Timber Price Dynamics Following a Natural Catastrophe

Jeffrey P. Prestemon and Thomas P. Holmes

Catastrophic shocks to existing stocks of a renewable resource can cause long-run price shifts. With timber, these long-run price shifts may be accompanied by a short-run price drop due to salvage. Hurricane Hugo damaged 20% of southern pine timber in the South Carolina Coastal Plain in 1989. To estimate the short- and long-run effects of the hurricane on the prices of timber stocks, we estimated an intervention model of the residuals of cointegration of South Carolina sawtimber and pulpwood stumpage prices with prices of similar products from other regions. Modeling revealed a 30% negative price spike due to salvage and a long-run enhancement effect, leading to prices that are 10% to 30% higher than they would have been had Hugo not occurred.

Key words: cointegration, disasters, efficiency, Hurricane Hugo, intervention analysis, resource stocks.

The existing stock of a renewable resource such as timber influences the long-run quantity supplied in the "flow" market (Binkley, Newman). Because trees take a long time to grow, large reductions in timber stocks can lead to a price shift due to increasing scarcity and enhancement in value of remaining stocks. Sudden changes in stocks can occur for a number of reasons. For example, catastrophic changes in stocks of standing timber (stumpage) can result from quirks of nature such as fire, hurricanes, and pest outbreaks. Damaged timber stocks have vanishingly small opportunity costs and the liquidation of damaged stocks can create a supply pulse and concomitant negative price spike (Holmes). Stock changes can also result from changes in government policy. A notable example is the federal government's taking of forest land from private owners to create Redwood National Park. The large reduction in standing stocks of old-growth timber induced an upward shift in the time path of redwood timber prices, thereby creating an "enhancement" to the owners of remaining old-growth redwood stocks (Berck and Bentley).

Enhancement impacts on resource stocks are important to recognize because they represent a wealth transfer between economic agents. In the case of Redwood National Park, enhancement led to an increase in compensation to resource owners above and beyond the monetary settlement by the federal government. In the case of storms or fires, a wealth transfer can occur between owners of damaged and undamaged timber stocks. This transfer will become more consequential if storm-related damage to timber stocks becomes increasingly prominent as a result of global climate change.

Catastrophic risk can alter forest harvest and investment decisions. Reed shows that risk adds a time premium to the discount rate, which effectively shortens the optimal rotation for forest stands and decreases stand value. Yin and Newman (1996a) extend Reed's analysis to the multiple stand or forest case and show that catastrophic risk not only decreases the value of an investment project but also increases the critical price level at which a firm would consider investing in forestry. These analyses are predicated on the assumption that catastrophic damage is complete (the entire stand or forest is damaged) and homogeneous (affecting all owners equally). Apparently, the implications of damage that is either incomplete or nonho-

Jeffrey P. Prestemon and Thomas P. Holmes are both research foresters with the Forestry Sciences Laboratory, Forest Service, U.S. Department of Agriculture, Research Triangle Park, North Carolina.

The authors thank Robert Abt, Mary Ellen Aronow, Joseph Buongiorno, Barry Goodwin, Lawrence Jahn, Brian Murray, John Pye, David Wear, and several anonymous reviewers for their help in the development of this paper. Any errors are the responsibility of the authors.

Amer. J. Agr. Econ. 82 (February 2000): 145–160

mogeneous have not been recognized in the literature. We argue that incomplete, nonhomogeneous damage leads to enhancement effects to residual stocks that mitigate losses, to some extent, relative to complete and homogeneous damage. Implications for forest policy are dependent on characteristics of ownership. For example, small landowners that own one or a few forest tracts are likely to discount enhancement benefits. Large landowners can hedge against natural hazard risk by owning forest land in a variety of forest types and locations (Zinkhan, Sizemore, Mason, and Ebner). Enhancement effects can partially mitigate investment disincentives attributable to catastrophic risk for owners with geographically diversified holdings.

Models of timber price dynamics typically view standing timber as a capital asset with owners holding rational expectations with respect to future timber prices (Berck 1979; Lyon; Washburn and Binkley 1990). Timber owners respond to supply and demand shocks by either holding timber off the market (in anticipation of higher prices) or offering it up for sale (in anticipation of falling prices). If timber markets are informationally efficient, then markets adjust freely to new information and no opportunities exist for making excess profits by optimal harvest timing.[1] The rational expectations model assures us that, following an unpredictable catastrophic shock, agents of timber supply and demand take account of the new information and prices adjust to a new equilibrium that equates supply and demand (Berck 1979).

In this article, we use a rational expectations model to analyze price dynamics for stumpage markets in the southern United States. In the next section, we review the theory of timber as a capital asset, show how cointegration can be used to identify aggregate stumpage markets in "information space," and demonstrate the use of cointegration equation errors in identification of short-run and long-run deviations from equilibrium due to catastrophic stochastic events. Next, we present our empirical methods followed by a description of the data. This is followed by results of data analysis, conclusions, and a discussion of the policy implications of our findings.

[1] Tests for timber market efficiency yield conflicting results (Washburn and Binkley 1990; Haight and Holmes; Hultkrantz; Yin and Newman 1996b). Timber market efficiency is important to timber producers because, if timber markets are not weak-form efficient with respect to information, opportunities for making excess trading profits by timing timber harvests exist (Brazee and Mendelsohn).

Theoretical Model

Let P_t represent the price of timber at the mill yard and let λ_t represent the price of timber standing in the forest in year t. Stumpage price (λ_t) is the rental value of standing timber and is related to mill price by the following relationship: $\lambda_t = P_t - C_t$, where C_t is the cost of extraction (harvesting and transportation). Changes in stumpage price reflect changes in resource scarcity due to interactions of timber supply and demand in the stock and flow markets (Berck 1979,1981). In a deterministic world, prices of old-growth timber are expected to follow Hotelling's rule for nonrenewable resources and increase at the rate of interest (Lyon; Berck and Bentley). Timber growth provides a dividend to timber owners and prices for timber stocks with positive growth are expected to increase at the rate of interest minus the rate of growth (Lyon).

Intertemporal Arbitrage

In a stochastic world, changes in stumpage price reflect expectations about future supply and demand conditions. If markets are efficient, all information is included in the determination of price (Fama). The efficient market hypothesis states that a storable commodity such as timber will be withheld from (sold to) the market if the expected change in price is greater (less) than the storage and capital costs (Williams and Wright). If all agents holding a storable commodity behave according to this rule, the market will produce a rational expectations equilibrium.

Washburn and Binkley (1990) apply this theory to stumpage markets and provide the following intertemporal arbitrage condition:

$$(1) \qquad \lambda_t = E[(\lambda_{t+1}|\Phi_t)\exp(g_t - c_t - r_t)]$$

where E is the expectations operator, Φ_t is the information set, g_t is the growth rate of the stock of stumpage, c_t is the cost of storing the marginal stumpage unit (e.g., land rent and protection costs) as a proportion of stumpage price, and r_t is the discount rate. Equation (1) says that expected stumpage price increases at the rate of interest appropriately discounted for current growth and storage cost.[2] If stumpage price is expected to increase by a rate greater than (g, – c, – r,) in the next period, then more stumpage will be withheld from the market in the current period, driving up current price. Likewise, if stumpage price is expected to increase by a rate less than (g, – c, – r,), stumpage owners will sell more stumpage in the current period, driving current price down. If equation (1) holds, stumpage price follows a nonstationary stochastic process and is integrated of degree one, I(1).

After taking natural logarithms, equation (1) can be rewritten as

$$(2) \qquad \ln(\boldsymbol{\lambda}_t) = \beta \ln(\mathrm{E}[\boldsymbol{\lambda}_{t+1}|\Phi_t]) + g_t - c_t - r_t$$

where β is the elasticity of expected next period price with respect to current price. If stumpage price is a martingale (LeRoy), then $\beta = 1$ and $\ln(\boldsymbol{\lambda}_t) = \ln(E[\boldsymbol{\lambda}_{t+1}])$. As shown by Hultkrantz, the timber manager's decision rule for this case is to harvest timber when g, $= c_t + r_t$.[3] For stumpage, Φ_t contains information on factors influencing timber markets such as lumber prices, trade, housing starts, gross national product (GNP), wage rates, and stochastic disturbances such as hurricanes, fires, and pest outbreaks.

The martingale difference $\boldsymbol{\lambda}_{t+1}$ – A, is a stochastic process that depends on stochastic shocks affecting timber supply and demand. If the stumpage price process is a martingale then

$$(3) \qquad \mathrm{E}(\boldsymbol{\lambda}_{t+1} - \boldsymbol{\lambda}_t|\Phi_t) = 0$$

although the difference actually observed, $\boldsymbol{\lambda}_{t+1}$ – A, may be nonzero. For example, the amount of timber planned for harvest may differ from the actual harvest due to storms, fires, or pest outbreaks, and $\boldsymbol{\lambda}_{t+1}$ – A, $= \varepsilon_{t+1} \neq 0$. If stumpage price changes are a fair game and if we assume that ε_t is independently and identically distributed over time, then timber prices are distributed as a random walk. A random walk process has the important property that any stochastic shock has a permanent effect. For example, stumpage price at time t can be described as price during some initial period l_0, plus the sum of the stochastic shocks ε:

$$(4) \qquad \boldsymbol{\lambda}_t = \lambda_0 + \sum_{i=1} \varepsilon_i.$$

As described below, unit root tests are used to test whether stumpage prices follow a nonstationary, random walk process.

Cointegration of Stumpage Prices

If a linear combination of nonstationary variables results in a stationary process, such variables are said to be cointegrated (Engle and Granger). For example, if $\boldsymbol{\lambda}_t$ is a vector of stumpage prices in spatially distinct submarkets, and if each of the price series in $\boldsymbol{\lambda}_t$ is nonstationary, then

$$(5) \qquad \nu_t = \alpha_0 + \alpha_1' \boldsymbol{\lambda}_t$$

and the variables in A, are cointegrated with the parameters a $= (\boldsymbol{\alpha}_0, \boldsymbol{\alpha}_1)$ if v, is stationary, I(0). Thus, a stochastic shock ε_t in any one of the variables in A, is accompanied by a statistically similar (but not necessarily identical) change in one or several of the other variables in A, The a vector describes long-run equilibrium relations among variables in the system and v, describes short-run deviations from equilibrium.

During the past several years, cointegration tests have been used to assess the degree of market integration in spatially distinct agricultural markets (Ravallion; Ardeni; Goodwin and Schroeder). Cointegration tests have also been conducted for wood pulp markets in Canada (Alavalapati, Adamowicz, and Luckert), markets for Canadian lumber (Sarker), newsprint markets in the United Kingdom and Germany (Hanninen, Toppinen, and Ruuska), roundwood markets in Finland (Toppinen and Toivonen), and lumber markets in the United States (Murray and Wear). In these studies spatial arbitrage is hypothesized to be the error correction mechanism driving cointegrating relationships. However, cointegration does not necessarily imply market integration or spatial arbitrage between markets (McNew and Fackler). In particular, spatial arbitrage may not make sense for in situ resource stocks which, by definition, are spatially fixed in the long-run for exhaustible resources and are spatially fixed in the short- and quasi-long-run for renewable resources such as standing timber.

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[2] Historically, real stumpage prices in the South rose at a rate of 4.6% per year prior to World War II and have risen at a real rate of about 3.1% per year since then (Binkley and Vincent).

[3] The stochastic process of price change implied by $\beta = 1$ is a fair game or martingale difference; that is, the expected change in price from the current to next period is zero given current information, Φ_t (LeRoy).

We argue that cointegration for *in situ* resource stocks can occur because of intertemporal (rather than spatial) arbitrage for asset markets.[4] We propose that stumpage markets can be defined over "information space" as those submarkets responding in a statistically similar way to the same information Φ_t about factors influencing timber supply and demand. Washburn and Binkley (1993) conduct an informal test of this hypothesis using correlation coefficients between sawtimber stumpage markets for various states in the South. Based on their analysis, they conclude that "... stumpage prices in distant states are responding to different economic forces (or responding differently to the same forces), and that stumpage markets in different states are at least partly distinct" (p. 241). Their conclusion is contrarv to Hultkrantz's assertion that a single stumpage market exists in the South.

If stumpage submarkets $m = 1, ..., n$ are cointegrated in aggregate market M due to intertemporal arbitrage in informationally efficient markets, then short-run deviations from long-run equilibrium relations between submarkets are a function of the short-run stochastic shocks in each of the submarkets:

$$(6) \qquad \nu_{t,M} = \psi(\varepsilon_{t,1}, \varepsilon_{t,2}, \ldots, \varepsilon_{t,n}) \quad \forall m \in M$$

where $\psi(\bullet)$ describes a functional relationship. Equation (6) suggests that the impact of a stochastic shock in a particular submarket at time t can be detected by evaluating the series of short-run deviations from long-run equilibrium relations in the cointegrated aggregate market. However, a potential imprecision occurs because $\nu\lambda_{t,M}$ reflects the impacts of all short-run deviations in cointegrated submarkets. This imprecision can be obviated by evaluating cointegrating errors for pairs of cointegrated submarkets. Replication over all pairs of cointegrated submarkets allows an average short-run impact to be estimated or an estimated median short-run impact to be identified.

A change in the long-run equilibrium relationship between cointegrated submarkets due to enhancement of the residual resource stock undamaged by a catastrophic event can also be evaluated using a cointegrating relationship between submarkets. Because the cointegrating parameter vector a in equation (5) defines the long-run equilibrium relationship between cointegrated submarkets, new equilibrium relationships can be evaluated by considering a change in the parameter vector **a**.

Empirical Methods

Cointegration errors from pairs of 1(1) nonstationary price series are used to identify short-run and long-run changes in equilibrium relationships between stumpage submarkets in the South. Let stumpage prices in the experimental submarket, λ_x, and control submarkets, λ_y, be expressed in logarithmic form in the following relationship (Engle and Granger; Goodwin and Schroeder):

$$(7) \qquad \nu_{xy,t} = \lambda_{x,t} - \beta_{0xy} - \beta_{1xy}\lambda_{y,t}$$

where $\nu_{x,y}$ is I(0).[5] The long-run price elasticity β_{1xy} between submarkets x and y. β_{0xy} provides for a scaling of the relationship that might exist if there are differences in market structure, competing market substitutes, transportation costs, or product quality between the submarkets.

Two methodologies are used to test for cointegration of experimental and control submarkets using equation (7). First, we use the two-step method proposed by Engle and Granger (EG). In multivariate systems, the EG method suffers from ambiguity regarding which variable in the first-step is the regressand, and different regressands may lead to different inferences regarding cointegration. However, in bivariate systems, the EG model is statistically comparable to bivariate equation estimates using the Johansen model without running the risk of misspecification due to an incorrect choice of the number of lags (Gonzalo). We also use the method of Johansen, which is based on the characteristic roots of a vector autoregression. For the Johansen test, we evaluate cointegration equations for the period prior to the intervention and for the entire series.[6] For our study, cointegration relies on the rule that the Johansen trace test must be significant at the 0.05 level or higher. If not, the EG test must be significant at the 0.01 level for cointegration.

[4] A more liberal definition of spatial arbitrage, however, could encompass intertemporal arbitrage of spatially distributed markets.

[5] The logarithmic transformation is appropriate for nominal prices that initially differ in magnitude, since under cointegration a constant ratio is maintained if inflation affects both series identically, while a constant difference is not.

[6] Cointegration errors must be stationary, which implies constant variance. Structural change due to catastrophic events may violate this criterion.

Intervention Analysis

Formal identification of a change in the mean of a stationary time series proceeds via the use of intervention analysis, whereby we test the effect of exogenous variables related to regime shifts on a univariate time series of cointegration equation errors (Enders, pp. 270–73).[7] We utilize a switching regression model (Judge et al.) to capture the short-run and long-run switching behavior due to a catastrophic event. The impacts of a stochastic catastrophic event can be handled ***ex post*** by the use of dummy variables. Let $P_t^{(T)}$ be a "pulse" dummy variable where

$$(8) \quad P_t^{(T)} = 0, \quad t \neq T \\ = 1, \quad t = T$$

and let $S_t^{(T)}$ be a "step" dummy variable where

$$(9) \quad S_t^{(T)} = 0, \quad t < T \\ = 1, \quad t \geq T.$$

The pulse function (8) is used to test for a short-run price impact associated with timber salvage. The step function (9) is used to test for a structural adjustment due to value enhancement of residual capital stocks.

Intervention analysis proceeds by estimating the parameters of the cointegration equation (7). For cointegrated submarkets, we re-specify equation (7) to account for three regimes spanned by the time series. The first regime change represents the impact of timber set-asides in the Pacific Northwest to protect the northern spotted-owl and old-growth forests. Murray and Wear report that this policy affects the structure of long-run equilibrium between lumber markets, and we test for an impact in stumpage markets by including a dummy variable D_t. The second regime change is due to the short-run pulse of timber salvaged from a catastrophic event, and the third regime change we test for is due to long-run enhancement in residual timber stocks. Equation (7) is re-specified as

$$(10) \quad \nu_{xy,t} = \lambda_{x,t} - \beta_{0xy} - \beta_{1xy}\lambda_{y,t} - \beta_{2xy}D_t\lambda_{y,t} \\ - \beta_{3xy}P_t^{(T)} - \beta_{4xy}S_t^{(T)}\lambda_{y,t}.$$

Equation (10) includes ***ex post*** information about short-run and long-run regime changes. In order to model the dynamic aspects of regime changes due to a catastrophic event, we compute the pseudo-residual series $\xi_{xy,t}$:

$$(11) \quad \xi_{xy,t} = \lambda_{x,t} - \beta_{0xy} - \beta_{1xy}\lambda_{y,t} - \beta_{2xy}D_t\lambda_{y,t}$$

where the parameters in equation (11) are estimates from equation (10). The pseudo-residual series ~,,,, contains information on impacts of the catastrophic event.

Next, we model the dynamic properties of the stationary $\xi_{xy,t}$ series as an ARMA(J,K) process:

$$(12) \quad \xi_{xy,t} = f(\xi_{xy,t-J}, \zeta_{xy,t-K}, P_t, S_t) + \zeta_{xy,t}$$

where ζ_{xy} is a white noise error with mean zero and constant variance, and J (>0) and K (>0) are finite numbers of past levels of ξ_{xy} and errors ζ_{xy}, respectively. Equation (12) is estimated by ordinary least squares.

In AR(1) form (which we use below), equation (12) is written explicitly as

$$(13) \quad \xi_{xy,t} = c_{0xy} + c_{1xy}\xi_{xy,t-1} + c_{2xy}P_t^{(T)} + c_{3xy}S_t^{(T)} \\ + \zeta_{xy,t}$$

where $0 < c_{1xy} < 1$. A sudden influx of salvage timber due to a catastrophic event suggests that c_{2xy} is negative. Enhancement due to a reduction in the stock of standing timber suggests that c_{3xy} is positive. Upon obtaining OLS estimates of the parameters in equation (13), the effect of a catastrophic event on stumpage price is calculated as $(c_{2xy} + c_{3xy})$ during the supply pulse.

The dynamic effects of a catastrophic intervention can be obtained from the impulse response function (Enders)[8]:

$$(14) \quad \xi_t = c_{0xy}/(1 - c_{1xy}) + c_{2xy}\sum_{i=0} c_{1xy}^i P_{t-i}^{(T)} \\ + c_{3xy}\sum_{i=0}^{\infty} c_{1xy}^i S_{t-i}^{(T)} + \sum_{i=0}^{\infty} c_{1xy}^i \zeta_{t-i}.$$

Equation (14) traces out the dynamic impacts of a catastrophic event on the time path of stumpage prices. The change in long-run equilibrium is G = $c_{3xy}/(1-$ c,,). Analytical standard errors for the supply pulse and the long-run equilibrium impact are computed using the Delta method (Goldberger, p. 110).

'Intervention analysis was introduced by Box and Tiao, who demonstrated its use by analyzing the impact of public policy on the output of economic and environmental systems.

[8] Impulse-response functions are also used to evaluate the response of an endogenous variable to a standard (typically, one standard deviation) shock in a cointegrated variable (Liitkepohl and Reimers).

Interventions in Submarket Controls

The model in equations (7)–(13) is built on the assumption that stumpage markets are cointegrated in "information space" via intertemporal, rather than spatial, arbitrage. If markets are integrated in the sense of Ravallion and McNew and Fackler, then interventions in the experimental submarket could be directly identified in control submarkets as well. For example, a supply pulse and downward price "spike" in submarket x may be associated with a supply pulse in submarket y if timber buyers in y haul logs from x to their own submarket for processing.

We test for direct interventions in submarket controls using ARMA models of first-differenced price series. We use the pulse variable $P_t^{(T)}$ and test whether or not this variable is statistically significant in the control submarkets at about the same time:

$$(15)\quad \Delta p_t = f(\Delta p_{t-L}, z_{t-M}, P_t^{(T)}, P_{t-1}^{(T)}, \ldots, P_{t-4}^{(T)}) + z_t$$

where Ap is the first-difference in the natural logarithm of the price series, L and M are the number of lags (>0) of the first-difference, and the z's are the random errors.

Data

The case we use to evaluate the impact of a catastrophic event on timber prices is Hurricane Hugo, a Class IV hurricane that struck the coast of South Carolina on 22 September 1989. This hurricane destroyed approximately 20% of the standing timber in the South Carolina coastal plain (Sheffield and Thompson). Because this natural disturbance is likely large enough to induce both a short-run supply pulse and long-run enhancement of residual stocks, it is chosen for analysis.

Timber price data used in the analysis are available from the *Timber Mart-South (TMS)* (Norris Foundation) price series. *TMS* is a quarterly price data report for timber submarkets throughout the South. Our data cover the period from the first quarter of 1977 (i.e., 1977:1) through the first quarter of 1997 (1997:1) (N = 81). The South Carolina coastal plain submarket SC(2) is the forested area that received significant damage from the hurricane, and a small adjacent Piedmont market for South Carolina, SC(1), is also included. Both are considered experimental submarkets for our analysis. The dummy variable corresponding to the Pacific Northwest timber inventory set-asides, D_t, is set to zero from 1977:1 through 1987:4, and set to one for 1988:1 through 1997:1. The supply pulse dummy, $P_t^{(T)}$, always takes on the value of zero except for one quarter, 1989:4, corresponding to the initial salvage pulse. The step dummy, $S_t^{(T)}$, which measures value enhancement to the remaining inventory as a result of the inventory shock, is zero from 1977:1 through 1989:3, and one from 1989:4 through 1997:1.

Figures 1 and 2 plot the path of southern pine sawtimber and pulpwood stumpage prices for the entire period of the analysis. The two South Carolina submarkets are shown along with a regional average price outside of South Carolina as a comparison. The negative price response to the pulse of salvage for the quarter immediately after the hurricane, 1989:4, is evident for both series and products.

Both temporal frequency and spatial aggregation of submarkets changed over the period covered by the price series. Consequently, it is necessary to adjust data across *TMS* submarkets within states and across time. From 1977 through 1991, most coastal states report price data for three *TMS* submarkets. From 1992 onward, these three *TMS* submarkets are consolidated into two. We create a new, two-region series from the prior (pre-1992) three-region series using a weighting scheme based on timber harvest volumes in the region.[1] Time aggregation involves converting monthly data to quarterly data. From 1977 through 1987, *TMS* reports monthly prices, and from 1988 onward, quarterly prices are reported. To avoid potential loss of information due to averaging price series (Haight and Holmes), we use middle-month price series observations for the pre-1988 period (i.e., the February price was treated as the first quarter price, the May price was treated as the second quarter price, and so on). Independent modeling (not reported here) indicates that the aggregation methods used do not affect the analysis.

Results

Unit Root Tests and Interventions in Submarket Controls

Table 1 summarizes our findings regarding stationarity of stumpage price series and the direct impacts of the hurricane on the experi-

[1] The weights are available from the authors.

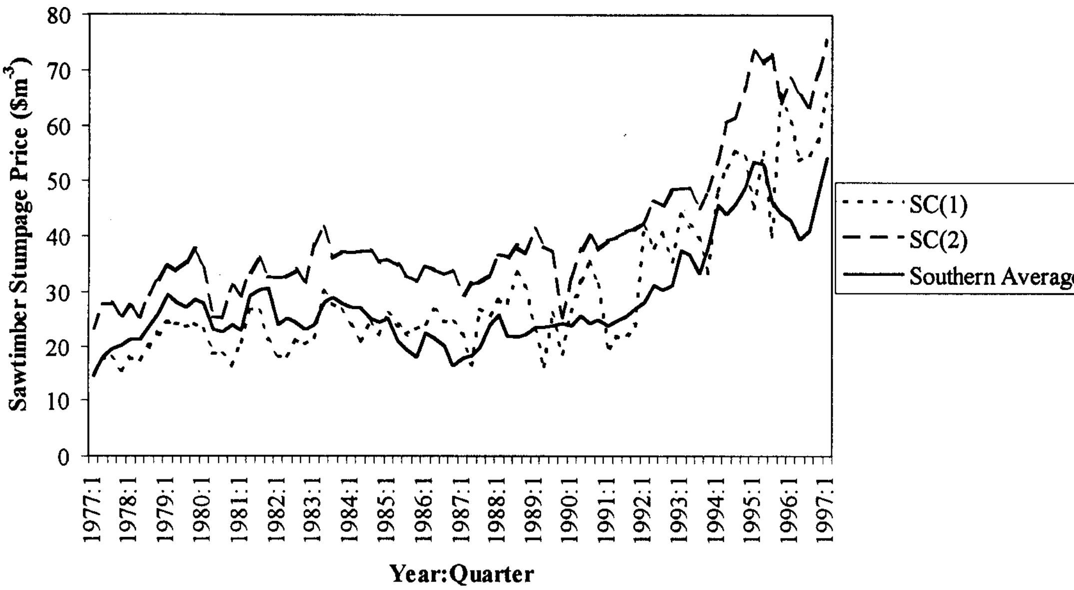

Figure 1. South Carolina southern pine sawtimber stumpage prices and a removals-weighted average of southern pine sawtimber stumpage prices for areas excluding South Carolina and bordering states, **1977:1** to **1997:1**

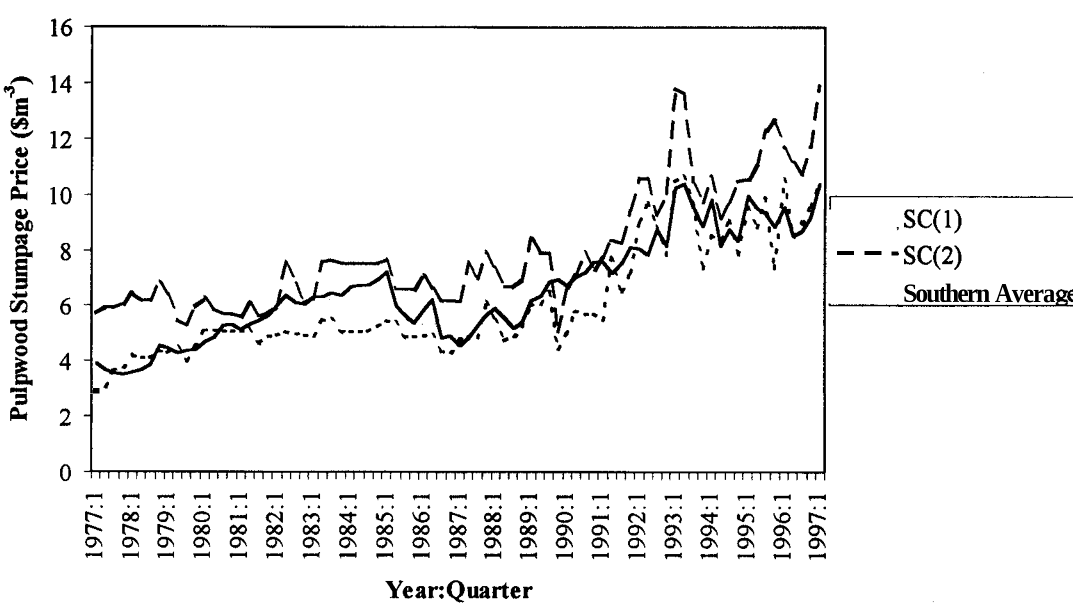

Figure 2. South Carolina southern pine pulpwood stumpage prices and a removals-weighted average of southern pine pulpwood stumpage prices for areas excluding South Carolina and bordering states, **1977:1** to **1997:1**

mental submarkets SC(1) and SC(2) and thirteen control submarkets for pine sawtimber and pulpwood. The first column of table 1 shows the results of augmented Dickey-Fuller (ADF) tests of the natural logarithms of nominal stumpage price series, including the number of lags of residual first-differences used in the ADF tests and the test statistic and associated significance. The next three columns report the results of autoregressive models of first-differences of these price series, including the number of lags of the dif-

Table 1. Unit Root Tests and First-Difference ARMA Equation Estimates for Selected Southern Pine Stumpage Price Series

		ADF Statistic		AR Equation Estimates		
Product	State (Area)	Criterion	Lagged Differences	Lagged Terms	Durbin-Watson	Short-Run Intervention Dummy
Sawtimber	AL(2)	−1.43	1	1	1.98	
	ARK(1)	−1.44	1	1, 2	2.07	
	FL(1)	−0.72	4	4	1.88	
	FL(2)	−1.17	1	none	1.87	
	GA(2)	−0.65	2	1, 2	1.95	
	LA(1)	−1.03	1	1	2.06	
	LA(2)	−0.62	3	1	1.96	
	MS(1)	−0.53	2	1	2.05	
	MS(2)	−0.99	2	1, 2	1.97	
	NC(2)	−1.33	2	1, 2, 5	2.01	
	SC(1)	0.56	6	1	2.06	*
	SC(2)	0.43	6	1	1.98	***
	TX(1)	−1.90	1	1	2.03	
	TX(2)	−1.50	2	1, 2	2.07	
	VA(2)	−1.17	1	1	1.92	a
Pulpwood	AL(2)	−1.45	1	1	2.05	a
	ARK(1)	−2.44	1	1	2.00	
	FL(1)	−1.88	1	1	2.03	
	FL(2)	−1.75	3	1, 2, 3	2.02	
	GA(2)	−1.57	2	1, 2	2.04	
	LA(1)	−1.66	2	1, 2	2.00	
	LA(2)	−1.49	2	1, 2	2.00	
	MS(1)	0.37	1	1	2.00	
	MS(2)	−1.03	2	1	2.12	
	NC(2)	−1.11	4	1	2.02	
	SC(1)	−0.85	3	1, 4	2.16	***
	SC(2)	0.16	8	1, 2	2.10	***
	TX(1)	−1.93	2	1, 2	1.96	
	TX(2)	−2.08	2	1, 2	2.02	
	VA(2)	−2.04	7	1, 2	2.11	

Note: Prices are natural logarithms and nominal, expressed in dollars per thousand board-feet (sawtimber) or dollars per standard cord (pulpwood). Asterisks indicate a significant price departure during at least one of the four quarters following the catastrophic intervention at 1% (***) or 10% (*).
[a] The $P_t^{(T)}$ shock has a positive impact on price, counter to expectations.

ferenced price terms, Durbin-Watson test statistics for each model, and an indication of whether any of the current or four lagged $P_t^{(T)}$ terms are statistically significantly different from zero.

As indicated by table 1, we cannot reject the hypothesis that logarithmic stumpage price series are nonstationary 1(1) processes for selected submarkets in the southern United States. This result implies that southern stumpage markets are informationally efficient and that no excess profits can be made by optimal timing of harvests using information on historical prices.[10] This conclusion contrasts with Hultkrantz and Yin and Newman (1996b) but confirms previous analyses by Washburn and Binkley (1990, 1993) and Haight and Holmes for southern pine stumpage prices. It is more robust than the latter two studies because (a) our prices are "spot" prices, not average prices, (b) we include pulpwood prices in addition to sawtimber prices, (c) we evaluate price series for submarkets and do not aggregate to the state level, and (d) our series are longer relative to earlier studies. Our finding of nonstationarity is consistent with intertemporal arbitrage described in equations (1) through (3), and allows further cointegration testing.

As shown in table 1, we can find no detectable effect of a short-run supply pulse following the hurricane in the price series of any control submarket series outside of South

[10] This assumes that timber contracts cannot be closed in less than three months.

Table 2. Cointegration Tests for Pairs of Nominal Price Series, 19721 to 19921, for Southern Pine Sawtimber Stumpage, TMS Submarkets 1 and 2, South Carolina

South Carolina Submarket	State (Submarket)	Engle-Granger $(p)^a$	Johansen Trace $(p)^b$	Johansen Trace $(p)^c$	Cointegrated?
Submarket 1	Virginia (2)	−4.93(2)***	22.83(1)**	23.03(1)**	Yes
	Florida (1)	−5.39(0)***	17.32(1)	18.97(1)*	Yes
	Florida (2)	−5.67(0)***	28.39(1)***	24.93(1)***	Yes
	Alabama (2)	−5.37(0)***	20.86(1)**	22.85(1)**	Yes
	Mississippi (1)	−3.21(0)*	20.64(4)**	18.72(1)*	Yes
	Mississippi (2)	−3.27(0)*	19.13(4)*	16.92(1)	No
	Arkansas (1)	−3.25(0)*	16.03(1)	12.03(1)	No
	Louisiana (1)	−3.67(0)**	14.54(4)	10.01(1)	No
	Louisiana (2)	−3.41(0)*	18.60(4)*	10.50(1)	No
	Texas (1)	−3.16(0)*	18.98(4)*	11.62(1)	No
	Texas (2)	−3.15(0)*	18.23(4)*	11.78(1)	No
Submarket 2	Virginia (2)	−3.35(0)*	14.87(1)	16.49(1)	No
	Florida (1)	−5.11(0)***	28.26(1)***	20.11(1)**	Yes
	Florida (2)	−5.63(0)***	30.50(1)***	22.77(1)**	Yes
	Alabama (2)	−5.95(0)***	31.54(1)***	19.54(1)*	Yes
	Mississippi (1)	−2.97(0)	18.11(4)*	16.03(1)	No
	Mississippi (2)	−2.93(0)	17.30(4)	15.52(1)	No
	Arkansas (1)	−3.01(0)	13.46(1)	10.30(1)	No
	Louisiana (1)	−3.09(0)	15.64(1)	8.16(1)	No
	Louisiana (2)	−3.26(0)*	16.73(1)	9.50(1)	No
	Texas (1)	−2.70(0)	15.19(1)	11.23(1)	No
	Texas (2)	−2.75(0)	21.91(1)**	12.06(1)	No

Note: ***hypothesis of no cointegration rejected at 1%, ** at 5%, and * at 1% significance.
[a] Augmented Dickey-Fuller test on residuals of the cointegrating equation (1977:1–1997:1), with p lagged difference terms.
[b] Johansen trace test of more than one cointegrating vector on pairs of series, 1977:1–1987:4, with an intercept in the cointegrating equation and none in the VAR, with p lagged difference terms.
[c] Johansen tests on pairs of series, 1977:1–1997:1, with an intercept in the cointegrating vector and none in the VAR, with p lagged difference terms.

Carolina.[11] We conclude that, because the pulse of salvage in the experimental submarket is not detected in control submarkets outside of South Carolina, the experimental pine stumpage submarket has very limited spatial integration with other control submarkets. This finding lends additional support to our claim that equilibrium relationships in southern stumpage prices derive from intertemporal, not spatial, arbitrage, and that large supply pulses within one submarket have undetectable effects in other submarkets.[12]

Cointegration and Interventions in Experimental Submarkets

Estimates of equation (7) and cointegration test statistics are shown in table 2 for southern pine sawtimber stumpage and in table 3 for southern pine pulpwood stumpage. Results in table 2 show that, for both of South Carolina's *TMS* submarkets, sawtimber stumpage prices are cointegrated with about 25% to 50% of the control submarket series. SC(1) sawtimber prices are more commonly cointegrated with control submarkets than are SC(2) prices. Both sawtimber series demonstrate geographic contiguity in that cointegration is less common the farther the control series is from South Carolina. Our finding that cointegration decays with distance is consistent with findings in Washburn and Binkley (1993).

As shown in table 3, pulpwood stumpage markets demonstrate complete geographic contiguity, with all control submarket price series cointegrated with SC(1) pulpwood prices. This result may arise because SC(1) is a very small pulpwood-producing region, and prices in this region follow prices in other regions. In contrast, no geographic contiguity is implied by the geographically dispersed cointegration displayed by the SC(2) pulpwood price series. SC(2) is an important pulpwood-producing region and market forces in this region appear to be mostly independent

[11] In only two cases did parameter estimates indicate a significant departure from zero in control price series, but in both cases the significant departure was positive, not negative.
[12] The negative price spike in SC1 is due to hauling logs from the experimental submarket SC2 to SC1, thereby depressing short-run stumpage price in SC1.

Table 3. Cointegration Tests for Pairs of Nominal Price Series, 19771 to 19971, for Southern Pine Pulpwood Stumpage, *TMS* Submarkets 1 and 2, South Carolina

South Carolina Submarket	State (Submarket)	Engle-Granger $(p)^a$	Johansen Trace $(p)^b$	Johansen Trace $(p)^c$	Cointegrated?
Submarket 1	Virginia (2)	−3.60(0)**	24.62(1)***	15.51(1)	Yes
	Florida (1)	−5.10(0)***	35.14(1)***	24.73(1)***	Yes
	Florida (2)	−4.63(0)***	33.61(1)***	22.91(1)**	Yes
	Alabama (2)	−4.28(0)***	35.08(1)***	25.71(1)***	Yes
	Mississippi (1)	−3.37(0)*	25.12(1)***	26.78(1)***	Yes
	Mississippi (2)	−3.97(0)**	21.45(1)**	21.53(1)***	Yes
	Arkansas (1)	−3.36(0)*	20.98(1)**	19.31(1)*	Yes
	Louisiana (1)	−3.84(0)**	19.91(1)**	16.90(1)	Yes
	Louisiana (2)	−3.35(0)*	18.39(1)*	20.99(1)**	Yes
	Texas (1)	−3.76(0)**	22.43(1)**	15.64(1)	Yes
	Texas (2)	−3.13(0)*	21.14(1)**	20.76(1)**	Yes
Submarket 2	Virginia (2)	−4.40(0)***	17.04(4)	15.69(4)	No
	Florida (1)	−2.74(0)	11.26(1)	12.51(1)	No
	Florida (2)	−3.00(0)	11.23(1)	11.78(1)	No
	Alabama (2)	−2.76(0)	12.64(1)	21.09(4)**	No
	Mississippi (1)	−1.67(3)	22.04(1)***	33.54(1)***	Yes
	Mississippi (2)	−0.76(3)	16.36(1)	22.06(1)**	Yes
	Arkansas (1)	−1.38(3)	16.93(1)	19.06(1)*	No
	Louisiana (1)	−2.96(0)	16.23(1)	16.90(1)	No
	Louisiana (2)	−3.35(0)*	17.31(1)	20.99(1)**	Yes
	Texas (1)	−1.84(3)	14.67(1)	15.14(1)	No
	Texas (2)	−1.59(3)	16.94(1)	18.81(1)*	Yes

Note: ***hypothesis of no cointegration rejected at 1%, ** at 5%, and * at 1% significance.
[a] Augmented Dickey-Fuller tests on residuals of pairs of series with intercept.
[b] Johansen trace tests of more than one cointegrating vector on pairs of series, 1977:1–1987:4, with an intercept in the cointegrating equation and none in the VAR, with p lagged difference terms.
[c] Johansen tests on pairs of series, 1977:1–1997:1, with an intercept in the cointegrating vector and none in the VAR, with p lagged difference terms.

Table 4. Southern Pine Sawtimber Stumpage Price Intervention Equation Estimates, *TMS* Submarkets 1 and 2, South Carolina

South Carolina Submarket	State (Submarket)	Intercept	ξ_{t-1}	$P_t^{(T)}$	$S_t^{(T)}$	Adjusted R^2
Submarket 1	Virginia (2)	0.002	0.39***	−0.41**	0.17***	0.44
		(0.024)	(0.10)	(0.17)	(0.05)	
	Florida (1)	0.002	0.35***	−0.40**	0.09**	0.26
		(0.021)	(0.10)	(0.15)	(0.04)	
	Florida (2)	0.001	0.30***	−0.44***	0.14***	0.32
		(0.022)	(0.10)	(0.16)	(0.04)	
	Alabama (2)	0.002	0.43***	−0.41**	0.10**	0.32
		(0.023)	(0.10)	(0.17)	(0.04)	
	Mississippi (1)	0.002	0.53***	−0.53***	0.09**	0.44
		(0.023)	(0.09)	(0.17)	(0.04)	
	Mississippi (2)	0.003	0.58***	−0.54***	0.09***	0.48
		(0.023)	(0.09)	(0.17)	(0.04)	
Submarket 2	Florida (1)	0.001	0.46***	−0.39***	0.04**	0.50
		(0.009)	(0.08)	(0.06)	(0.01)	
	Florida (2)	−0.000	0.40***	−0.42***	0.07***	0.54
		(0.010)	(0.08)	(0.07)	(0.02)	
	Alabama (2)	0.001	0.58***	−0.39***	0.04**	0.55
		(0.011)	(0.08)	(0.08)	(0.02)	

Note: *** indicates significance at 1%, ** at 5%, and * at 10%. Standard errors in parentheses.

of other pulpwood-producing regions. In sum, these results suggest that the geographic contiguity of sawtimber markets differ from, and may be less variable than, the geographic contiguity of pulpwood markets.

Table 4 shows that typical intervention equation estimates for sawtimber stumpage have substantially good fit, register significant short-run price effects from the hurricane, and exhibit broad support for price enhance-

Table 5. Estimated Short-Run and Long-Run Southern Pine Sawtimber Stumpage Price Effects (1989 $\$m^{-3}$) Attributable to Hurricane Hugo, TMS Submarkets 1 and 2, South Carolina

South Carolina Submarket	State (Submarket)	Short-Run Effect (natural log)	Long-Run Effect (natural log)	Short-Run Effect ($\$m^{-3}$)	Long-Run Effect
Submarket 1	Virginia (2)	–0.24	0.28***	–5.06	7.60
		(0.17)	(0.11)		
	Florida (1)	–0.31**	0.14**	–6.76	3.75
		(0.15)	(0.07)		
	Florida (2)	–0.30*	0.20***	–6.49	5.47
		(0.15)	(0.07)		
	Alabama (2)	–0.31*	0.17**	–6.83	4.67
		(0.16)	(0.08)		
	Mississippi (1)	–0.44***	0.20*	–10.23	6.37
		(0.17)	(0.10)		
	Mississippi (2)	–0.45***	0.22*	–10.51	7.06
		(0.17)	(0.12)		
Submarket 2	Florida (1)	–0.36***	0.07**	–11.05	2.48
		(0.06)	(0.03)		
	Florida (2)	–0.35***	0.11***	–10.88	4.33
		(0.07)	(0.04)		
	Alabama (2)	–0.35***	0.09*	–10.66	3.59
		(0.08)	(0.05)		

Note: *** indicates significance at 1%, ** at 5%, and * at 10%. Standard errors, in parentheses, computed using the delta method.

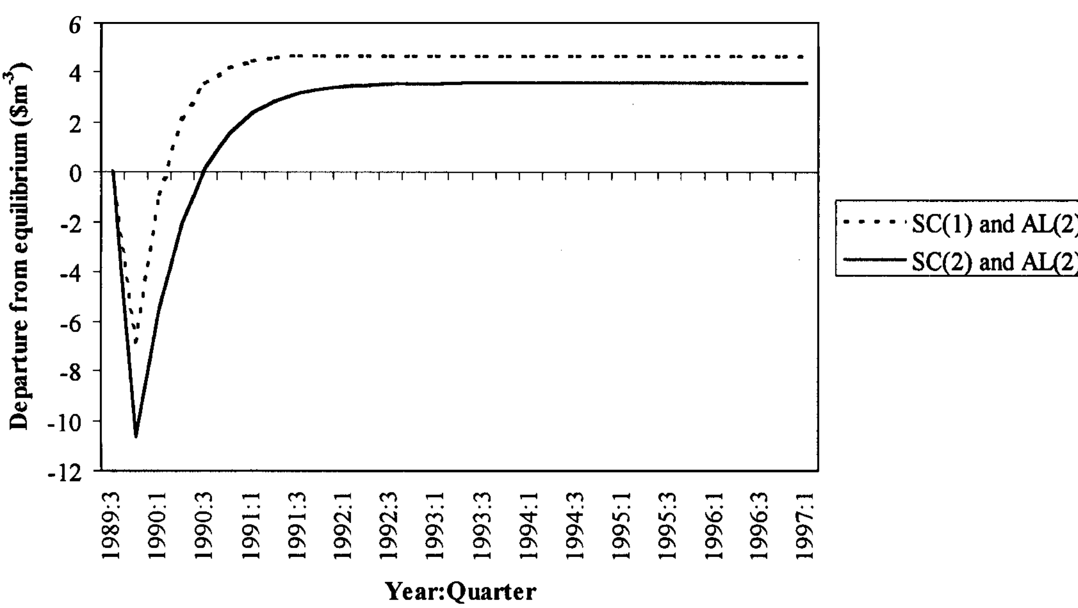

Figure 3. Impulse response functions of Hurricane Hugo on southern pine sawtimber stumpage prices, 1989:3 to 1997:1, TMS sub-markets 1 and 2, using Alabama sub-market 2 as the comparison cointegrated series

ment to residual stands. Equation R^2's are around 0.50, ranging from 0.26 to 0.55.

As shown in tables 4 and 5, nearly all equations reveal statistically significant negative short-run price spikes. Sawtimber stumpage prices in SC(1) drop by $5.1 to $10.5 per cubic meter (21% to 36%) and in SC(2) drop by $10.2 to $11.2 per cubic meter (29% to 30%). Standard errors of short-run effects are shown in natural logs in table 5. The short-run effects in levels ($\$m^{-3}$) are $\lambda_{1989:4}$ *[1 – 1/ $\exp(c_2 + c_3)$], where $\lambda_{1989:4}$ is the actual price ($\$m^{-3}$) observed in the quarter immediately after the hurricane struck and where c_2 and c_3 are the parameter estimates for $P_t^{(T)}$ and $S_t^{(T)}$ from equation (13).

The parameter estimates of the intervention variable for enhancement effects are significant in all paired comparisons with SC series. For SC(1), the implied long-run price increase ranges from about $3.8 to $7.6 per cubic meter (18% to 32%). For SC(2), the implied long-run value enhancement ranges from $2.5 to $4.3 per cubic meter (6% to 12%). For long-run enhancement, standard errors are shown in natural logs in table 5. The long-run effects in levels ($\$m^{-3}$) are computed as [A,,,,,; / $\exp(c_2 + c_3)$][$-1 + \exp(c_3/(1 - c_1)$)], where the estimates of c_1, c_2, and c_3 are shown as the estimates of the coefficients on $\xi_{xy,t-1}$, $P_t^{(T)}$, and $S_t^{(T)}$, respectively (table *4*).

Given our method of modeling supply shocks on stumpage markets, our methods of data aggregation, and the period of price data chosen, the weight of the evidence strongly supports enhancement effects on sawtimber stumpage in both ***TMS*** submarkets 1 and 2 in South Carolina. Figure 3 shows the predicted path of the ξ_{xy} series created using equation (14) and the estimated cointegrating relationship between the South Carolina series and the most typical comparison series. The price drop from the supply pulse vanishes from the South Carolina market within three quarters,

Table 6. Southern Pine Pulpwood Stumpage Price Intervention Equation Estimates, TMS Submarkets 1 and 2, South Carolina

South Carolina Submarket	State (Submarket)	Intercept	ξ_{t-1}	$P_t^{(T)}$	$S_t^{(T)}$	Adjusted R^2
Submarket 1	Virginia (2)	0.009	0.62***	−0.44***	0.15***	0.76
		(0.016)	(0.08)	(0.12)	(0.04)	
	Florida (1)	0.011	0.57***	−0.48***	0.09***	0.67
		(0.014)	(0.07)	(0.10)	(0.03)	
	Florida (2)	0.009	0.57***	−0.50***	0.09***	0.60
		(0.015)	(0.08)	(0.11)	(0.02)	
	Alabama (2)	0.007	0.45***	−0.25***	0.01	0.21
		(0.018)	(0.10)	(0.13)	(0.03)	
	Mississippi (1)	0.009	0.46***	−0.34***	−0.009	0.29
		(0.015)	(0.09)	(0.11)	(0.02)	
	Mississippi (2)	0.007	0.41***	−0.39***	0.04	0.28
		(0.016)	(0.10)	(0.11)	(0.03)	
	Arkansas (1)	0.008	0.59***	−0.44***	0.11***	0.64
		(0.016)	(0.08)	(0.12)	(0.03)	
	Louisiana (1)	0.009	0.54***	−0.49***	0.12***	0.64
		(0.016)	(0.08)	(0.11)	(0.03)	
	Louisiana (2)	0.010	0.57***	−0.35***	0.12***	0.65
		(0.016)	(0.08)	(0.12)	(0.03)	
	Texas (1)	0.008	0.53***	−0.37***	0.12***	0.64
		(0.015)	(0.09)	(0.11)	(0.03)	
	Texas (2)	0.007	0.56***	−.38***	0.12***	0.66
		(0.015)	(0.09)	(0.11)	(0.03)	
Submarket 2	Mississippi (1)	0.000	0.41***	−0.47***	−0.02	0.38
		(0.012)	(0.09)	(0.09)	(0.02)	
	Mississippi (2)	−0.000	0.55***	−0.53***	0.04**	0.53
		(0.012)	(0.08)	(0.08)	(0.02)	
	Louisiana (2)	0.0001	0.57***	−0.47***	0.09***	0.65
		(0.013)	(0.08)	(0.09)	(0.02)	
	Texas (2)	−0.000	0.59***	−0.51***	0.10***	0.69
		(0.013)	(0.08)	(0.09)	(0.02)	

Note: *** indicates significance at 1%, ** at 5%, and * at 10%. Standard errors in parentheses while prices since have increased 18% and 10% above preintervention equilibrium in submarkets 1 and 2, respectively.

Pulpwood stumpage price intervention equations produce statistically significant parameter estimates for nearly all short-run and long-run effects (tables 6 and 7). Results show both a short-run supply pulse and a long-run value enhancement that are similar in magnitude (in percentage price changes) and dynamic structure as in the sawtimber stumpage market (figure 4). As noted above, the proximity of SC(1) and SC(2) allows spatial arbitrage to occur through the shipment of logs. Value enhancement in SC(2) due to increased timber scarcity influences the demand for logs in SC(1), thereby increasing the value of standing timber. Value enhancement does not occur in other submarkets beyond the maximum log haul distance.

Conclusions

Our analysis leads us to three major conclusions. First, analysis of price series for major pine stumpage markets in the South suggests that southern pine stumpage submarkets are informationally efficient. Timber prices adjust efficiently to new information within the temporal period of observation (one-quarter year). This result, however, does not rule out the existence of "excess profits" within this time period. Timber producers who can complete timber sale contracts within this window of opportunity may be able to capture above-average profits. Above-average profits vanish, however, within this time period as timber stocks adjust to the new equilibrium. For example, a high (low) price in the current period (and an expectation of declining [increasing] price) shortens (lengthens) the Faust-

Table 7. Estimated Short-Run and Long-Run Southern Pine Pulpwood Stumpage Price Effects (1989 $\$m^{-3}$) Attributable to Hurricane Hugo, TMS Submarkets 1 and 2, South Carolina

South Carolina Submarket	State (Submarket)	Short-Run Effect (natural log)	Long-Run Effect (natural log)	Short-Run Effect ($\$m^{-3}$)	Long-Run Effect ($\$m^{-3}$)
Submarket 1	Virginia (2)	–0.29** (0.11)	0.38** (0.16)	–1.50	2.75
	Florida (1)	–0.39*** (0.10)	0.22** (0.09)	–2.08	1.57
	Florida (2)	–0.41*** (0.10)	0.20** (0.09)	–2.26	1.47
	Alabama (2)	–0.24* (0.13)	0.01 (0.05)	–1.21	0.08
	Mississippi (1)	–0.35*** (0.11)	–0.02 (0.05)	–1.82	–0.10
	Mississippi (2)	–0.34*** (0.11)	0.08* (0.04)	–1.80	0.52
	Arkansas (1)	–0.34*** (0.12)	0.26** (0.12)	–1.76	1.84
	Louisiana (1)	–0.37*** (0.11)	0.26** (0.10)	–1.95	1.87
	Louisiana (2)	–0.23** (0.12)	0.27** (0.12)	–1.15	1.73
	Texas (1)	–0.25** (0.11)	0.26** (0.10)	–1.25	1.69
	Texas (2)	–0.26** (0.11)	0.28** (0.12)	–1.28	1.82
Submarket 2	Mississippi (1)	–0.48*** (0.09)	–0.03 (0.04)	–3.10	–0.22
	Mississippi (2)	–0.49*** (0.08)	0.09* (0.05)	–3.17	0.82
	Louisiana (2)	–0.38*** (0.09)	0.21** (0.08)	–2.30	1.71
	Texas (2)	–0.41*** (0.09)	0.24*** (0.09)	–2.57	2.10

Note: *** indicates significance at 1%, ** at 5%, and * at 10%. Standard errors, in parentheses, computed using the delta method

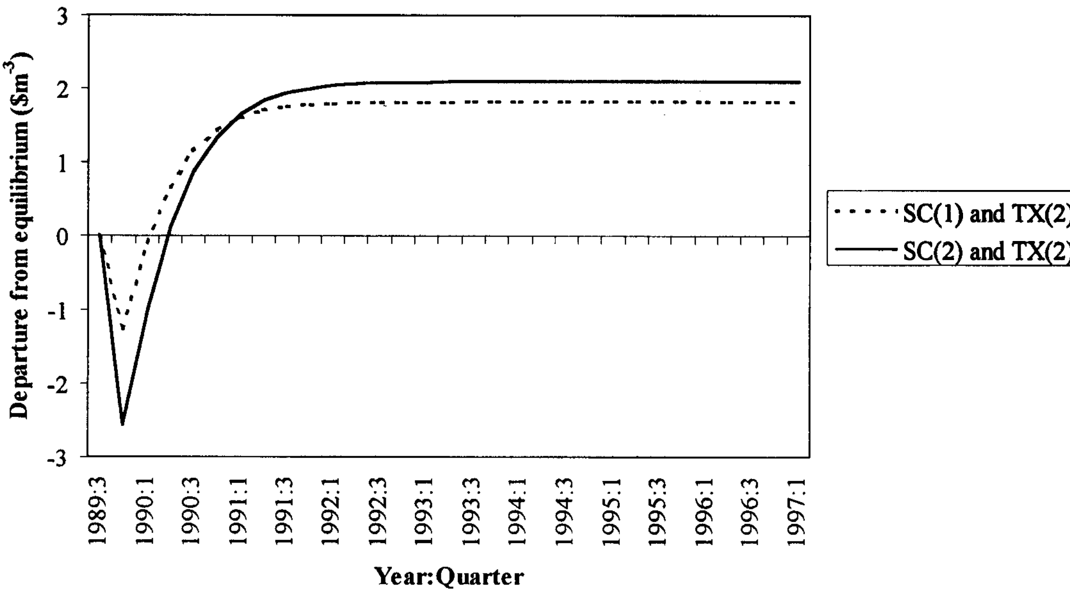

Figure 4. Impulse response functions of Hurricane Hugo on southern pine pulpwood stumpage prices, 1989:3 to 1997:1, TMS sub-markets 1 and 2, using Texas sub-market 2 as the comparison cointegrated series

mann rotation, increases (decreases) timber supplied this period and, therefore, causes price to decline (increase) in the current period. The actions of agents with rational expectations cause the intertemporal arbitrage condition to obtain.

Our second conclusion is that cointegration of asset markets for standing timber is consistent with intertemporal arbitrage. Because we find no significant imprints outside of South Carolina of the supply pulse experienced in South Carolina after the hurricane, we conclude that there is very limited evidence of the kind of spatial arbitrage driven by the threat of direct product movement. We find instead that cointegrating relationships are much more common, implying informational spatial relationships among markets. For sawtimber markets, we find that cointegration decays with distance and extends well beyond the maximum haul distance for logs. Our result is consistent with the correlation analysis reported by Washburn and Binkley (1993) but is at variance with Hultkrantz's assertion that an aggregate pine sawtimber market exists for the entire South. Aggregate sawtimber markets, as defined by cointegrating relationships, may be responding to local and regional factors such as labor markets, other input prices, and segmented product demand. Pulpwood markets, on the other hand, appear to have more variable cointegrating relations that are apparently not primarily related to distance. A promising avenue for future research is to analyze cointegration among the entire matrix of submarkets in the South and identify factors influencing cointegrating relationships.

Our third conclusion is that catastrophic weather events cause a short-run supply pulse associated with a negative price spike and a long-run enhancement to residual forest stock. The inventory impact due to the hurricane in South Carolina was similar to the inventory reduction due to the second Redwood Park taking (20% versus 16.2%, respectively) and the relative price enhancement appears to be about the same (from 6% to 32% for pine sawtimber versus 21% for old-growth redwood).

Value enhancement of residual timber stocks subsequent to a catastrophic event causes a wealth transfer from owners of damaged timber stands to owners of undamaged stands. This effect has not been recognized in the literature prior to this study and suggests that corrective policy mechanisms be considered. Large timberland investors are less susceptible to major losses as a proportion of total asset value than are small timberland owners. If timberland holdings are geographically diversified, timberland owners are less subject to natural hazard risk as a proportion of their entire holdings and, in addition, are more likely to experience enhancement effects if catastrophic damage is incomplete and nonhomogeneous. Small timberland owners with one or a few forest parcels that are not geographically diversified are at greater risk from natural hazards and less likely to realize enhancement benefits. Timber insurance could help obviate financial losses for small woodland owners, although creation of actuarial tables presents significant difficulties and timber insurance is expensive. For this important class of forest owners, catastrophic risk will reduce the desirability of forest investments even in the presence of enhancement effects. For large landowners, enhancement effects are windfalls.

[Received May 1998; accepted June 1999.1

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