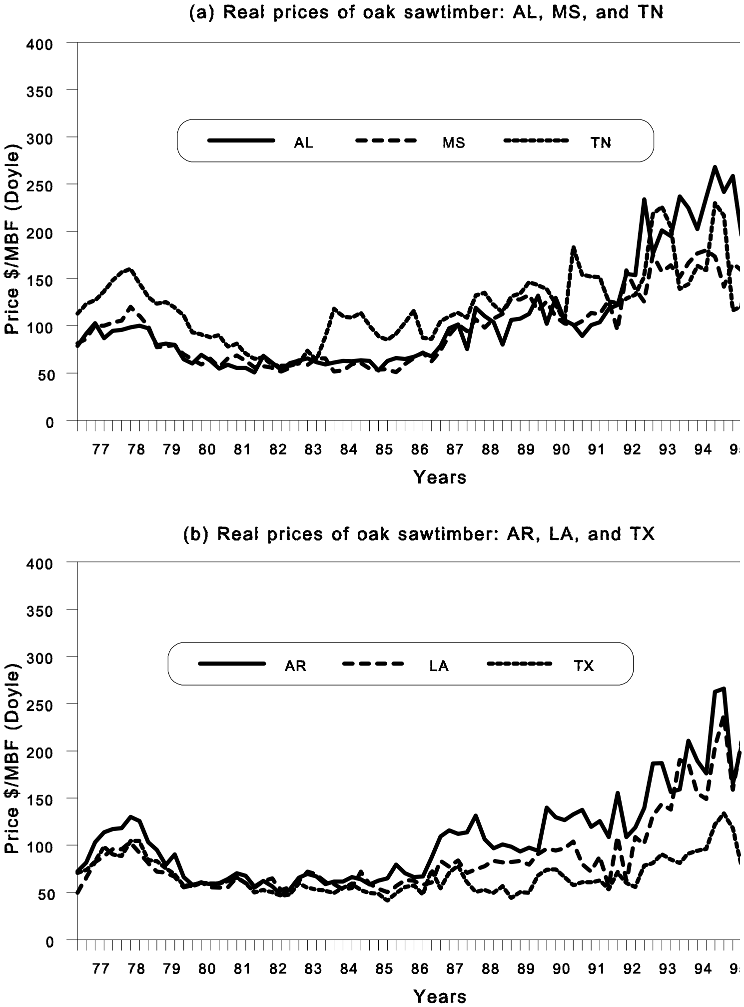

FIGURE 3. REAL OAK SAWTIMBER PRICES IN THE SOUTHCENTRAL U.S.

sas, for which the null hypothesis of a unit root was rejected at the 5 % level. So the first-differenced data are stationary. Thus, all the price series were integrated of order one, i.e., $I(1)$. The Durbin-Watson statistic is approximately two for all price series, indicating that there is no evidence of auto-correlation.

Johansen's Simultaneous Multivariate Cointegration Tests

The second step in the analysis of market integration is testing for cointegration and finding the number of cointegration vectors among the system of variables.

TABLE 3. AUGMENTED DICKEY-FULLER (ADF) UNIT ROOT TESTS FOR HARDWOOD STUMPAGE PRICES: 1977 TO 1997.

State	Levels			First-differenced		
	# of lags[a]	ADF[b]	DW[c]	# of lags[a]	ADF[b]	DW[c]
			Hardwood Pulpwood			
AL	1	−2.70	1.99	1	−6.57**	1.99
AR	1	−2.07	2.01	2	−7.89**	1.87
LA	1	−2.07	2.01	1	−8.38**	2.07
MS	2	−1.90	1.97	1	−9.25**	1.98
TN	5	−2.20	1.85	4	−7.71**	1.86
TX	1	−3.15	2.00	4	−6.28**	2.02
			Mixed Hardwood Sawtimber			
AL	2	−1.65	2.01	1	−9.42**	2.01
AR	5	−2.72	2.05	4	−3.97*	1.97
LA	2	−1.88	2.02	1	−9.27**	2.05
MS	1	−1.90	2.03	1	−8.34**	2.06
TN	1	−2.27	1.98	1	−7.38**	2.00
TX	1	−2.31	2.01	1	−7.69**	2.04
			Oak Sawtimber			
AL	1	−1.89	2.04	1	−8.00**	1.98
AR	1	−2.14	1.97	1	−7.18**	2.02
LA	2	−1.74	2.06	1	−7.67**	2.05
MS	1	−1.69	2.02	1	−7.84**	2.01
TN	2	−2.74	1.96	1	−8.42**	2.01
TX	1	−2.72	2.00	1	−7.85**	1.99

*[a] Lag order was chosen using the minimum value of Schwarz's Bayesian Criterion. [b] Augmented Dickey-Fuller test; In all the ADF tests a constant and a time trend were included. Critical values are taken from MacKinnon (1991). [c] Durbin-Watson statistic. ** and * denote rejection of null hypothesis of existence of a unit root at the 1%, and 5 % significance level.*

Johansen's maximum likelihood multivariate cointegration test results for hardwood pulpwood, mixed hardwood and oak sawtimber markets are reported in Table 4. The multivariate cointegration test evaluates the long-run equilibrium relationship in prices between the six states in the region simultaneously, i.e., it tests the null hypothesis of $\beta' x_t$ is stationary with respect to prices in the region. A model with a constant and no linear trend in the cointegrating equation was used.

For the hardwood pulpwood market, the likelihood ratio tests for the null hypothesis of at most two cointegrating vectors is rejected against the alternative hypothesis of existence of three cointegrating vectors at the 5 % level of significance (Table 4). Hence, the cointegration tests reveal that there are three cointegration vectors or stationary linear combinations in the hardwood pulpwood stumpage market in the region. Thus the rank, r, for the hardwood pulpwood market is three. Since there are six state price variables ($p = 6$) in the model, acceptance of full market integration requires evidence for five ($p-1 = 5$) stationary linear combinations. Since the test results indicate only three stationary linear combinations, the hypothesis of full market integration in the region for the hardwood pulpwood stumpage market cannot be accepted. Since the rank, $r = 3$, it can be inferred that there are three ($p-r = 3$) common stochastic trends in the hardwood pulpwood stumpage market in the region (Stock & Watson, 1988).

Results for the mixed hardwood and oak sawtimber markets reveal four long-run equilibrium relationships along with two common stochastic trends in each of these markets (Table 4). In both cases, the likelihood ratio test for the null hypothesis of at most three cointegrating vectors was rejected at the 5 % level of significance in favor of the existence of four cointegrating vectors. Thus the hypothesis of full market integration cannot be accepted for either mixed hardwood sawtimber and oak sawtimber stumpage markets in the region. The results, indicating four stationary linear combinations, suggest the presence of two common stochastic trends in each of the mixed hardwood and oak sawtimber stumpage markets in the region.

The simultaneous multivariate cointegration tests show that the hypothesis of full market integration cannot be

TABLE 4. RESULTS OF COINTEGRATION TESTS FOR HARDWOOD STUMPAGE COMMODITIES IN THE SOUTHCENTRAL U.S.: 1977–97.

Null Hypothesis	Eigenvalues	Likelihood ratio	Critical values[a]	
			5 %	1%
		Hardwood Pulpwood		
H_0: $r = 0$	0.464	131.96**	94.15	103.18
H_0: $r \leq 1$	0.331	80.81**	68,52	76.07
H_0: $r \leq 2$	0.243	47.82**	47.21	54.46
H_0: $r \leq 3$	0.162	24.95	29.68	35.65
H_0: $r \leq 4$	0.117	10.47	15.41	20.04
H_0: $r \leq 5$	0.004	0.30	3.76	6.65
		Mixed Hardwood Sawtimber		
H_0: $r = 0$	0.425	134.69**	94.15	103.18
H_0: $r \leq 1$	0.361	89.29**	68.52	76.07
H_0: $r \leq 2$	0.238	52.61**	47.21	54.46
H_0: $r \leq 3$	0.203	30.33**	29.68	35.65
H_0: $r \leq 4$	0.129	11.71	15.41	20.04
H_0: $r \leq 5$	0.004	0.33	3.76	6.65
		Oak Sawtimber		
H_0: $r = 0$	0.374	115.47**	94.15	103.18
H_0: $r \leq 1$	0.261	77.09**	68.52	76.07
H_0: $r \leq 2$	0.231	52.25**	47.21	54.46
H_0: $r \leq 3$	0.208	30.73**	29.68	35.65
H_0: $r \leq 4$	0.130	11.60	15.41	20.04
H_0: $r \leq 5$	0.002	0.16	3.76	6.65

[a] *The critical values for the likelihood ratio test are taken from Osterwald-Lenum (1992). ** and * denote rejection of the null hypothesis at the 1%, and 5% significance level.*

accepted for any of these three hardwood stumpage commodities in the region. Hence the law of one price does not hold for the hardwood stumpage market in these six states of the Southcentral region. However, between these hardwood stumpage markets, there is evidence for a higher degree of market integration for sawtimber markets than pulpwood markets.

The cointegration vectors are not identified unless some arbitrary normalization is imposed. Normalization allows the r cointegration relations for the first r variables to be solved as a function of the remaining $p–r$ variables. For any cointegrating vector, $\beta = \{\beta_1, \beta_2, ..., \beta_p\}$ and for any non-zero value of π, the vector $\{\pi\ \beta_1, \pi\ \beta_2, ..., \pi\ \beta_p\}$ is also an equivalent cointegrating vector. The coefficient of one variable is used to normalize the cointegrating vector by fixing its value equal to one by setting the value of $\pi = 1/\beta_1$. The normalized cointegration equations showing long-run equilibrium relationships between various state prices for each of the commodities are presented in Table 5. From these equations, there appear to be cointegrated relationships in the long run between Alabama and Tennessee prices, Arkansas and Texas prices, and Louisiana and Texas prices in the hardwood pulpwood stumpage market. In the mixed hardwood sawtimber stumpage market, there are cointegrated relationships between Alabama and Tennessee prices, Arkansas and Tennessee prices, and Louisiana and Tennessee prices. However, there does not appear to be any cointegrated relationships between oak sawtimber prices for the various states in the region in these long-run normalized equations.

The hardwood pulpwood market in the region exhibited three cointegrating relationships (rank = 3), hence three normalized equations have to be incorporated in the error correction models. For the mixed hardwood and oak sawtimber markets, four normalized cointegration equations have to be included in the error correction models because the cointegration tests revealed four cointegration relationships (rank = 4) in each of these markets. These equations represent the long-run effects in the error correction models.

Bivariate Cointegration Tests

According to the simultaneous multivariate cointegration tests for the six states, none of the hardwood stumpage

TABLE 5. ESTIMATED STATIONARY COINTEGRATING EQUATIONS (CE).

Hardwood Pulpwood:

$$CE_1 = AL_{t-1} - 0.64 - 0.38\ MS_{t-1} - 0.98^{**}\ TN_{t-1} + 0.35\ TX_{t-1}$$
$$CE_2 = AR_{t-1} - 0.10 + 0.19\ MS_{t-1} - 0.07\ TN_{t-1} - 1.10^{**}\ TX_{t-1}$$
$$CE_3 = LA_{t-1} - 0.36 + 0.10\ MS_{t-1} + 0.05\ TN_{t-1} - 1.02^{**}\ TX_{t-1}$$

Mixed Hardwood Sawtimber:

$$CE_1 = AL_{t-1} + 0.32 - 1.94^{**}\ TN_{t-1} + 0.95\ TX_{t-1}$$
$$CE_2 = AR_{t-1} - 0.54 - 1.26^{**}\ TN_{t-1} + 0.44\ TX_{t-1}$$
$$CE_3 = LA_{t-1} - 0.57 - 1.39^{**}\ TN_{t-1} + 0.60\ TX_{t-1}$$
$$CE_4 = MS_{t-1} - 0.31 - 2.20^{**}\ TN_{t-1} + 1.38\ TX_{t-1}$$

Oak Sawtimber:

$$CE_1 = AL_{t-1} - 10.32 - 5.21\ TN_{t-1} + 7.34\ TX_{t-1}$$
$$CE_2 = AR_{t-1} - 4.21 - 3.09\ TN_{t-1} + 3.45\ TX_{t-1}$$
$$CE_3 = LA_{t-1} - 14.24 - 5.76\ TN_{t-1} + 8.95\ TX_{t-1}$$
$$CE_4 = MS_{t-1} - 4.23 - 3.00\ TN_{t-1} + 3.36\ TX_{t-1}$$

** and * indicate significance levels at 1 % and 5 %.

commodities exhibited full market integration. To understand the dynamics of price relationships between various pairs of states separately for the respective commodities, bivariate cointegration tests were also performed. Since there are six states in the region, there are 15 possible pairs for which cointegration relations can be tested. For each of the bivariate cointegration tests only one lag was chosen.

The results of the bivariate cointegration tests for the three hardwood stumpage commodities are presented in Table 6. Only the Likelihood Ratio (LR) statistics (trace test) for the tested pairs are shown. For the hardwood pulpwood market, the calculated LR statistics were significant for four pairs at the 1 % level, and another four pairs at the 5 % level. The LR statistic for the cointegration test between Louisiana and Tennessee was very close to the critical value at 5 % level. Including this, for nine out of 15 pairs there was a long-run equilibrium relationship in the hardwood pulpwood market. Texas had cointegrating relationships with all other states in the region, while Tennessee also had cointegration relationships with all but Arkansas. Ala-

TABLE 6. BIVARIATE COINTEGRATION TESTS FOR HARDWOOD STUMPAGE MARKETS: LIKELIHOOD RATIOS.

State	*AL*	*AR*	*LA*	*MS*	*TN*
			Hardwood Pulpwood		
AR	9.82				
LA	13.00	37.44**			
MS	11.87	12.90	14.15		
TN	21.88**	14.34	15.37	17.05*	
TX	15.67*	26.78**	31.76**	19.37*	20.39*
			Mixed Hardwood Sawtimber		
AR	25.48**				
LA	37.64**	23.79**			
MS	24.71**	23.64**	30.74**		
TN	16.85**	23.73**	23.20**	21.09**	
TX	17.88**	21.73**	23.08**	14.99	21.50**
			Oak Sawtimber		
AR	20.37**				
LA	18.85**	13.67			
MS	15.40	22.17**	10.44		
TN	17.37*	18.34*	13.88	20.16**	
TX	12.95	11.13	11.10	13.86	15.52*

*Critical values for the Likelihood Ratio test, taken from Osterwald-Lenum (1992) are: 20.04 (1%) and 15.41 (5%). ** and * indicate significance levels at the 1% and 5% probability.*

bama, Arkansas, and Louisiana each have cointegrating relationships with two other states, while Mississippi had a long-run equilibrium relationship with only one state, Texas.

Although simultaneous multivariate cointegration tests revealed equal number (four) of cointegrating vectors for mixed hardwood and oak sawtimber markets, pair-wise cointegration test results showed significant differences between these two markets. For mixed hardwood saw-timber, long-run equilibrium relationships were supported for nearly all pairs of states in the region. The LR statistic for the cointegration test between Mississippi and Texas was close to the critical value at the 5 % level of significance.

Long-run equilibrium relationships in prices for oak sawtimber were evident for 8 out of 15 pairs, including the relationship between Alabama and Mississippi for which the LR statistic was very close to the critical value at the 5 % level. Tennessee had the maximum (four) number of long-run equilibrium relationships with other states. Alabama and Arkansas each had long-run equilibrium relationships with three other states, while Mississippi had long-run relationships with two other states, and Louisiana and Texas each had only one long-run relationship with other states.

The multivariate cointegration results indicate that hardwood stumpage markets are not fully integrated in the Southcentral U.S. In general, the bivariate cointegration results also support these results. However, in case of mixed hardwood sawtimber, only one pair of states is not cointegrated suggesting a situation that is closer to full market integration.

Error Correction Representation

Even though there is a long-run equilibrium between markets, in the short-run there can be deviations from the equilibrium relationship. The short-run dynamics are influenced by the deviation from the long-run equilibrium relationships. While cointegrating equations represent long-run relationships between markets, short-run relationships may vary significantly. The error correction models combine both short-run and long-run relationships between prices of different markets.

The error correction models regress changes in the state price variables on lagged deviations from the long-run equilibrium relationships and also on the lagged deviations from the prices of states in the short-run periods. Deviations from equilibrium, as reflected by error correction coefficients, will bring about changes in the equilibrium among the cointegrated variables. The coefficients for error correction terms (*ECT*) in error correction models measure the speed of adjustment toward the long-run equilibrium relationship between the markets (Enders, 1995). The speed of adjustment is represented by the absolute value of the error correction term. The error correction term is interpreted as the change in the real stumpage prices per quarter that is attributed to the disequilibrium between the actual and equilibrium levels. A larger coefficient indicates a quicker adjustment towards long-run equilibrium values and a smaller coefficient indicates a slower adjustment towards long-run equilibrium values. The influence of the previous period's price changes of various states in the model can be interpreted as short-run adjustments while the markets are equilibrium in the long-run with other markets in the analysis.

The results of the error correction representation are provided in Tables 7 to 9. In these tables, the coefficients in the *ECT* ($ECT1_{t-1}$, $ECT2_{t-1}$, and so on) rows are the error correction coefficients representing the speed of adjustment per period towards the normalized long-run equilibrium relationships shown in Table 5, for the current price changes in the respective states (ΔAL, ΔAR, and so on) indicated under the column heading dependent variable. The coefficients listed against rows, ΔAL_{t-1}, ΔAR_{t-1}, and so on, represent the magnitude of the adjustment due to the short-run price changes in previous period in various states on the current price changes of the states listed under the dependent variable. Thus the error correction models represent both long–run and short-run dynamics in the equilibrium relationships.

In the hardwood pulpwood market, the error correction coefficients ranged from –0.521 to 0.651, and at least one error correction term was significant in influencing current price changes in all states except Mississippi (Table 7). This indicates the importance of long-run cointegration relationships in the price determination process in hardwood pulpwood markets in various states in the Southcentral region. However, current hardwood pulpwood prices in Mississippi were not affected by any of the long-run relationships, but were affected only by their own previous period's price changes. This indicates that Mississippi may be a dominant market and weakly exogenous in the hardwood pulpwood market in the region. In Texas, the hardwood pulpwood price changes were influenced by one long-run equilibrium relationship and previous period's price changes in Alabama.

TABLE 7. ERROR CORRECTION MODEL: HARDWOOD PULPWOOD (T-VALUES WITHIN PARENTHESES).

Variable[@]	Dependent Variable					
	$\Delta\ AL$	$\Delta\ AR$	$\Delta\ LA$	$\Delta\ MS$	$\Delta\ TN$	$\Delta\ TX$
Constant	0.016 (0.97)	0.018 (1.18)	0.016 (0.92)	0.013 (0.79)	0.317 (1.17)	0.428 (0.80)
$ECT1_{t-1}$	−0.195* (−1.89)	0.070 (0.72)	−0.096 (−0.85)	−0.117 (−1.12)	0.371** (3.65)	0.223 (1.43)
$ECT2_{t-1}$	−0.151 (−0.96)	−0.455** (−3.04)	0.368* (2.14)	−0.059 (−0.37)	−0.030 (−0.19)	0.274 (1.14)
$ECT3_{t-1}$	0.140 (0.67)	0.651** (3.33)	−0.521* (−2.32)	−0.018 (−0.09)	0.244 (1.20)	0.601* (1.92)
$\Delta\ AL_{t-1}$	0.012 (0.08)	0.172 (1.30)	0.170 (1.11)	0.105 (0.74)	−0.030 (−0.21)	0.504** (2.37)
$\Delta\ AR_{t-1}$	−0.009 (−0.06)	0.067 (0.45)	−0.099 (−0.58)	0.036 (0.23)	−0.090 (−0.58)	−0.301 (−1.26)
$\Delta\ LA_{t-1}$	0.093 (0.53)	−0.260 (−1.58)	0.068 (0.36)	0.255 (1.45)	0.221 (1.29)	−0.164 (−0.62)
$\Delta\ MS_{t-1}$	0.120 (0.97)	−0.146 (−1.10)	0.058 (0.43)	−0.303** (−2.41)	−0.075 (−0.62)	0.048 (0.26)
$\Delta\ TN_{t-1}$	−0.156 (−1.21)	−0.134 (−1.10)	−0.069 (−0.49)	−0.150 (−1.15)	0.088 (0.70)	−0.135 (−0.69)
$\Delta\ TX_{t-1}$	0.071 (0.80)	−0.037 (−0.44)	−0.045 (−0.46)	−0.046 (−0.51)	0.043 (0.49)	0.172 (1.28)
R-squared	0.16	0.28	0.12	0.14	0.32	0.43

*[@] ECT= Error correction term. Δ = First difference operator. ** and * denote rejection of the null hypothesis at 1%, and 5% significance level* .

For mixed hardwood sawtimber, all state prices, except those for Tennessee, were significantly influenced by at least one long-run relationship. Neither error correction terms nor previous price changes in any of the states had significant effects on current prices for mixed hardwood sawtimber in Tennessee (Table 8). This indicates that Ten-

TABLE 8. ERROR CORRECTION MODEL: MIXED HARDWOOD SAWTIMBER (T-VALUES WITHIN PARENTHESES).

Variable[@]	Dependent Variable					
	Δ *AL*	Δ *AR*	Δ *LA*	Δ *MS*	Δ *TN*	Δ *TX*
Constant	0.010 (0.72)	0.008 (0.47)	0.007 (0.57)	0.008 (0.65)	0.006 (0.35)	0.000 (0.01)
$ECT1_{t-1}$	−0.465[**] (−2.67)	0.343 (1.62)	0.477[**] (3.00)	0.347[*] (2.27)	−0.110 (−0.53)	0.060 (0.33)
$ECT2_{t-1}$	0.237[*] (1.78)	−0.719[**] (−4.45)	−0.097 (−0.79)	0.148 (1.27)	0.116 (0.74)	−0.048 (−0.35)
$ECT3_{t-1}$	−0.194 (−1.03)	−0.196 (−0.85)	−1.018[**] (−5.88)	−0.004 (−0.03)	0.059 (0.26)	0.324 (1.64)
$ECT4_{t-1}$	0.357[**] (2.58)	0.129 (0.77)	0.238[*] (1.88)	−0.397[**] (−3.27)	0.166 (1.01)	−0.364[**] (−2.52)
ΔAL_{t-1}	−0.221 (−1.61)	−0.004 (−0.03)	−0.068 (−0.54)	0.052 (0.43)	0.002 (0.01)	0.179 (1.24)
ΔAR_{t-1}	−0.089 (−0.81)	−0.128 (−0.96)	0.037 (0.37)	0.012 (0.13)	0.015 (0.12)	−0.092 (−0.80)
ΔLA_{t-1}	0.219 (1.62)	0.169 (1.02)	0.108 (0.49)	−0.159 (−1.33)	0.073 (0.46)	0.035 (0.25)
ΔMS_{t-1}	−0.173 (−1.25)	−0.097 (−0.57)	0.127 (1.00)	−0.058 (−0.47)	−0.047 (−0.29)	0.397[**] (2.73)
ΔTN_{t-1}	0.147 (1.31)	0.085 (0.62)	0.016 (0.15)	0.067 (0.68)	−0.072 (−0.55)	−0.116 (−0.99)
ΔTX_{t-1}	0.104 (0.95)	−0.035 (−0.26)	−0.060 (−0.60)	0.198[*] (2.06)	−0.181 (−1.38)	−0.070 (−0.61)
R-squared	0.40	0.45	0.48	0.35	0.20	0.34

[@] *ECT= Error correction term. Δ = First difference operator. [**] and [*] denote rejection of the null hypothesis at 1%, and 5% significance level* **.**

nessee may be a dominant and weakly exogenous market with respect to mixed hardwood sawtimber. This may be because of its dominant position with respect to hardwood inventories. For other states, at least one error correction term was significant in the current price changes for mixed

TABLE 9. ERROR CORRECTION MODEL: OAK SAWTIMBER (T-VALUES WITHIN PARENTHESES).

Variable[@]	Dependent Variable					
	Δ *AL*	Δ *AR*	Δ *LA*	Δ *MS*	Δ *TN*	Δ *TX*
Constant	0.015 (0.98)	0.013 (0.77)	0.016 (1.06)	0.011 (0.92)	0.007 (0.43)	–0.005 (–0.26)
$ECT1_{t-1}$	–0.202 (–1.30)	0.327* (1.98)	0.561** (3.65)	0.019 (0.16)	0.185 (1.09)	0.284 (1.58)
$ECT2_{t-1}$	0.043 (0.30)	–0.656 ** (–4.36)	–0.372** (–2.65)	0.316** (2.87)	0.057 (0.37)	–0.302* (–1.83)
$ECT3_{t-1}$	0.038 (0.38)	–0.121 (–1.14)	–0.344** (–3.49)	–0.054 (–0.70)	–0.295** (–2.71)	–0.175 (–1.51)
$ECT4_{t-1}$	0.243* (1.69)	0.319* (2.08)	0.089 (0.63)	–0.266** (–2.38)	0.310* (1.97)	0.084 (0.50)
$\Delta\ AL_{t-1}$	–0.335** (–2.45)	–0.081 (0.55)	–0.066 (–0.48)	0.020 (0.19)	–0.182 (–1.22)	–0.024 (–0.15)
$\Delta\ AR_{t-1}$	0.144 (0.96)	0.460** (2.89)	0.302* (2.04)	–0.078 (–0.67)	0.309* (1.89)	0.344* (1.98)
$\Delta\ LA_{t-1}$	0.105 (0.91)	–0.136 (–1.11)	–0.365** (–3.19)	0.192** (2.14)	0.000 (0.00)	0.085 (0.64)
$\Delta\ MS_{t-1}$	–0.043 (–0.29)	–0.009 (–0.06)	0.295* (1.97)	–0.097 (–0.82)	–0.069 (–0.42)	–0.093 (–0.53)
$\Delta\ TN_{t-1}$	–0.056 (–0.49)	–0.101 (–0.83)	–0.025 (–0.22)	–0.108 (–1.22)	0.076 (0.60)	–0.026 (–0.19)
$\Delta\ TX_{t-1}$	0.116 (1.14)	–0.107 (–0.99)	0.062 (0.61)	0.271** (3.43)	–0.037 (–0.33)	–0.266* (–2.26)
R-squared	0.29	0.33	0.52	0.36	0.27	0.32

[@] *ECT= Error correction term. Δ = First difference operator. ** and * denote rejection of the null hypothesis at 1%, and 5% significance level.*

hardwood sawtimber. This suggests interdependency in prices between the states in the long-run. Apart from one error correction term, previous period price changes in Mississippi influenced Texas mixed hardwood sawtimber current period price changes. Also, apart from two significant error correction terms, Mississippi current price changes were influenced by previous period price changes in Texas. In the remaining states, short-run influences in prices were not significant.

The situation is different for the oak sawtimber market. Both the error correction terms and previous period price changes were influential in the price determination process of oak sawtimber in all states in the region (Table 9). This indicates both long-run equilibrium relationships and short-run relationships in prices interact dynamically in the determination of current price changes for oak sawtimber. There is more interdependence among state-level oak sawtimber prices in the region than for mixed hardwood sawtimber prices.

Thus, the results of error correction models indicate that Mississippi and Tennessee are dominant markets for hardwood pulpwood and mixed hardwood sawtimber markets respectively. However, the oak sawtimber market has shown interdependence between all states without any evidence for dominant markets.

DISCUSSION AND IMPLICATIONS

The results of Johansen's multivariate cointegration analysis indicated that none of the hardwood stumpage commodity markets exhibited full market integration in the study area. The degree of market integration, however, differed among the hardwood stumpage products. Hardwood sawtimber markets exhibited a higher degree of market integration than the hardwood pulpwood markets in the region. Although full market integration was rejected for all commodities, subsequent analyses did not clearly identify what the appropriate sub-markets may be.

In the hardwood pulpwood market, there was evidence for three long-run equilibrium relationships with three common stochastic trends. Thus, the hardwood pulpwood stumpage market may actually be three independent markets in the region. That the market was not fully integrated was supported by the bivariate cointegration analysis that found no long-run equilibrium relationship between many pairs of states for hardwood pulpwood stumpage market. The error correction models indicated that Mississippi may be a dominant and weakly exogenous market for hardwood pulpwood stumpage in the region.

In the mixed hardwood sawtimber market, there was evidence for four long-run equilibrium relationships with two common stochastic trends. Thus, the mixed hardwood sawtimber market may actually be two independent markets. However, the mixed hardwood sawtimber market appears very close to full market integration since bivariate cointegration tests indicated long-run equilibrium relationships for nearly all pairs of states. The error correction models indicated that Tennessee may be a dominant and weakly exogenous market with respect to mixed hardwood sawtimber.

For the oak sawtimber market, there was evidence for four long-run equilibrium relationships and two common stochastic trends in the region indicating that the oak sawtimber market in the region may actually be two markets also. The bivariate cointegration analysis found long-run equilibrium relationships between oak sawtimber prices in only 7 pairs of states. The bivariate tests for oak sawtimber also indicated that Texas may be a separate market since it has no long-run equilibrium relationship with any other states, except Tennessee, in the region. However, the error correction models indicate that there is more interdependence between state prices in the oak sawtimber market than in the mixed sawtimber market.

Since none of the hardwood stumpage markets in the region exhibited full market integration and the hypothesis of the law of one price could not accepted, the six states in the region cannot be treated as a single market with respect to these commodities. If six states in the Southcentral region cannot be treated as a single market, then it is doubtful that the entire southern region or entire United States can be treated as a single market with respect to timber supply and demand modeling.

One reason that hardwood stumpage markets are not fully integrated might lie in the bulky and highly dispersed nature of hardwood stumpage commodities. The bulky nature of stumpage commodities results in high transportation costs between stumpage sources and processing centers. For example, more than one-fourth of the hardwood inventory in the region is located in Tennessee.

From the results of the analysis, it is clearly evident that hardwood pulpwood stumpage markets are less integrated than hardwood sawtimber stumpage markets. Procurement, logging, and transportation costs constitute a much larger share of the delivered price for hardwood pulpwood than for mixed or oak sawtimber. Due to the higher proportion of these costs for hardwood pulpwood stumpage, it may be uneconomical to move hardwood pulpwood between markets. Being centrally located between Alabama and Louisiana which together control more than 55% of pulping capacity, may have contributed to making Mississippi a dominant market with respect to hardwood pulpwood stumpage market in the region. Another contributing factor to Mississippi's dominance may be the Tennessee-Tombigbee Waterway which runs between Mississippi and Alabama connecting to Gulf-Coast ports from where pulp chips are exported. This waterway contributed to higher hardwood pulpwood removals in Alabama, Mississippi and possibly Louisiana.

Another reason that hardwood pulpwood stumpage markets are less integrated than hardwood sawtimber markets might be the nature of market power and the possible presence of oligopsony in hardwood pulpwood stumpage markets in the region. Murray (1995) notes that pulpwood markets are more oligopsonistic than sawlog markets though both perform closer to perfect competition than monopsony. In general, the pulp and paper industry is the most concentrated among the forest industries (Duerr, 1993), and buyer behavior in the pulp and paper industry is closer to oligopsonistic behavior than competitive behavior due to the market power exercised in the pulp and paper industry. The lower degree of integration in hardwood pulpwood markets in the Southcentral United States may indicate the presence of such oligopsonistic tendencies while the higher degree of market integration in hardwood sawtimber markets indicates that the hardwood sawtimber markets are more competitive than pulpwood markets in the region.

Since the hypothesis of full market integration is rejected for hardwood stumpage commodities in the Southcentral region, the assumption of spatial equilibrium in the analysis of timber supply at international, national, or regional levels is not appropriate. Segmentation of markets needs to be considered to incorporate more information at dis-aggregated levels in timber supply analyses. Using elasticity estimates based on segmented markets will improve the results of timber supply and projection analyses in the future.

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