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Price transmission between products at different stages of manufacturing in forest industries

Mo Zhou, Joseph Buongiorno*

Department of Forest Ecology and Management of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 53706, USA

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Abstract

The theory of demand and supply implies a positive relationship, or "price transmission" between the prices of products at different stages of manufacturing. This relationship was investigated with quarterly prices of softwood stumpage in the US South, and national prices of forest products, from 1977 to 2002. All prices, net of inflation, were found to be nonstationary and there was no evidence of co-integration between prices. Vector autogressive models, augmented by Granger causality tests and multiplier analysis showed that there was a one-to-one permanent positive response of the southern sawtimber stumpage price to a permanent change in the national lumber price. There was also a one-third permanent positive response of the national paper price to a permanent change in the national pulp price. There was no relation between regional pulpwood prices and national pulp or paper prices. When price transmission was significant, the full adjustment took about 2 years.

JEL Classification: D49; L73
Keywords: Prices; Stumpage; Timber; Lumber; Pulpwood; Pulp; Paper; Econometrics; Co-integration; Causality; Multiplier

*Corresponding author. Tel.: +1 608 238 3844; fax: +1 608 262 9922.
E-mail address: jbuongio@wisc.edu (J. Buongiorno).

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Introduction

Due to the growing importance of the South in the United States forest economy, its markets have been the subject of several previous studies. Early works emphasized the determinants of southern pine stumpage prices (Guttenberg and Fasick, 1965; Anderson, 1969; Guttenberg, 1970). More recent papers has examined the efficiency of stumpage markets in the South (Washburn and Binkley, 1990, 1993; Hultkrantz, 1993; Nagubadi et al., 2001; Prestemon, 2003).

This paper studies the relation between southern stumpage prices and national forest product prices. Other studies have pursued similar goals. Haynes (1977) models the link between regional stumpage and national lumber markets with a mostly theoretical derived demand approach. Luppold et al. (1997) examine the relationship between hardwood lumber prices and sawtimber stumpage prices in Ohio, with market margin models. They conclude that lumber and stumpage prices "did not always move in the same direction, but tended to move in the same direction when there were large changes in lumber prices". Similar studies of price transmission through stage of processing or marketing have been done for other sectors as well (Brorsen et al., 1985; Azzam, 1999; Goodwin and Holt, 1999; Bettendorf and Verboven, 2000).

In forest industries, stumpage is a primary factor of production. The effect of a change in the product price on the factor price is explained by the theory of derived demand (Tomek and Robinson, 1990). If the demand for the product increases, other things equal, its price increases and a larger quantity is produced. This induces a larger demand for the factor, which leads to an increase of its price. This adjustment process terminates when the new market equilibrium is established. Therefore, the theory suggests that the price of the input (say, sawtimber stumpage) is positively affected by the product price (lumber). Furthermore, a symmetric effect is possible since an exogenous negative shock in factor supply will lead to an increase in factor price, which will translate into an increase in product price, other things being equal.

The magnitude of these relationship is important to evaluate the effects of policies that affect national product prices, such as housing and international trade policies, on regional stumpage prices, and symmetrically to judge the effects of regional forest policies that affect regional stumpage supply and prices on national product prices.

Data and methods

Price data

Nominal stumpage prices of softwood sawtimber and pulpwood were obtained from *Timber Mart-South* (TMS), in six states[1] in the US South. From the beginning

[1] Alabama, Arkansas, Louisiana, Mississippi, Tennessee, and Texas.

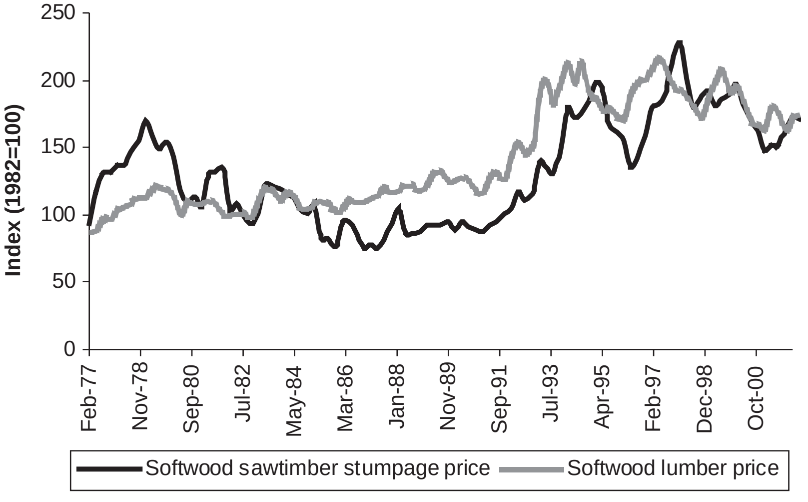

Fig. 1. Quarterly US softwood lumber price and southern softwood sawtimber stumpage price, 1977–2002.

of 1988, "the reporting frequency changed from monthly to quarterly" (Prestemon and Pye, 2000). For consistency, the mid-month observations in each quarter before 1988 were used as quarterly observations. In 1992, "(typically) three reporting regions per state" (Prestemon and Pye, 2000) were changed to two. The method of Prestemon and Pye (2000)[2] was applied to merge three area prices into two before 1992.

We averaged stumpage prices of pine sawtimber and pulpwood over 12 TMS areas in the six states, and deflated the averages with the "All Commodities Producer Price Index" (1982 = 100) (US Bureau of Labor Statistics, 2002). The results represented the real prices of pine sawtimber and pulpwood stumpage in the South.

The national forest product prices were quarterly prices of US softwood lumber, paper, and wood pulp, during the same period, represented by Producer Price Indices (1982 = 100) (US Bureau of Labor Statistics, 2002).

The price series, each consisting of 102 observations, are plotted in Figs. 1 and 2. All of them had a slightly positive long-term trend. In the short run, the prices of lumber and sawtimber tended to move in the same direction, but not simultaneously. The prices of pulp and paper moved in the same direction, but the price of pulp fluctuated much more than that of paperulp. The prices of pulp and pulpwood

[2]The price for wood product r in the new TMS area j ($j = 1, 2$) at time t was calculated as: $P_{jr,t} = \sum_{i=1}^{I}\left(\sum_{k=1}^{K} A_{ijk} q_{kr}\right) P_{ir,t}$ where A_{ijk} is the ratio of the area of county k previously assigned to the old TMS area i ($i = 1, \ldots, I$) to the area of the same county assigned to the new area j; q_{kr} is the timber removal volume in county k ($k = 1, \ldots, K$) for product r and $P_{ir,t}$ is the price for the same product in the old TMS area i at time t.

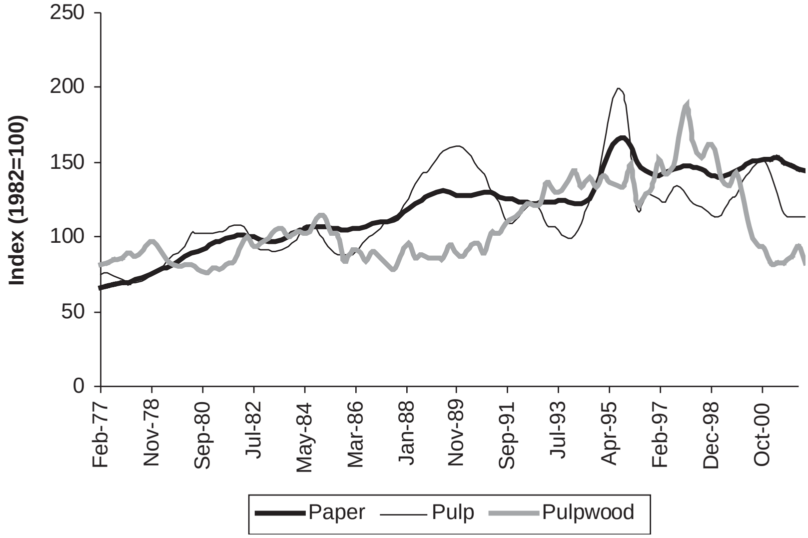

Fig. 2. Quarterly US paper and pulp prices, and southern softwood pulpwood stumpage price, 1977–2002.

seemed to move in opposite directions through several periods, for example between the first quarter of 1986 and the third quarter of 1991.

Co-integration tests

Co-integration between variables is "the statistical implication of the existence of a long-run relationship" between them (Thomas, 1993). Co-integrated variables are nonstationary but their linear combination is stationary. They "move together over time so that short-run disturbances from the long-term trend will be corrected" (Manning and Adriacanos, 1993). A lack of co-integration suggests instead no long-run relationship between variables: "they can wander arbitrarily far away from each other" (Dickey et al., 1991).

Thus, the presence or absence of co-integration is informative in and by itself. Furthermore variables that are nonstationary but not co-integrated can be represented with vector autoregressive (VAR) models in their first differences (Hamilton, 1994, p. 562).

Figs. 1 and 2 suggested that the prices were not stationary. This was tested with the augmented Dickey-Fuller (ADF) test (Said and Dickey, 1984), based on the regression:

$$P_t = \xi_1 \Delta P_{t-1} + \xi_2 \Delta P_{t-2} + \cdots + \xi_n \Delta P_{t-n} + \alpha + \rho P_{t-1} + \varepsilon_t, \quad (1)$$

where P_t was the price of interest. The null hypothesis of nonstationarity, or unit root ($\rho = 1$), was accepted at the 0.05 level if the ADF statistic was greater than the critical value of −2.89. The order of the autoregression was set at $n = 8$ "to avoid over-parameterization of the unit root test and therefore to give the test greater statistical power" (Luppold et al., 1997).

After finding that the prices were non-stationary (see results), we tested if they were co-integrated, using the residuals, u, in the following regression (Engle and Granger, 1987):

$$L_t = a + bS_t + u_t, \tag{2}$$

where in testing for co-integration between lumber and sawtimber prices, L was the lumber price and S was the sawtimber stumpage price. In testing for co-integration between paper, pulp and pulpwood prices, the dependent variable was the paper price, and the independent variables were the pulp and pulpwood prices. Co-integration was rejected if u was not stationary, that is if ρ was not significantly different from 1 in the autoregression (1) where P was replaced by u.

Vector autoregressive models and causality tests

Because the prices were not co-integrated (see results), it was justified to build VAR models in first differences to describe the dynamic relationship between the variables and use them for causality tests (Engle and Granger, 1987). The appendix describes how these VAR models result from the theory of demand and supply.

The bivariate model of lumber and sawtimber stumpage prices was

$$L_t = f_1 + \sum_{i=1}^{m} g_{1,i} L_{t-i} + \sum_{i=1}^{m} h_{1,i} S_{t-i} + u_{1,t}, \tag{3}$$

$$S_t = f_2 + \sum_{i=1}^{m} g_{2,i} L_{t-i} + \sum_{i=1}^{m} h_{2,i} S_{t-i} + u_{2,t}, \tag{4}$$

where L and S denote the first differences of lumber and sawtimber prices, respectively; f, g and h indicate constant parameters, and u refers to white noise error, with zero mean, constant variance–covariance between $u_{1,t}$ and $u_{2,t}$, and zero autocorrelation. To maximize efficiency, the shortest lag length, m, was used that would lead to white noise residuals (based on the Ljung–Box (Ljung and Box, 1978) statistic with 20 lags).

The trivariate model of paper, wood pulp and pulpwood stumpage prices was:

$$P_t = a_1 + \sum_{i=1}^{n} b_{1,i} P_{t-i} + \sum_{i=1}^{n} c_{1,i} U_{t-i} + \sum_{i=1}^{n} d_{1,i} W_{t-i} + e_{1,t}, \tag{5}$$

$$U_t = a_2 + \sum_{i=1}^{n} b_{2,i} P_{t-i} + \sum_{i=1}^{n} c_{2,i} U_{t-i} + \sum_{i=1}^{n} d_{2,i} W_{t-i} + e_{2,t}, \tag{6}$$

$$W_t = a_3 + \sum_{i=1}^{n} b_{3,i} P_{t-i} + \sum_{i=1}^{n} c_{3,i} U_{t-i} + \sum_{i=1}^{n} d_{3,i} W_{t-i} + e_{3,t}, \tag{7}$$

where P, U and W denote paper, wood pulp and pulpwood stumpage prices, respectively; a, b, c and d indicate parameters, and e refers to white noise error.

The VAR models were estimated by OLS. Since all the right-hand-side variables in each model are the same, the OLS estimates of each equation are the same as seemingly unrelated regression estimates. The test of causality of sawtimber price S on lumber price L is equivalent to the test of the null hypothesis that the coefficients of lagged S in the L equation are all zero. This was tested with the following F ratio:

$$F_{S\to L} = \frac{(\mathrm{SSE_R} - \mathrm{SSE_U})/m}{\mathrm{SSE_U}/(2m+1)} \sim F_{m,2m+1}(\alpha), \tag{8}$$

where $\mathrm{SSE_R}$ is sum of squared errors of Eq. (3) with the coefficients of lagged S set to zero; $\mathrm{SSE_U}$ is sum of squared errors of the unrestricted equation and α is the critical value. If $F_{S\to L}$ is less than $F_{m,2m+1}(\alpha)$, S does not cause L; otherwise, S causes L. If S causes L and L causes S, there is a feedback relationship between S and L. The causality is in Granger's sense, i.e., in the sense of predictability.

Multiplier analysis

Dynamic multipliers measure the change in the dependent variables caused by a permanent one-unit change in independent variables, other things being kept equal.[3] The multipliers use the VAR(p) model written as a first-order system:

$$\mathbf{y}_t = \boldsymbol{\mu} + \boldsymbol{\Pi}_0 \mathbf{y}_{t-1} + \boldsymbol{\varepsilon}_t. \tag{9}$$

For example, Eqs. (5)–(7), assumed to be of order $n = 3$ for presentation purpose, can be written as

$$\begin{bmatrix} P_t \\ P_{t-1} \\ P_{t-2} \\ U_t \\ U_{t-1} \\ U_{t-2} \\ W_t \\ W_{t-1} \\ W_{t-2} \end{bmatrix} = \begin{bmatrix} a_1 \\ 0 \\ 0 \\ a_2 \\ 0 \\ 0 \\ a_3 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} & b_{13} & c_{11} & c_{12} & c_{13} & d_{11} & d_{12} & d_{13} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ b_{21} & b_{22} & b_{23} & c_{21} & c_{22} & c_{23} & d_{21} & d_{22} & d_{23} \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ b_{31} & b_{32} & b_{33} & c_{31} & c_{32} & c_{33} & d_{31} & d_{32} & d_{33} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} P_{t-1} \\ P_{t-2} \\ P_{t-3} \\ U_{t-1} \\ U_{t-2} \\ U_{t-3} \\ W_{t-1} \\ W_{t-2} \\ W_{t-3} \end{bmatrix} + \varepsilon_t. \tag{10}$$

[3]King and Watson (1997) argue that studying the effect of a permanent one-unit change in a variable on the others only makes sense when the variables are integrated of order one. This measure is meaningful only when "permanent changes … exist in the historical data; that is, … (the data) must contain a unit root" (Rapach, 2002). If a variable is stationary, "the data will obviously be uninformative concerning the effects of a permanent change" (Rapach, 2002). Here, the variables are integrated of order one and not co-integrated, which allows a multiplier analysis based on VAR models in first differences.

The ith delayed-run multiplier (DRM) matrix indicating the effect of a one-unit change occurring i period ago, is

$$\mathrm{DRM}(i) = \mathbf{\Pi}_0^i. \tag{11}$$

The intermediate-run multiplier (IRM) matrix, measuring the cumulative impact of a unit change up to time m, is

$$\mathrm{IRM}(m) = \sum_{i=1}^{m} \mathbf{\Pi}_0^i. \tag{12}$$

And the long-run multiplier (LRM) matrix, measuring the total cumulative impact of a unit change in the variables is

$$\mathrm{LRM} = \sum_{i=1}^{\infty} \mathbf{\Pi}_0^i, \tag{13}$$

which converges to $(\mathbf{I} - \mathbf{\Pi}_0)^{-1}$, given that $\mathbf{\Pi}_0$ is a stable matrix. The (p,q) element of the matrix is the long-run multiplier for the change in the qth independent variable on the pth dependent variable.

We applied bootstrap resampling (Runkle, 1987) to derive the 95% confidence intervals of the long-run multipliers,[4] thus avoiding the normality assumption. The residuals were calculated as:

$$\hat{\boldsymbol{\varepsilon}}_t = \mathbf{y}_t - (\hat{\boldsymbol{\mu}} + \hat{\mathbf{\Pi}}_0 \mathbf{y}_{t-1}). \tag{14}$$

We then artificially generated a new set of $\hat{\mathbf{y}}_t$ by

$$\hat{\mathbf{y}}_t = \hat{\boldsymbol{\mu}} + \hat{\mathbf{\Pi}}_0 \mathbf{y}_{t-1} + \boldsymbol{\varepsilon}'_t, \tag{15}$$

where $\boldsymbol{\varepsilon}'_t$ was randomly selected from the time series of observed residuals $\{\hat{\boldsymbol{\varepsilon}}_t\}$, with replacement. This process was repeated for $M = 5000$ times, and each time, $\hat{\boldsymbol{\mu}}$, $\hat{\prod}_0$ and the long-run multipliers were calculated. The confidence interval of the long-run multipliers were then derived from the M replications.

Results

Presence of unit roots

The hypothesis of unit root could not be rejected, for all the price series, i.e., they were all nonstationary and integrated of order one (Table 1).

[4]The confidence bounds of multipliers can be calculated by asymptotic normal approximation (Dhrymes, 1973; Mittnik and Zadrozny, 1993), or by simulation (Runkle, 1987).

Table 1. Tests of unit roots in quarterly softwood stumpage prices and forest products prices from 1977 to 2002

Variable	Region	ADF[a] test statistic
Softwood lumber	US	−0.92
Softwood sawtimber stumpage	US South[b]	−1.1
Paper	US	−2.36
Pulp	US	−2.58
Softwood pulpwood stumpage	US South[b]	−2.13

[a]Augmented Dickey-Fuller test with an intercept, based on the regression: $P_t = \xi_1 \Delta P_{t-1} + \xi_2 \Delta y_{t-2} + \cdots + \xi_n \Delta P_{t-n} + \alpha + \rho P_{t-1} + \varepsilon_t$. where P_t is the price of interest. The null hypothesis of unit root ($\rho = 1$) cannot be rejected if the ADF statistic is greater than the critical value of −2.89 (95% confidence level). All tests were done with a maximum lag of eight quarters.

[b]Alabama, Arkansas, Louisiana, Mississippi, Tennessee, and Texas.

Absence of co-integration

For the co-integration tests, the ADF critical value for a model with an intercept was −2.89 at 0.05 significance level. The ADF statistic for co-integration between lumber and sawtimber was −2.44, and for paper, pulp and pulpwood −1.02. Thus, there was no evidence of significant co-integration.

VAR models

Tables 2 and 3 report the estimated coefficients of Models (3)–(7). A lag length of $m = 4$ for Eqs. (3) and (4), and $n = 3$ for Eqs. (5)–(7) led to white noise residuals. Since we took the first difference of quarterly series, this implied that in Eqs. (3)–(7) the short-run effects lasted 1 year and a quarter in the lumber-sawtimber subsystem, and one year in the pulpwood-pulp-paper subsystem.

Causality tests

The results of the Granger causality tests (Table 4) implied a short-run unidirectional and positive effect from the national price of softwood lumber to the price of softwood sawtimber stumpage in the US South. There was a significant, positive feedback relationship between US paper and wood pulp prices. In other words, they affected each other in the short-run. The prices of paper and pulp did not cause the price of pulpwood, but the price of pulpwood did cause that of pulp, in Granger's sense, and the effect was negative.

Long-run multipliers

The long-run multipliers and their 95% confidence intervals are in Table 5. The long-run multiplier of lumber price on sawtimber price was 1.1, significant at 95%

Table 2. Estimated vector autoregression model of lumber and sawtimber prices

$$\Delta L_t = \underset{(0.006)}{0\ .003} + \underset{(0.10)}{0.073}\,\Delta L_{t-1} - \underset{(0.11)}{0.17}\,\Delta L_{t-2} + \underset{(0.11)^*}{0.24}\,\Delta L_{t-3} + \underset{(0.11)^*}{0.29}\,\Delta L_{t-4} - \underset{(0.07)}{0.06}\,\Delta S_{t-1} - \underset{(0.06)}{0.08}\,\Delta S_{t-2} - \underset{(0.07)}{0.08}\,\Delta S_{t-3} - \underset{(0.06)^*}{0.16}\,\Delta S_{t-4}$$

$R^2 = 0.19$ Ljung box statistic = 9.89 (P-value = 0.971)

$$\Delta S_t = \underset{(0.008)}{-0.008} + \underset{(0.15)^*}{0.38}\,\Delta L_{t-1} + \underset{(0.16)}{0.24}\,\Delta L_{t-2} + \underset{(0.16)^*}{0.80}\,\Delta L_{t-3} + \underset{(0.18)^*}{0.40}\,\Delta L_{t-4} \underset{(0.11)}{-0.13}\,\Delta S_{t-1} - \underset{(0.10)}{0.18}\,\Delta S_{t-2} - \underset{(0.10)^*}{0.32}\,\Delta S_{t-3} + \underset{(0.10)}{0.03}\,\Delta S_{t-4}$$

$R^2 = 0.30$ Ljung box statistic = 19.90(P-value = 0.465)

Notes: Δ indicates first differencing. L = US softwood lumber price. S = Southern softwood sawtimber stumpage price. Both price series were quarterly and from 1977 to 2002. Numbers in parentheses are standard errors. *Indicates coefficients significantly different from zero at the 5% level.

level, suggesting a positive, persistent and almost one-to-one impact of the change in national lumber prices on the price of sawtimber stumpage in the US South. The full price of sawtimber stumpage responded sharply to the price of lumber within 1 year, and the full adjustment took about 2 years (Fig. 3). On the other hand, there was no long-run effect of the price of sawtimber stumpage in the South on the national price of softwood lumber.

The other significant multiplier was that of US wood pulp price on US paper price, equal to 0.3. This indicated a positive, though modest effect of a change in the wood pulp price on the paper price in the long run. The full adjustment process took about two years (Fig. 4). The short-term negative effect of the price of pulpwood on the price of pulp was not significantly different from zero in the long run (Table 5).

Summary and conclusion

Time–series methods were effective to study the transmission of price changes of wood products at different stages of manufacturing and in different regions. All the prices examined here were nonstationary and not co-integrated. Nevertheless, subsequent analysis and results suggests that the prices are not independent.

Table 3. Estimated vector autoregression model of paper, pulp and pulpwood prices

$$\Delta P_t = \underset{(0.0006)^*}{0.002} + \underset{(0.11)^*}{0.77}\,\Delta P_{t-1} - \underset{(0.14)}{0.07}\,\Delta P_{t-2} - \underset{(0.10)^*}{0.35}\,\Delta P_{t-3} + \underset{(0.03)^*}{0.08}\,\Delta U_{t-1} - \underset{(0.03)}{0.002}\,\Delta U_{t-2} + \underset{(0.03)}{0.04}\,\Delta U_{t-3} - \underset{(0.02)}{0.03}\,\Delta W_{t-1} - \underset{(0.02)}{0.01}\,\Delta W_{t-2} + \underset{(0.02)}{0.002}\,\Delta W_{t-3}$$

$R^2 = 0.74$ Ljung box statistic $= 13.71$(P-value $= 0.845$)

$$\Delta U_t = \underset{(0.002)}{0.0004} + \underset{(0.44)^*}{1.56}\,\Delta P_{t-1} - \underset{(0.55)}{0.36}\,\Delta P_{t-2} - \underset{(0.41)}{0.75}\,\Delta P_{t-3} + \underset{(0.12)^*}{0.44}\,\Delta U_{t-1} - \underset{(0.12)}{0.18}\,\Delta U_{t-2} - \underset{(0.12)}{0.05}\,\Delta U_{t-3} - \underset{(0.07)^*}{0.20}\,\Delta W_{t-1} + \underset{(0.07)}{0.11}\,\Delta W_{t-2} - \underset{(0.07)}{0.02}\,\Delta W_{t-3}$$

$R^2 = 0.52$ Ljung box statistic $= 22.22$(P-value $= 0.329$)

$$\Delta W_t = -\underset{(0.003)}{0.0014} + \underset{(0.68)}{0.17}\,\Delta P_{t-1} + \underset{(0.85)}{0.89}\,\Delta P_{t-2} - \underset{(0.63)}{0.42}\,\Delta P_{t-3} - \underset{(0.18)}{0.11}\,\Delta U_{t-1} + \underset{(0.19)}{0.07}\,\Delta U_{t-2} - \underset{(0.18)^*}{0.42}\,\Delta U_{t-3} - \underset{(0.10)}{0.08}\,\Delta W_{t-1} - \underset{(0.11)}{0.11}\,\Delta W_{t-2} + \underset{(0.11)}{0.13}\,\Delta W_{t-3}$$

$R^2 = 0.11$ Ljung box statistic $= 26.58$(P-value $= 0.147$)

Notes: Δ indicates first differencing. $P =$ US paper price. $U =$ US pulp price. $W =$ Southern softwood pulpwood stumpage price. All price series were quarterly and from 1977 to 2002. Numbers in parentheses are standard errors. *Indicates coefficients significantly different from zero at the 5% level.

The lack of co-integration allowed the construction of VAR models of price systems in first differences. The causality tests and multiplier analysis based on the VAR models indicated a positive causality, in Granger's sense, from the national lumber price and the price of sawtimber stumpage in the US South, both in the short-run and long-run. However, contrary to the "pass-through" and "price transmission" theories (Haynes, 1977), there was no reciprocal effect of the price of sawtimber stumpage on the national price of lumber. Therefore, even though the softwood sawtimber harvest from the South Central region is 29% of the national harvest of softwood sawtimber (USDA Forest Service, 1997), it is unlikely that policies that would alter the timber harvest in the South would substantially affect

Table 4. Tests of Granger causality between US wood-product and southern stumpage prices

Direction of causality	Magnitude[a]	df	F
Lumber → Sawtimber	1.82	4, 88	8.1*
Sawtimber → Lumber	−0.38	4, 88	2.3
Paper → Pulp	0.45	3, 88	6.5*
Pulp → Paper	0.12	3, 88	3.1*
Paper → Pulpwood	0.64	3, 88	0.7
Pulpwood → Paper	−0.02	3, 88	1.5
Pulp → Pulpwood	−0.46	3, 88	1.9
Pulpwood → Pulp	−0.11	3, 88	3.9*

*indicates that the F statistic is significantly different from zero at 95% confidence level.
[a]The magnitude of the causality of x on y is the sum of the coefficients of all lagged x in Tables 2 and 3.

Table 5. Long-run multipliers for US wood-product and southern stumpage prices

Direction of effect	Multiplier[a]	Confidence interval[b]
Lumber → Sawtimber	1.1*	(0.6,1.6)
Sawtimber → Lumber	−0.2	(−0.5, 0.1)
Paper → Pulp	0.9	(−1.7, 3.1)
Pulp → Paper	0.3*	(0.1, 0.5)
Paper → Pulpwood	0.6	(−1.9, 3.1)
Pulpwood → Paper	−0.1	(−0.2, 0.1)
Pulp → Pulpwood	−0.5	(−1.2, 0.3)
Pulpwood → Pulp	−0.2	(−0.6, 0.2)

[a]A long-run impact of a permanent one-unit change in price x on the price y.
[b]Empirical 95% confidence interval obtained from bootstrap re-sampling.

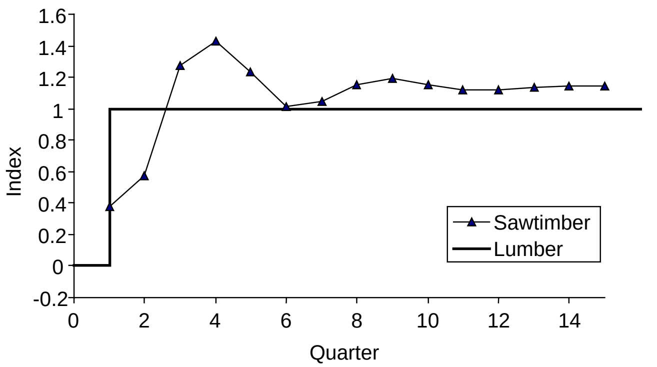

Fig. 3. Effect of a permanent one-unit increase in US softwood lumber price on southern softwood sawtimber stumpage price.

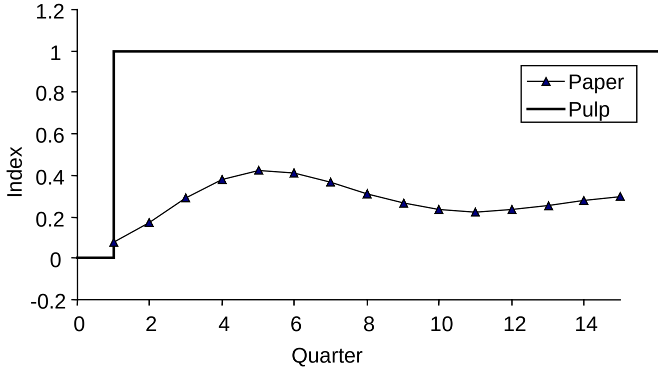

Fig. 4. Effect of a permanent one-unit increase in US wood pulp price on US paper price.

national lumber prices. On the other hand, policies that have an impact on national softwood lumber demand and therefore on its price would have a strong effect on the stumpage price of softwood sawtimber in the South. An example would be monetary policies keeping interest rates low to stimulate housing starts and lumber demand. Even more directly, policies that affect softwood lumber imports and exports would have an effect on sawtimber stumpage in the South Central region and presumably in other regions as well. This would include exchange rate policies (Sarker, 1993), and policies meant to mitigate the allegedly unfair competition from Canadian imports (Adams, 2003).

The lack of a long-term relation between the price of pulp and paper and the price of pulpwood suggests that the pulpwood market in the South is not competitive. Because there are few pulp and paper mills compared to the numerous small forest land owners in the South, pulp and paper mills have enough monopsony power to keep local prices of pulpwood low even when prices of pulp and paper are high, and thus reap substantial rent. A possible policy response for forest owners would be to set up cooperatives to negotiate prices collectively with the paper industry, and thus move up the price of pulpwood towards what it would be under pure competition, thus restoring a relationship between the price of pulpwood and the price of pulp and paper.

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Appendix A. Theoretical development of the vector autoregressive models of prices at different stages of manufacturing

Consider lumber and sawtimber stumpage prices for example. The lumber demand function is

$$L^{\mathrm{d}} = h_1(l, x), \tag{A.1}$$

where L^{d} is the quantity demanded, l is the lumber price, and x represents other factors influencing demand for lumber, such as housing starts and prices of other goods and services.

The lumber supply, L^{s}, depends on lumber price l, sawtimber stumpage price s, and other factors, denoted by y, such as the cost of labor, energy, and capital:

$$L^{\mathrm{s}} = h_2(l, s, y). \tag{A.2}$$

The derived demand function for sawtimber stumpage is

$$S^{\mathrm{d}} = h_3(l, s, y). \tag{A.3}$$

Finally, the supply function of sawtimber stumpage is

$$S^{\mathrm{s}} = h_4(s, z), \tag{A.4}$$

where z represents the cost of factors of production in producing sawtimber stumpage, such as land and capital.

At equilibrium $L^{\mathrm{d}} = L^{\mathrm{s}}$ and $S^{\mathrm{d}} = S^{\mathrm{s}}$, model (A.1)–(A.4) can be written as a reduced-form model

$$l = l(x, y, z), \tag{A.5}$$

$$s = s(x, y, z). \tag{A.6}$$

Disequilibrium causes dynamic price adjustments. This price adjustment process is a short-run phenomenon that converges to an equilibrium after a few time periods (Brorsen et al., 1985). Let $p_t = (l_t, s_t)'$ be the vector of prices at time t and $k_t = (x_t, y_t, z_t)'$ the vector of exogenous factors at time t, a general dynamic form of Eqs. (A.5) and (A.6), can be written as a multivariate autoregressive moving average process (Zellner and Palm, 1974):

$$B(L)\begin{bmatrix} p_t \\ k_t \end{bmatrix} = C(L)\begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix}, \tag{A.7}$$

where

$$B(L) = \begin{bmatrix} B_1(L) & B_2(L) \\ B_3(L) & B_4(L) \end{bmatrix} \text{ and } C(L) = \begin{bmatrix} C_1(L) & C_2(L) \\ C_3(L) & C_4(L) \end{bmatrix} \tag{A.8}$$

in which $B_i(L)$ and $C_i(L)$, for $i = 1,\ldots, 4$, are matrices of polynomials in the lag operator, L. e_{1t} and e_{2t} are vectors of random errors with zero mean, constant variance–covariance and no autocorrelation. Assuming that $B_4(L)$ is invertible, the process generating the exogenous variables can be written as

$$k_t = -B_4^{-1}(L)B_3(L)p_t + B_4^{-1}(L)C_3e_{1t} + B_4^{-1}(L)C_4(L)e_{2t} \tag{A.9}$$

which substituted in Eq. (7) gives

$$[B_1(L) - B_2(L)B4^{-1}(L)B_3(L)]p_t = [C_1(L) - B_2(L)B_4^{-1}(L)C_3(L)]e_{1t} + [C_2(L) - B_2(L)B_4^{-1}(L)C_4(L)]e_{2t}, \tag{A.10}$$

which is an autoregressive moving average model involving only lumber and sawtimber prices and random errors. If the right hand side of (A.10) is invertible, the model can be written as a bivariate vector autoregressive model like Eqs. (3) and (4) in the text. Similarly, the relationship between national paper, pulp prices and pulpwood stumpage prices in the South can be described by a tri-variate vector autoregressive model like Eqs. (5)–(7).

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