

Federal Timber Restrictions and Interregional Arbitrage in U.S. Lumber

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ABSTRACT. Harvesting restrictions to protect the habitat of the northern spotted owl on federal forests in the Pacific Northwest (PNW) substantially reduced timber available for processing by the forest products industry. We consider the extent to which these restrictions may have altered the degree of integration of the PNW and U.S. South in a national market for lumber. Descriptive statistics and econometric analysis of monthly price data suggest that a structural break occurred in the relationship between the two regions' product prices around the time of timber harvest restrictions leading to a more integrated market after the restrictions were imposed. (JEL Q23)

I. INTRODUCTION

A principal source of conflict regarding the protection of natural areas is the extent to which restrictions on land use alter the economic welfare of various stakeholders. In this paper we focus on efforts to protect the habitat for the northern spotted owl (*Strix occidentalis caurina*) by restricting the harvest of old-growth timber from federally owned lands-National Forest System (NFS) and Bureau of Land Management (BLM) in the Pacific Northwest (PNW)-where the remaining members of the species reside. We concentrate especially on how this regional restriction might affect welfare by altering the structure of forest product markets. Our empirical focus is on the degree of market integration between the PNW and U.S. South lumber markets. The PNW and South are the two major lumber-producing regions of the U.S.

Timber harvest restrictions on federal forests affect the welfare of timber processors by restricting the use of their primary input. Federal forests have traditionally been the largest timber supplier to the forest products industry in the PNW, which for most of this century has been the largest regional producer in the U.S. forest products industry. Harvest restrictions can be expected to inten-

sify the competition for harvestable inputs, to raise unit costs, and to reduce output. These effects separately and collectively have negative impacts on timber processors. Constrained producers include firms making up the demand side in markets where the affected timber would normally be exchanged. A contraction in timber supply negatively affects surpluses accruing to timber processors. All buyers in the relevant market experience negative effects through an increase in the equilibrium market price. These buyers may include those who typically do not conduct harvest transactions with the federal forest(s) of interest but nonetheless are affected because the remaining timber in the market becomes more scarce, thus inflating the price paid by all.

Because timber is a bulky commodity and transportation costs are relatively high, the geographic extent of timber markets is limited. Thus, federal forest restrictions in the PNW will not directly restrict timber supplies in other regions such as the South. However, processors of PNW timber produce outputs, such as lumber, plywood, and paper, that directly compete with similar outputs produced in the South. Thus, although the input markets are not directly linked, the output markets may indirectly link the spatially distinct input markets. This linkage is consistent with the factor price equalization theorem in international trade theory (Samuelson 1948).

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We refer to the strength of the linkage between regional forest product output markets as the degree of market integration. At one extreme, the linkage is absent and the markets are autarkic. At the other extreme, each region's outputs are traded in a perfectly homogeneous national or world market for each commodity, facing essentially the same output price (adjusted for transportation costs). That is the case of full or perfect integration. Actual markets fall somewhere between these two extremes.

The magnitude of policy effects from regional timber supply restrictions depends on the degree of integration of the forest product output markets. The empirical focus here is on markets for lumber. On the one hand, if PNW lumber producers are fairly well insulated from output market competition from other regions (i.e., the markets are not well integrated), the effects of the input supply contraction could be offset to a large degree by an increase in the price of PNW lumber resulting from the supply shift. On the other hand, if regional lumber markets are highly integrated, supplies from other regions will readily substitute for PNW lumber, thereby mitigating price increases for PNW lumber. Thus the empirical determination of market integration has important policy implications for how sectoral shocks in one region are distributed across several regions. This form of analysis implicitly views market integration as exogenous. However, if the policy is important enough to fundamentally alter regional supply and demand conditions, the degree of market integration itself might change. In this paper, we analyze the extent to which significant restriction of national forest harvesting in the PNW may have changed the interregional structure of lumber markets in the U.S.

Our primary objective is to measure the degree of regional market integration of U.S. lumber and to test whether it changes as a result of the spotted owl-related federal **harvesting** restrictions, commencing in the late 1980s. We focus on the lumber industry because (1) it is the processing industry most heavily affected by PNW federal timber restrictions, (2) interregional competition in lumber is particularly intense, and (3) com-

parable and frequently reported interregional price data are readily available to support empirical analysis. To further refine the scope of analysis, we focus specifically on integrating the PNW and Southern markets, which combined to produce about two-thirds of national softwood lumber output in 1985, before the federal harvest restrictions were instituted (Adams, Jackson, and Haynes 1988).

In the section that follows, we provide some detail on the regional composition of the U.S. lumber industry and the nature of the federal timber harvest restrictions imposed to protect the habitat of the spotted owl. We then review market integration (arbitrage) theory and evidence in the U.S. lumber industry. We provide different empirical models to test our hypotheses, expanding on previous market integration studies for lumber and other commodities. We conclude with a summary of our findings and corresponding policy implications.

II. BACKGROUND

In the U.S., softwood lumber production is concentrated in the PNW and Southern regions. Each area has accounted for roughly one-third of domestic output over the last two decades. The remaining third is spread throughout the remainder of the country, especially in the Rocky Mountains and the Northeast. Differences between these major lumber-producing regions have led to substantial shifts in production patterns in recent years. Forests, timber growth, and production differ substantially between the PNW and the South.

Harvests have historically come from old-growth forests in the PNW, although forestry is now shifting from "mining" of old growth to renewable management. The pattern of forest ownership also varies. The PNW is dominated by public lands with significant shares of timber inventories (approximately 60 percent) managed by the BLM, USDA Forest Service, and state departments of natural resources, in addition to private landowners, especially large industrial holdings (Alig et al. 1990). The Forest Service manages the largest share of the timber inventory

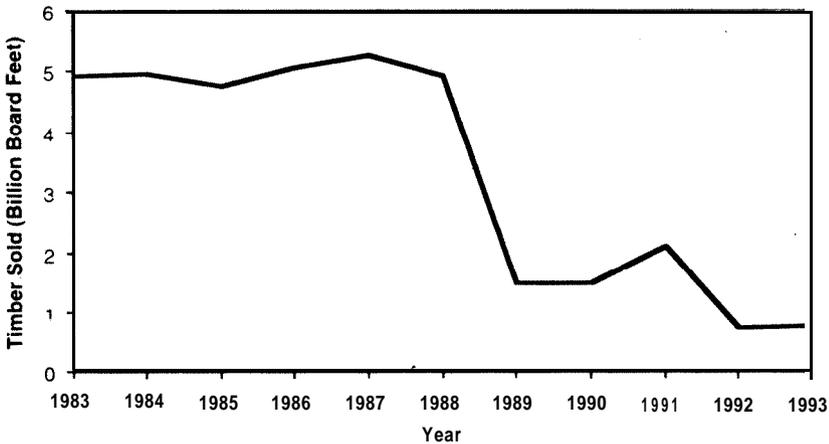


FIGURE 1
FEDERAL TIMBER SOLD IN THE PACIFIC NORTHWEST REGION

in the PNW. In the South, much of the harvest is derived from agricultural forestry with commercial timber rotation of 25 to 30 years. The forested landscape is dominated by private owners (90 percent), a majority of which are small, nonindustrial entities.

As timber from old growth in the PNW has become more scarce, so has the habitat afforded by these forests. As a result, flora and fauna dependent on these forests have become increasingly rare and, in some cases, threatened or endangered according to the Endangered Species Act of 1973 (ESA). The ESA prohibits the destruction of an endangered species' habitat—technically labeled an "indirect taking"—so that the presence of an endangered species can severely restrict management options. In most cases, species use only small portions of a region—often limited to small areas defined by specialized, microsite conditions. However, some species require a fairly large complement of habitat per individual to thrive. In the case of the northern spotted owl, roughly 300 acres of old growth may be required for each nesting pair.

The northern spotted owl was proposed as endangered in the *Federal Register* on June 23, 1989; final listing came in the *Federal Register* on June 22, 1990. The listing of the northern spotted owl as an endangered spe-

cies has had a substantial impact on timber production from national forests in the PNW. To protect the owls, the federal government proposed changes in forest management in 1986, but these changes were immediately challenged as inadequate under the ESA and other resource management statutes. As a result, a federal court enjoined a large share of the national forest timber sale program in the region in 1989 (Yaffe 1994). The federal government responded with a series of administrative studies of various management options followed by additional judicial wrangling. This process culminated on April 2, 1993, with a "Forest Summit," headed by President Clinton and a subsequent federal forest plan. The plan has, to date, passed judicial tests and is being implemented.¹

A significant reduction in timber production resulted in 1989 and was sustained thereafter (see Figure 1). Timber sales volumes from the national forests in 1989 amounted to only 33 percent of sales in 1988. After that, national forests sold only 25 to 35 percent of the 1983–88 average. At the same time, lumber production from the PNW coast

¹ See Montgomery (1995) and Yaffe (1994) for detailed descriptions of the chain of administrative and judicial actions in response to the listing of the northern spotted owl.

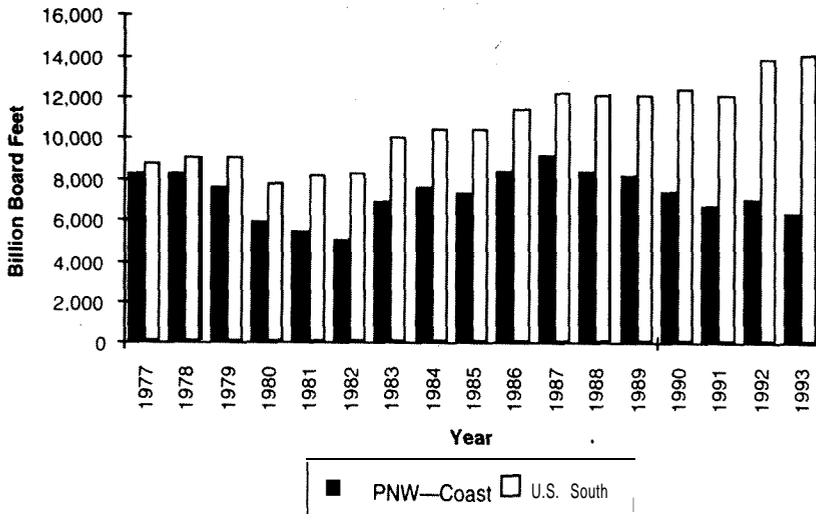


FIGURE 2
LUMBER PRODUCTION IN PNW (COAST) AND SOUTH OVER TIME

region—the primary production region in the PNW and the one affected by the spotted owl restrictions—declined both in absolute terms and relative to the South (see Figure 2). Unlike many resource/environmental issues, conservation measures for the northern spotted owl caused an immediate and sustained structural impact on resource supply.

III. ARBITRAGE AND MARKET INTEGRATION

In the introduction, we described how cross-regional market effects can influence the impacts of the spotted owl timber harvesting restrictions. In this section, we present theoretical models describing inter-regional market linkages. These models provide the conceptual framework for the empirical analyses described later.

We can view apparently separate (e.g., regional) markets as comprising one effective market if the prices in each market move together over time. The force that keeps these prices moving together is arbitrage; the pursuit of opportunities to profitably move commodities across markets until price differences just offset transaction costs (e.g.,

transport costs). Below we present three different cases of geographically separate lumber markets linked by arbitrage.

A. Case 1: Homogeneous Goods, Two Regions

Suppose lumber is produced in regions N and S . Assume for now that lumber is a homogeneous good; that is, lumber produced from each region has identical characteristics. The price of lumber in each region is P^N and P^S , respectively. Because of basic differences in regional supply and demand, prices are higher in S than they are in N ; that is, lumber is relatively more scarce in region S . If, for a given value of P^N , the quantity demanded in region N is less than the quantity supplied at that price, producers in region N will ship the excess supply to region S as long as the price they receive there is at least high enough to cover transport costs between regions, T_{NS} . If the price difference were to exceed transport costs, then arbitrage opportunities would exist, wherein some agent could reap profits merely by the act of shipping lumber from N to S .

The standard view of competitive market equilibrium is that prices will adjust until

these arbitrage opportunities are eliminated. As a result, the price difference between regions will be no greater than transportation costs:

$$P^N - P^S \leq T_{NS} \quad [1]$$

With efficiently linked regions, the price difference ($P^N - P^S$) will be identical to the transport costs, and some of region N's excess supply at P^N will be shipped to region S and sold for $P^S = P^N + T_{NS}$. However, for a given price of P^N , there may be no price, P^S , that can be established both high enough to accommodate the transport costs from N to S and low enough to generate excess demand for lumber in region S (i.e., positive demand for imports from region N). If this holds true for the range of values of P^N high enough to generate excess supply from region N, then no equilibrium is sustainable in which trade from region N to region S can occur. In other words, market autarky arises. Prices would then vary independently over time.

B. Case II: Homogeneous Goods, More Than Two Regions

The scenario just described is somewhat limiting because it allows only one-way trade flows between two regions. Suppose, instead, that both regions N and S export to a third region, M (and neither N nor S imports). The same basic principle still applies: when markets are efficient and trade occurs, the price difference between the exporting and importing regions differs by exactly the transport costs:

$$P^M = P^N + T_{NM} = P^S + T_{SM} \quad [2]$$

The difference in prices between regions N and S is now

$$P^N - P^S = T_{NM} - T_{SM} \quad [3]$$

Thus, the notion that the price difference between any two regions linked by trade must be equal to the transport cost between those regions is not strictly correct. As we see here, regions N and S are linked via their

concurrent service of market M. However, no generalizable relationship exists between the difference in the transport costs from N to S, T_{NS} , and the differences in their transport costs to region M, which, as equation [2] indicates, is the source of their price difference in region M.

What is generalizable across both situations—direct trade occurs between regions N and S, and both regions serve an outside market—is that under efficient arbitrage conditions and stable transportation costs, price movements in region N should identically track price movements in region S if the regions are linked by trade. If, by definition, markets are integrated when linked by trade, parallel price movements should provide evidence of this integration.

C. Case III: Product Heterogeneity

Up to now we have assumed that lumber is a homogeneous product and that lumber from different regions has functionally identical characteristics. However, interregional differences in timber species could impart interregional differences in lumber quality. In the context of U.S. lumber regions, PNW softwood timber (most prominently, Douglas fir) generally takes longer to grow to maturity and has a finer grain compared to its Southern pine counterparts. This difference imparts varying qualities of "workability" and stability to the two products. If these factors are significant in the eyes of demanders, they may view lumber from the PNW and the South as imperfect substitutes. Consequently, differences in willingness to pay for the different products may be pervasive, and the market-clearing prices for these products at any geographical location need not be identical, as they would if products were purely homogeneous.

This situation can be characterized by a demand function for region N lumber, specified as follows:

$$Q_{in}^N = D(P_i^N, P_i^S, Z_i^N); \quad [4]$$

Q_{in}^N is the quantity demanded of region N lumber in geographic market i ; P_i^N and P_i^S are

the prices for region N and region S lumber sold in market i ;

$$\begin{aligned} P_i^N &= P^N + T_{Ni} \\ P_i^S &= P^S + T_{Si}; \end{aligned} \quad [5]$$

and Z_i^N is a vector of nonprice factors affecting demand (e.g., income, housing starts). Here, the price of region S lumber enters into the demand for region N lumber because the two products are seen as substitutes, rather than as identical products. Rearranging equation [5] gives the following relationship between the home market prices:

$$P^N - P^S = (P_i^N - P_i^S) - (T_{Ni} - T_{Si}). \quad [6]$$

Because the market i prices, P_i^N and P_i^S , need not be identical, neither their price movements nor, by extension, the movement of "home" prices, P^N and P^S , need be identical. This is true even if transport costs are stable and the markets are linked by trade. The implication is that, although nonparallel price movements can provide evidence against efficiently linked homogeneous goods markets, they do not provide evidence against efficiently linked heterogeneous goods markets. However, even efficiently linked heterogeneous goods markets cannot be viewed as constituting a single market for a good. It is the single-market case that maximizes interregional spillovers from a regional market shock, such as northern spotted owl-related timber restrictions. Anything short of this condition involves some regional concentration of effects, although it is a matter of degree. Markets that are separate (nonparallel) but very closely linked may not be significantly different from a single market in an economic sense, even if they are significantly different in a statistical sense—a distinction encouraged by McCloskey and Ziliak (1996).

Price movements of heterogeneous goods are approximately parallel if the cross-price elasticity is very high, that is, if the products are very close substitutes (Stigler and Sherwin 1985). In the limiting case of perfectly substitutable goods, price movements are parallel. Thus, we can view deviations from

perfect parallel price movements as indicating either imperfect market linkages or imperfect substitution across products. Without further institutional detail on the markets in question, differentiating quantitatively between market efficiency and imperfect substitution factors is not possible.²

D. Previous Studies of Market Integration in U.S. Lumber

The integration of softwood lumber markets in the U.S. has been investigated, first by Uri and Boyd (1990) and then by Jung and Doroodian (1994). Both studies use identical annual data on prices aggregated across broad regions and several product groups (Adams, Jackson, and Haynes 1988) and evaluate the same four regions (South, West, North Central, and Northeast). Although the researchers used different methods (Uri and Boyd apply pairwise Granger Causality tests; Jung and Doroodian apply multivariate cointegration tests), their findings support the Law of One Price and therefore a national softwood lumber market. Uri and Boyd caution that more disaggregated data in terms of space, products, or regions might give rise to different findings. Applying our analysis to more disaggregated data addresses some of their concerns.

Traditional lumber market models (e.g., Adams and Haynes 1980; Robinson 1974; Adams, McCarl, and Hamayounfarokh 1986; Boyd and Krutilla 1987) recognize linkages between regions in a transportation cost framework. Integration and product homogeneity are maintained hypotheses in these models. However, the most recent installment in this line of inquiry applies monthly rather than annual data and generalizes the production relationships among

² Sexton, Kling, and Carman (1991) differentiate between product heterogeneity and market efficiency factors in their study of market integration in U.S. celery because they are able to obtain paired price comparisons for celery produced in California and Florida that is sold in the same terminal markets. Although the publication *Random Lengths* publishes similar types of terminal price data for lumber, careful scrutiny of the data indicated that these price quotes are essentially constructed from the free-on-board (FOB) prices and not directly observed.

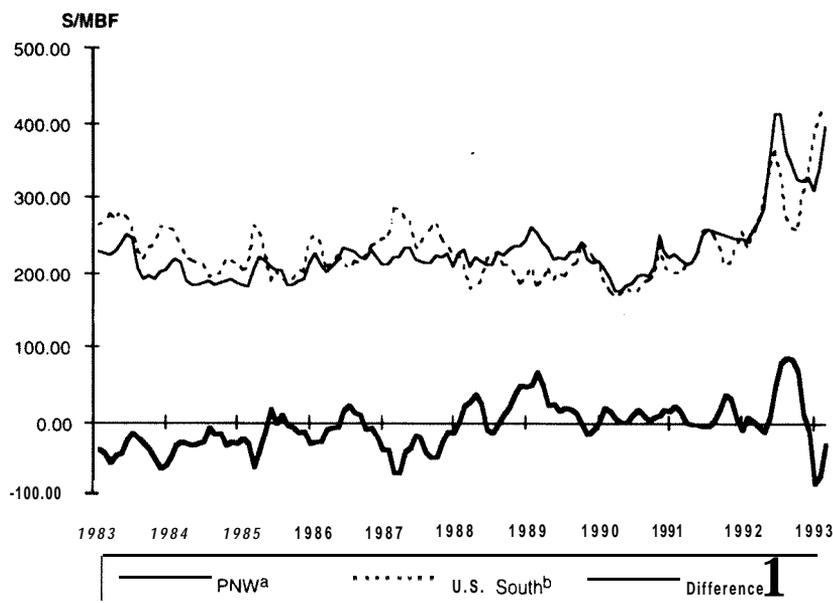


FIGURE 3

PNW AND U.S. SOUTH LUMBER PRICES, 1983 TO 1993 (REAL DOLLARS, BASE 1982-1984)

Source: Random Lengths (1994), 1993 Yearbook—Forest Products Market Prices and Statistics.

^aDouglas fir, kiln dried, 2 X 4, standard and better, FOB mill (Random Lengths 1994, 34).

^bSouthern pine (westside), kiln dried, 2 X 4, #2, FOB mill (Random Lengths 1994, 73).

products from different regions (Lewandowski, Wohlgenant, and Grennes 1994). That study finds little evidence of cross-product demand elasticities, thereby suggesting that Southern pine and Douglas fir are not substitutes in the very short run.

None of the previous studies of the extent of the U.S. lumber market specifically addresses one primary element of our analysis here: estimating the effect of a specific policy on the degree of integration across regional markets.

IV. DATA AND PRELIMINARY ANALYSIS

We are interested in testing two hypotheses: (1) whether lumber produced in the PNW and South can be considered in the same market and (2) whether the validity of hypothesis (1) changes subsequent to the PNW harvest restrictions of the late 1980s. To provide context, in this section we describe the data used to test the hypotheses

and examine the data graphically and descriptively.

A. Data and Graphical Analysis

Figure 3 graphs the PNW and Southern lumber monthly price series from 1983 through 1993 as reported in the industry publication *Random Lengths*. The PNW price is for Douglas fir, kiln-dried, standard and better 2 X 4 lumber. The Southern price is for Southern pine, westside, kiln-dried, #2 2 X 4 lumber. All prices are FOB prices for that region and are expressed in real dollars. This figure illustrates an apparent change in the price relationship about 1988 to 1989. Prior to that period, the Southern lumber price was consistently higher than the PNW price, with a mean difference of approximately \$20/thousand board feet (MBF) in real terms for 1983 to 1988. The situation is quickly reversed in the 1989 to 1993 period: the PNW price exceeds the Southern price, also by an amount in the \$20/MBF range.

It is tempting to conclude that the exact price reversal reflects a situation of Case I arbitrage in which the PNW region goes from an exporter to the South, with an arbitrage price condition of $P^S = T^{SP} + P^N$, to an importer of lumber from the South, with an arbitrage condition of $P^N = T^{SP} + P^S$. In such a case, we would expect to see the PNW move from the lower-price region to the higher-price region and the absolute price difference between regions maintained at the interregional transport cost, T^{SP} . However, closer scrutiny of FOB and delivered price data suggests that the transport cost from the South to the PNW exceeds \$20/MBF (Random Lengths 1994).

The linkage between the PNW and Southern markets would then appear to arise from either Case II (intermediate geographic markets) or Case III (product heterogeneity) conditions. The Random Lengths price data indicate the existence of several intermediate markets served by both the PNW and South (e.g., North Central and Northeast U.S.). Therefore, the relative price change could reflect an expansion of Southern lumber sales in areas farther from the South, where they are replacing PNW sales. Thus the geographic market boundary, where delivered prices are roughly equal, may have shifted westward, because PNW FOB prices are now higher than Southern FOB prices. If so, the change in relative prices would follow the pattern observed here. However, the Random Lengths data also indicate that different prices are observed for PNW and Southern lumber sold in the same location, which suggests some product differentiation may exist.³ If so, then the change in relative (FOB) prices is not explained entirely by changes in market boundaries or by reversal of export/import status but may also reflect changes in the price spread of these two differentiated products in the same markets.

B. Correlations

Stigler and Sherwin (1985) base their empirical analysis of market definition on analysis of correlation coefficients for products hypothesized to be in the same market. Correlation coefficients provide an index mea-

TABLE 1
CORRELATION COEFFICIENTS - PNW
AND SOUTHERN LUMBER PRICES

	Correlation Coefficient
1983-93	0.7197
1983-88	0.5558
1989-93	0.8819

sure of market integration; values near + 1.0 suggest products are clearly in the same market, and values near zero suggest products are clearly in different markets. We computed correlation coefficients for the price series for each region over time as a measure of the interdependence of PNW and Southern lumber. Table 1 reports these coefficients. The estimated correlation coefficient is 0.7197, suggesting that PNW and Southern monthly prices are moderately correlated over the 1983 to 1993 period.

Motivated by the apparent structural break in 1988 to 1989 illustrated in Figure 3, we separately examine the price correlations for the periods before and after the apparent break. Here, we find that the correlation coefficient for the price data from 1983 through 1988 is relatively low ($r = 0.5558$), compared to the later period 1989 to 1993 ($r = 0.8819$). This finding, by itself, suggests greater integration between the PNW and Southern markets after the apparent break in 1988 to 1989. This finding will be examined more rigorously below.

V. COINTEGRATION TEST AND RESULTS

Testing the arbitrage/one-market hypothesis has traditionally been an important feature of empirical analyses of commodity markets (Richardson 1978; Ravallion 1986; Sexton, Kling, and Carman 1991; Goodwin, Grennes, and Wohlgenant 1990; Goodwin

³ As indicated above, the comparison of PNW and Southern delivered prices at the same terminal market (e.g., Chicago) is clouded somewhat because the Random Lengths price "quotes" for PNW lumber and Southern lumber at the same place are based on a construction of FOB price plus transportation costs, not a direct observation of delivered prices in that market.

TABLE 2
UNIT ROOT TEST FOR NONSTATIONARITY
OF PNW AND SOUTHERN LUMBER PRICE SERIES

Price Series	Estimated Value of ρ (<i>t</i> -statistic for null hypothesis)	Number of Observations	\bar{R}^2	F-value
PNW	1.085 (0.691)	120	0.2648	4.269***
South	1.026 (0.189)	120	0.2346	3.782***

Note: Levels of significance: *** = 0.01 or better

and Schroeder 1990; Uri and Boyd 1990; Jung and Doroodian 1994), international trade (Dibooglu and Enders 1995; Strauss and Terrell 1995; Hamilton 1994), and anti-trust analysis (Horowitz 1981; Stigler and Sherwin 1985; Spiller and Huang 1994). Statistical tests of the hypothesis have traditionally been performed by estimating both static and dynamic forms of the arbitrage price conditions outlined in Section II. Drawing inferences on market integration from parameters estimated in these price regressions causes some statistical problems. One such problem is that a time series of prices is often generated by a nonstationary process (the mean and covariances are nonconstant over time). As a result, traditional statistical inference may not apply to these regressions. Many of the more recent studies have addressed this problem by employing cointegration test methods for testing the arbitrage/one-market hypothesis (e.g., Dibooglu and Enders 1995; Strauss and Terrell 1995; Jung and Doroodian 1994).

Separate price series are cointegrated when each series is individually nonstationary, but a linear combination of the variables is stationary." The existence of this stabilizing relationship among the series suggests a common fundamental force tying these series together. In this particular instance, the hypothesized common force is arbitrage linking geographically separate markets together by the linear relationships presented in Section III.

To test whether the PNW and Southern prices are cointegrated, we first determine if

each price series is nonstationary. As a sufficient condition for nonstationarity, we test whether each price series can be characterized by the following unit root process:

$$P_{i,t} = \mu + P_{i,t-1} + e_{i,t} \quad [7]$$

If so, then it is nonstationary. A test of this condition can be constructed using Dickey and Fuller's (1979) unit root test, augmented for time lags (Hamilton 1994):

$$\Delta P_{i,t} = \mu + (1 - \rho)P_{i,t-1} + \sum_{k=2}^L \Delta P_{i,t-k} \quad [8]$$

where Δ is the first difference operator and L is the number of time lags considered. We follow Hamilton's (1994) suggestion of applying 12 lagged values when using monthly data. The testable null and alternative hypotheses are

$$H_0: \rho = 1: \text{unit root process}$$

$$H_a: \rho < 1: \text{stationary process.}$$

We apply this test to the monthly price data for PNW and Southern lumber and find that we cannot reject the null hypothesis of a unit root for either time series (see Table 2). This is confirmed by a Dickey-Fuller test on the second differences regression, in which the unit root hypothesis was rejected. Series,

⁴ A detailed discussion of cointegration concepts and tests for its existence in data series can be found in Hamilton (1994).

TABLE 3
COINTEGRATION TEST RESULTS

Stage I: Cointegrating equation regression						
Dependent variable: PNW price						
		Parameter Estimates				
Explanatory Variable	(a)			(b)		
	Without	Structural	Break	With	Structural	Break
Intercept		54.03			130.69	
Southern price		0.7535			0.3496	
POST88		---			74.67	
POST88 * Southern price		---			0.4804	
Number of observations		132			132	
R ²		0.5595			0.7636	

Stage II: Unit root test on residual from Stage I regression						
Estimated equation: $\Delta e_t = (1 - \rho)e_t + \sum \Delta e_{t-i}$						
Null hypothesis $\rho = 1$						
		Parameter Estimates				
	(a)			(b)		
	Without	Structural	Break	With	Structural	Break
Estimated value of ρ		0.8665			0.6162	
T-statistic for null hypothesis		(-1.245)			(-1.978)*	
Probability value of t-statistic		0.2157			0.0505	
Number of lags		12			12	
Number of observations		120			120	
R ²		0.2899			0.3896	
F-value		4.736***			6.842***	

Note: Levels of significance: *** = 0.01 or better, ** = 0.05 or better, * = 0.10 or better.

such as these, that demonstrate unit roots in first differences and stationarity in second differences are said to be integrated of order 1, I(1).

Next we test for the existence of a cointegrating linear relationship between the two price series. The natural candidate for this relationship is the arbitrage condition asserted in Section II. This condition can be specified for estimation as follows:

$$P_t^N = \beta_0 + \beta_1 P_t^S + I^*, \quad [9]$$

with P_t^N representing the PNW price in period t and P_t^S being its counterpart for Southern lumber.

Following the method established by Engle and Granger (1987), we test for cointegration in two steps:

1. Estimate equation [9] using ordinary least squares (OLS).
2. Test for a unit root in the residuals

from Step 1 using the Dickey-Fuller test.

If the null hypothesis of a unit root cannot be rejected in Step 2, then the two series are deemed not cointegrated (i.e., the markets are separate); conversely, if the unit root hypothesis is rejected, then the series are cointegrated (there is one market).

Results of the cointegration test are presented in Table 3. We first analyze the case in column (a) where the cointegration relationship is provided by equation [9], the standard arbitrage relationship between regions over the time period covered by the data. The upper part of the table gives results from the Stage I price regression, and the lower part presents unit root test results from Stage II.⁵ The Stage II results suggest we cannot reject the hypothesis of no cointegration of the two

⁵ Test statistic is omitted in the Stage I results because hypothesis testing on the Stage I regression requires modifications we introduce below.

markets at the typical levels of statistical significance (the probability value is over 0.20). Consequently, based on this evidence alone, we might conclude that the PNW and Southern markets are separate.

To test for the existence of a structural break in the price relationship commencing about 1988, a break which we implicitly attribute to the federal harvest restrictions in the PNW, we test for cointegration using an alternative specification of the cointegrating equation:

$$P_t^S = \gamma_0 + \gamma_1 P_t^N + \gamma_2 (POST88_t) + \gamma_3 (POST88_t * P_t^N) + v_t \quad [10]$$

$POST88_t$ is a dummy variable taking the value of one for price observations after 1988 and zero otherwise. As a result, γ_0 can be viewed as the intercept of the equation for the years 1983 to 1988; the intercept for 1989 to 1993 is represented by $\gamma_0 + \gamma_3$. Likewise, the slope coefficient is γ_1 for 1983 to 1988 and $\gamma_1 + \gamma_3$ for 1989 to 1993.

Results of the structural break equation are presented in column (b) of Table 3. Imposing this structure on the Engle-Granger two-step test yields different conclusions than the case without the structural break imposed. The null hypothesis of no cointegration is now rejected at approximately the 0.05 level of significance (probability value = 0.0505). These results suggest that the PNW and South are effectively in the same market, once we adjust for the structural break that altered the relative price relationship in the latter part of the period.

The second regression allows us to test whether a significant structural change in market integration occurred from 1989 onward. A significant change in relative prices is implied if the estimated parameter for $POST88$ (γ_2) is not zero, and a significant change in the correlation of prices is implied if the parameter value for the interaction term (γ_3) is not zero. The following joint hypothesis tests whether an overall structural change event occurred:

$$H_0: \gamma_2 = \gamma_3 = 0. \quad [11]$$

TABLE 4
STRUCTURAL BREAK RESULTS

Dependent variable: PNW price		
Explanatory Variable	Parameter Estimate	Modified Test Statistic ^a
Intercept	103.41	1.89*
Southern price	0.4611	1.96**
$POST88$	-105.16	-2.00**
$POST88 * \text{Southern price}$	0.6155	2.64**
R^2	0.8168	---
F-value	33.886	---

Note: Levels of significance: *** = 0.01 or better, ** = 0.05 or better, * = 0.10 or better.

^a T-statistic transformation for testing cointegration vector hypotheses as shown in Hamilton (1994, 610).

Because both price series have been shown to possess a unit root structure, hypothesis testing of the cointegration equation [10] requires modifying the usual OLS *t*- and F-tests. To make the modification, we followed the "lead-lag" method for performing hypothesis on the cointegrating equation, first introduced by Saikkonen (1991).⁶

The structural break results are presented in Table 4. The intercept-shifting parameter, γ_2 , and the slope-shifting parameter, γ_3 , are both individually significant at 0.05. The positive and significant value of γ_3 confirms the evidence presented earlier that the two price series become more interdependent after 1988. The effective post-1988 price coefficient is $\gamma_1 + \gamma_3 = 1.05$, compared to the pre-1989 price coefficient of $\beta_1 = 0.47$. The post-1988 value is not statistically or economically different from the perfect arbitrage value of 1.0. A Chow test confirms joint significance of γ_2 and γ_3 (F-statistic = 25.3). We take this as evidence that a structural break in the relationship between PNW and Southern prices occurred after 1988.⁷

A. Asymmetric Regional Price Effects

A potential problem with the cointegration test used above is that the results are not in-

⁶ See Hamilton (1994, 608) for a presentation of the lead-lag method.

⁷ Alternative "break" years were modeled (1986, 1987, 1989, 1990), but none had as high an explanatory power as the model with 1988 as the break year.

TABLE 5
COINTEGRATION TEST RESULTS — SENSITIVITY
TO DEPENDENT/INDEPENDENT VARIABLE ORDERING

Stage I: Cointegrating equation regression						
Dependent variable: Southern price						
		Parameter Estimates				
Explanatory Variable	(a)			(b)		
	Without	Structural	Break	With	Structural	Break
Intercept		61.74		40.5		
PNW price		0.747		0.90	17	
POST88		—		-33.00		
POST88 * PNW price		—		0.006	1	
Number of observations		132		132		
R ²		0.5595		0.6553		

Stage II: Unit root test on residuals from Stage I regression						
Estimated equation: $\Delta e_t = (1 - \rho)e_{t-1} + \sum \Delta e_{t-k}$						
Null hypothesis $\rho = 1$						
		Parameter Estimates				
	(a)			(b)		
	Without	Structural	Break	With	Structural	Break
Estimated value of ρ		0.7554		0.4805		
T-statistic for null hypothesis		-1.83 ^{**}		-2.274 ^{***}		
Probability value of t-statistic		0.070	1	0.025		
Number of lags		12		12		
Number of observations		120		120		
R ²		0.3048		0.3539		
F-value		5.013 ^{***}		6.015 ^{***}		

Note: Levels of significance: *** = 0.01 or better, ** = 0.05 or better, * = 0.10 or better.

variant to which price series is selected as the dependent variable and which is the regressor, unless the resulting R^2 is 1.0, which it is not. We tested for the sensitivity of the results to the ordering of these variables. We found that the results of the cointegration test with the structural break are sensitive to ordering (see Table 5). The results of regressing the PNW price on the Southern price to form the cointegrating vector (Tables 3 and 4) show that up through 1988, the Southern price has a weak explanatory effect on the PNW price, while after 1988 the effect is much stronger. However, when the Southern price is regressed on the PNW price to form the cointegrating vector, the structural break evidence is not as strong (see second column in Table 5). The results in Table 5 suggest a slight strengthening in cointegration effects, once adjusting for the structural break, but the improvement is modest.

Moreover, the hypothesis tests for the structural break parameters in the cointegrating equations (Table 6) indicate that the structural break effects are not significant when the Southern price is viewed as a function of the PNW price. It is worth noting that the perfect arbitrage hypothesis cannot be rejected for the early (1983 to 1988) or later (1989 to 1993) period, because the PNW price parameter equals roughly 0.86 prior to the break and 0.93 after the break. In both cases, 1.0 fails within the usual confidence intervals.⁷

What are we to make of the conflicting evidence in the face of reordering the variable

⁸ We note that the Chow test suggests that the two structural break parameters collectively add explanatory power to the cointegrating equation. The finding that individual effects are not significant but joint effects are suggests that multicollinearity may be a problem.

TABLE 6
STRUCTURAL BREAK RESULTS:
SENSITIVITY TO DEPENDENT/
INDEPENDENT VARIABLE ORDERING

Dependent variable: Southern price		
Explanatory Variable	Parameter Estimate	Modified Test Statistic ^a
Intercept	46.95	0.61
PNW price	0.8598	2.34**
POST88	-45.7	-0.61
POST88 * PNW price	0.0666	0.19
R ²	0.6544	—
F-value	14.968	—

Note: Levels of significance: *** = 0.01 or better, ** = 0.05 or better, * = 0.10 or better.

^aT-statistic transformation for testing cointegration vector hypotheses as shown in Hamilton (1994, 610).

relationship? Johansen (1991) suggests circumventing the problem by estimating the cointegrating relationship using full information maximum likelihood (FIML) methods. This method essentially forces the price relationship to be symmetric. However, we believe that the asymmetric price relationship revealed in the exercise above merits further inquiry, especially because the asymmetry appears so stark. It may be revealing something important about the nature of interdependence between PNW and Southern markets over time.

To examine this issue further, we conducted Granger causality tests on the relationship between PNW and Southern prices (Granger 1969). The Granger causality test involves regressing one variable on its own lagged values and current and lagged values of a potential "causal" variable. If the potential causal variable terms add explanatory

power as demonstrated through an F-test, then they are said to "Granger cause" the dependent variable. Applying this to the PNW and Southern price series, we can test the following hypotheses: (i) P^S "Granger causes" P^N and (ii) P^N "Granger causes" P^S .

Hypothesis (i) holds if changes in P^S map directly to changes in P^N ; likewise (ii) holds if changes in P^N lead to changes in P^S . If the PNW and Southern markets are part of the same national market, then both (i) and (ii) should hold: that is, Granger causality would be bidirectional. Note that bidirectional causality is a necessary condition for one national market but not a sufficient condition. One commodity's price might be influenced by the price of a closely related but separate commodity.

Granger causality tests were performed for the two price series over the entire sample period and separately for the 1983–88 and 1989–93 periods. Results are presented in Table 7. In the full sample (1983 to 1993) model, Granger causal effects are significant in each direction, suggesting that price feedback exists across regional markets. The causal effects of the PNW price on the Southern price, however, appear somewhat stronger than the causal effects of the Southern price on the PNW price. In short, there is evidence of feedback between markets, but the effects are not directionally symmetric. The earlier period model results (1983 to 1988) show a lack of bidirectional feedback. The PNW price is found to "Granger cause" the Southern price but not vice versa. However, strong evidence of feedback exists in the later period model (1989 to 1993). Moreover, the effects are essentially symmetric, as

TABLE 7
GRANGER CAUSALITY TESTS FOR PNW AND SOUTHERN PRICES

Hypothesis	F-test Statistics		
	1983–93	1983–88	1989–93
Southern price "causes" PNW price	5.42***	1.45	7.70***
PNW price "causes" Southern price	1.66***	3.00***	9.08***

Note: Level of significance: *** = 0.01 or better.

Lag structure: Own-price lags = 12. Cross-price lags = 10.

evidenced by similarly sized F-statistics for the later period.

In summary, the Granger causality rests suggest that

1. the PNW and Southern lumber prices exhibit bidirectional feedback in the very short run.
2. through 1988 the Southern price more closely depended on the PNW price than vice versa, but
3. after 1988, the PNW price became more dependent on the Southern price, and the markets were more tightly linked through price feedback mechanisms.

This change may be due to the post-1988 decline in the PNW's role as dominant player in jointly served markets. When a product dominates a market, competing producers may be more likely to pivot off of changes in the dominant product price than vice versa. However, when no clear dominant producer exists, the price feedback is more likely to be symmetric. Although these heuristic explanations of the observed asymmetry are intuitive, a more rigorous analysis of the issue may be warranted in future research.

VI. CONCLUSIONS AND POLICY IMPLICATIONS

Graphical analysis, descriptive statistics, and econometric analysis all suggest a significant intensifying of market integration between the PNW and Southern lumber regions after the northern spotted owl-related harvest restrictions in the PNW. For several reasons, the structural change brought on by the spotted owl restrictions might change the nature of interregional market integration. For one, prior to the restrictions, the PNW was a significant net exporter of lumber, with large shipments sold throughout the U.S. and abroad. PNW output levels have significantly declined since the restrictions: thus, the scope of extraregional trade has declined. Holding the supply of lumber from the South (and other regions) constant, one might expect the decline in extraregional trade of PNW lumber to *weaken* interregional linkages. However, taking other regions' re-

sponses into account, lost market share by PNW producers translates to gained market share by other producers. Other regional producers may enter markets traditionally dominated by PNW producers, thereby increasing the direct competition between PNW and Southern lumber and strengthening the integrating forces of arbitrage.

The other potential change in market structure may relate to product differentiation. As explained earlier, Douglas fir lumber from the PNW has traditionally possessed a number of desirable characteristics not held by Southern pine lumber. Some of these characteristics derive from the attributes of the old-growth timber processed into lumber. Restricting the harvesting of old-growth timber restricts the availability of these characteristics. To the extent that the restrictions force substitution of old-growth resource with second- and third-growth timber, PNW lumber may not be as differentiated in quality from Southern lumber as it once was. If the products are closer substitutes with old-growth restricted (i.e., the cross-product demand effects become higher), then the PNW and Southern lumber markets would be more closely integrated after the restriction.

From a policy perspective, the analysis confirms the supposition that regional forest policies, if large enough in scope and duration, can have significant interregional effects. This conclusion is not ours alone; Uri and Boyd (1990) make similar suggestions regarding the policy implications of their finding that the U.S. lumber market is a single market with regionally linked producers. Unique to our analysis, however, is the finding that a significantly strong regional forest policy, such as the spotted owl timber harvest restrictions, can actually change the nature of inter-regional market linkages. This finding can also be placed in the context of other studies which demonstrate that market structure may be endogenous in the setting of environmental regulations (e.g., Markusen, Morey, and Olewiler 1993).

An important policy implication of significant interregional spillover effects stemming from forest policies directed at one region is the potential it creates for rent-seeking and other socially inefficient strategic be-

havior. Lumber producers concentrated in the South may have strong incentives to lobby for stricter regulation of harvesting in the PNW and other competing regions. Likewise, producers concentrated in the PNW may have incentives to lobby for harvest restrictions of Southern forests (e.g., habitat protection for rare species dwelling in Southern pine forests, such as the red cockaded woodpecker). To the extent that these efforts effectively alter the terms of forest policy debate, the resulting decisions may be based more on strategic behavior of the regulated industry and less on behalf of environmental protection.

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