AN EXAMINATION OF THE RELATIONSHIPS BETWEEN HARDWOOD LUMBER AND STUMPAGE PRICES IN OHIO

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ABSTRACT

Understanding the relationship between hardwood lumber and stumpage prices is critical in evaluating market efficiency and in understanding the potential impact of changing technology on stumpage markets. Unfortunately, the complexity of the hardwood lumber market and lack of reliable data make it difficult to evaluate this relationship using traditional econometric systems. However, the relationship can be evaluated using economic theory, a review of market history, and statistical procedures. This paper first presents a theoretical development of the demand and supply of hardwood stumpage and then examines the history of the white oak, red oak, yellow-poplar, and hard maple markets between 1970 and 1995. Using this information, a multi-period market margin model was developed. Analysis of short-term relationships between lumber price and stumpage price revealed that these series did not always move in the same direction, but tended to move in the same direction when there were large changes in lumber prices. However, continual declines in lumber prices did not always result in continual declines in stumpage price because of apparent price expectations of the stumpage owner. In the long run, the market margin between stumpage and lumber price has declined in a discrete manner. These declines are related to periodic increases in lumber production and price that occur at the beginning of the hardwood production and price cycle. Theory stipulates that during periods of declining prices, the less efficient sawmills will be forced out of the market. Following these periods, inventories usually are insufficient to satisfy any increase in lumber demand. Therefore, when demand increases, lumber prices increase sharply causing surviving, efficient mills to increase production and to bid up stumpage prices to new, higher levels. This bidding transfers any short-term economic gains that result from increased production or marketing efficiency to the resource owners.

Keywords: Hard maple, hardwood lumber prices, hardwood market history, hardwood stumpage prices, market margin, red oak, white oak, yellow-poplar.

INTRODUCTION

Understanding the relationship between stumpage prices and lumber price is pivotal in evaluating market efficiency and understanding the potential impact of changes in technology and regulations on stumpage prices. Previous analysis of red oak and yellow-pop-

lar lumber, log, and stumpage prices in Ohio revealed that stumpage prices increased faster than lumber prices (Luppold and Baumgras 1995). This divergence was attributed to competitive market forces transferring any increase in production and marketing efficiency to the resource owners. However, the 1995 study did not determine how this transfer occurred.

One way of examining how this transfer occurs is to develop an econometric system that includes all relevant demand, supply, and price relationships. Unfortunately, the hardwood market is heterogeneous with each grade and species of lumber having a different set of markets. This difference is reflected in the findings of Luppold and Baumgras (1995) that real price of red oak lumber has increased by 1.7% annually over the last 20 years, while the price of yellow-poplar lumber has decreased 1.3% per year. Another factor that confounds traditional econometric analyses is the poor quality of secondary data for quantities produced and demanded. Estimates of hardwood lumber production have been plagued with errors (Cardellichio and Binkley 1984; Luppold and Dempsey 1989), and there is no reliable estimate of production by species. Estimates of hardwood lumber consumption published every 5 years in the Census of Manufacturers are not developed by species. However, it may be possible to analyze market relationships using economic theory combined with a historical overview of hardwood markets.

In this paper we analyze the relationship of lumber and stumpage prices of four important hardwood species (white oak, red oak, yellow-poplar, and hard maple) in Ohio for periods between 1970 and 1995.[1] Since Ohio is a net importer of hardwood sawlogs (Widmann and Long 1992), this analysis also reflects stumpage markets in the bordering states of Kentucky, West Virginia, Indiana, and Pennsyl-

vania. Specific issues examined are the market margin between stumpage and lumber prices, how this margin has been changing over time, and what these changes mean in terms of economic efficiency. This study focuses on stumpage by considering logs as an intermediate product. Although some large mills rely on gate logs, stumpage is the primary timber product purchased by most grade sawmills in the Appalachian Region (Ed Murriner, W.V. Div. of For. and M. Long, Ohio Dep. Nat Resour., pers. communc.). Further, it is difficult to develop a weighted log price because grade definitions seem to have changed over time.

This paper consists of five sections. The first section presents a theoretical overview of the stumpage supply, stumpage demand, and stumpage/lumber price margin. This overview is followed by an examination of changes in the hardwood lumber market over the last 27 years, with emphasis on the changing demand for the four species being studied. The third section discusses data used in this study, defines variables, and develops the model used in the analysis. Results of analysis are presented in the fourth section, while major findings are reiterated in the final section of this paper.

THEORETICAL DEVELOPMENT

The economic relationships relevant to this analysis are the supply of, and demand for, hardwood sawtimber stumpage. Although the demand for stumpage emanates from a production function, the supply of stumpage emanates mainly from private, nonindustrial forest (NIPF) lands and is considerably more ambiguous. This section explores these relationships first as separate processes and then combines them in terms of market margins.

Nearly 80% of the hardwood stumpage in Ohio and adjoining states is controlled by NIPF land owners (Powell et al. 1993). These owners range from individuals controlling only a few acres to large institutional owners such as insurance companies. Forest industry (mainly sawmills and pulpmills) control an ad-

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[1] Although Ohio stumpage prices were reported since 1960 by the Ohio Agricultural Statistical Service, the earlier reports provided prices only for regions of the state. After examining the data, we decided to focus on the period from 1970 to 1995.

ditional 4.4%, while natural forest and other public sources own less than 16%. Since most of the sawtimber on industry land is not available for the open market and most public timber is either unavailable for harvesting or is sold to achieve some multiple use objective, NIPF lands are the primary open market source for hardwood sawtimber.

The fact that most of the hardwood timber supplied is from NIPF poses some difficult conceptual problems. Only 5% of NIPF owners and less than 20% of NIPF lands are managed for timber production (Birch 1996). Other factors that NIPF owners consider of greater priority are recreation use, esthetic enjoyment, and part of a farm or residence. Still 49% of NIPF land owners who control 75% of the timber had some portion of their land harvested in the past 10 years (Birch 1996). This large amount of harvesting experience indicates that regardless of primary interest, most NIPF lands are available for harvesting.

It is generally assumed that the physical supply of stumpage is fixed in the short-run, but supply of sawtimber is price-sensitive (not totally inelastic) because most individuals will sell their stumpage if a high enough price is offered. Still there has been no conclusive study on what motivates NIPF owners to sell timber and how these owners receive market information. Stumpage price is reported in Ohio on a semi-annual basis but is released 6 months after the reporting period (Ohio Agriculture Statistics Service). Most smaller NIPF owners probably are not aware of this information, but most of the larger owners such as insurance companies do monitor stumpage price. In this paper it is assumed that timber owners can receive information on the value of their timber by reading stumpage price reports, hiring a consulting forester, contacting a state forester, communicating with other land owners who have sold stumpage recently, or hearing from the firm that is offering to buy stumpage. Because of the various ways in which NIPF owners receive market information, timber prices across individual timber sales have the possibility to vary radically.

Although most NIPF owners may not have access to market information, it is assumed that more information exists during periods of high timber demand. The reason for this assumption is that the number of bidders for a specific timber stand increases, thus providing more information from buyers and more sales on neighboring lands providing more information from neighbors. Also, since economically mature stumpage can be held for several decades, there may be a point below which the price of stumpage will not decline further because of owner price expectations.

In this analysis, it is assumed that the demand for stumpage is the sum of the derived demand that emanates from the production functions of individual sawmills in a specific procurement area, and that procurement areas for individual mills overlap, creating a competitive market for stumpage. It also is assumed that in the long run adoption of new technologies causes hardwood sawmills to pay higher stumpage prices or sell lumber at lower prices. Also it is assumed that mills that do not have the capital or management necessary to adopt new technologies become relatively less efficient and eventually are forced out of the market. These assumptions imply that the market for stumpage is competitive and that the sawmilling industry has only minimal market power over the stumpage markets in the long run.

The margin between lumber price and stumpage price is primarily the result of processing and harvesting costs but may include short-term economic gains and losses (gains or losses above or below cost of production). Other factors that affect the margin between lumber and stumpage prices are the demand for high-grade veneer logs and exports of veneer and sawlogs. It is assumed that the competitive market structure causes sawmills and logging operations employed or contracted by the sawmills to adopt new production technologies and marketing procedures in an effort to increase profits. If these new methods seem to be profitable, then increased numbers of sawmills or logging operations adopt them, re-
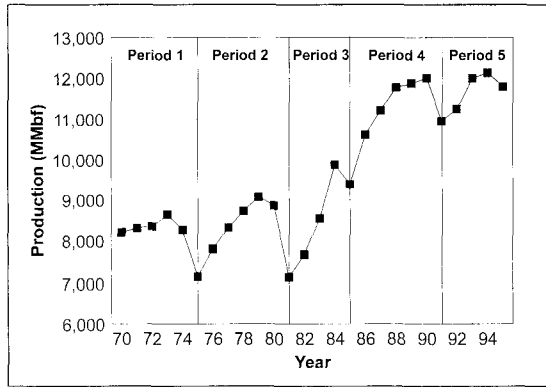
Fig. 1. Hardwood lumber production in the United States 1971–1994 in millions board feet.
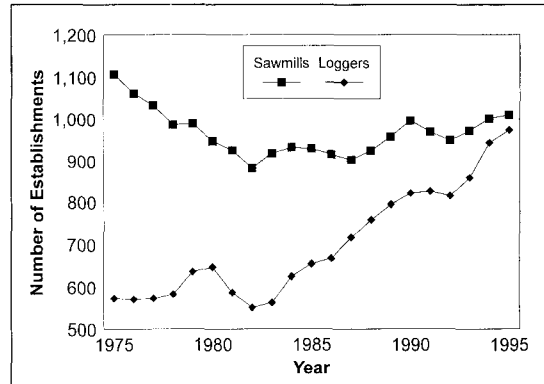

Fig. 2. Number of sawmills and logging establishments contributing to unemployment insurance pools in Ohio, Kentucky, Pennsylvania, and West Virginia 1979–1995.

sulting in an upward shift in the derived demand for stumpage and/or a downward shift in lumber supply.

The last theoretical concept to be examined is the hardwood production cycle and its potential impact on market margin. Hardwood lumber production cycles every 5 to 6 years (Fig. 1), and these cycles affect the number of sawmill and logging operations (Fig. 2).[2] It is hypothesized that firms with less efficient technology are forced from the market during periods of lower production and price. During the next period of price increases, the remaining efficient firms can pay higher prices for stumpage, causing market margins to decrease. However, it is an open question if these cycles are the result of activity in the economy at large or are internal to the hardwood market.

Luppold (1984) attributed market cycles to the recursive structure of the hardwood lumber market. In such a market, cycles can be made more severe when combined with a general

[2] Data not available for cycles 1 and 2. According to the U.S. Department of Labor, the operations represented in Fig. 6 are those that contributed to state unemployment insurance pools. Although these mills and loggers produce most of the lumber and logs, there are more than 1,000 operations that do not pay into unemployment insurance pools. Since the mills and loggers that do not contribute tend to be small, family-run firms that frequently go in and out of production, Fig. 6 may underrepresent the true fluctuations in the number of mills and loggers.

economic downturn, delayed by economic growth, are perturbed by price shocks; but would occur even if all exogenous input and output prices grew at constant rates. Using a simulator based on a recursive model, Luppold (1981) predicted that low points in production would occur in 1981, 1986, 1990, 1995. Actual market downturns occurred in 1981, 1985, 1991, and 1995. An equally compelling argument attributes dips in production to changes in the overall economy. The 1975, 1981, and 1991 downturns coincided with recessions. Still there is no evidence that macroeconomics forces influenced the smaller downturns that occurred in 1985 and 1995.

CHANGES IN THE HARDWOOD LUMBER MARKET

As previously discussed, the hardwood market has cycled five times between 1970 and 1995. During this 25-year period, the relative demand and prices for the various species also have been changing. In this section we examine changes in species demand in context of the hardwood cycle by examining demand for the five periods shown in Fig. 1.

Period 1 (1970 to 1974) was marked by economic change resulting from moderate inflation, federally mandated wage and price controls, and the adoption of floating exchange rates. During this period, the demand

and price of red and white oak surged as oak became an important furniture lumber and a major export to the European market (Frye 1996; Luppold and Araman 1988) and the elimination of wage and price controls. Prices for yellow-poplar lumber also increased sharply in 1972 and 1973 as furniture producers could finally obtain required volumes with the lifting of wage and price controls (see Hardwood Market Report, March 1971 through August 1973). Although the price of maple also increased during this period, the magnitude of the increase was considerably less than that for the other three species. This period ended in 1975 with a large drop in lumber prices and a 17% decrease in production (Luppold and Dempsey 1989).

Period 2 (1975 to 1980) was marked by increased export demand and high inflation. Prices for oak lumber increased sharply during this period as red oak became the predominant furniture lumber, and a weak dollar caused white oak exports to Europe to increase (Frye 1996; Luppold and Araman 1988; Nolley 1994). Demand for yellow-poplar also increased as U.S. furniture production peaked in 1978 (Nolley 1994). Prices for maple lumber cycled moderately as the use of this species began to decline. Overall, the production of eastern hardwood lumber increased by 27% between 1975 and 1979 but decreased by 21% between 1979 and 1981 (Luppold and Dempsey 1989).

During Period 3 (1981 to 1985) the influence of the furniture industry decreased, while the use of lumber by the flooring, kitchen cabinet, millwork, and pallet industries increased. Exports grew little because of the high value of the dollar against European currencies (Nolley 1994). The use of red oak as an appearance lumber continued to increase, while the use of maple continued to decline (Frye 1996). Although there were slight decreases in domestic production of furniture and cabinets at the end of Period 3, a 5% decrease in production at the end of 1984 was influenced by a drop in international demand (Nolley 1994) due to historically high exchange rates.

Period 4 (1986 to 1990) was marked by rapid growth in exports to Europe and Asia and relatively strong demand by the furniture, flooring, pallet, and kitchen cabinet industries. The use of red oak as an appearance lumber peaked in 1990, while the use of maple began to rebound in the late 1980s (Frye 1996). Production of eastern hardwood lumber increased nearly 28% between 1986 and 1989 and dropped by 8% between 1989 and 1991.

The post-1990 hardwood market (Period 5) was marked by large increases in lumber prices in 1992 and 1993 that resulted from the wood-products industry's inability to increase production as demand for lumber increased. Although part of the reason for this was sawmill attrition that occurred following the 1991 downturn, wet logging conditions and a lack of loggers seemed to be the primary hindrances to increased lumber production. The post-1991 lumber market also was marked by the increased use of closed-grained lumber by the furniture industry and a maturing export market (Frye 1996; Nolley 1994).

DATA AND MODEL DEVELOPMENT

As previously stated, the stumpage price data used in this study were reported by the Ohio Agriculture Statistics Service (1970–1995) and were developed in cooperation with the Ohio Department of Natural Resources. This price series is developed from a biannual survey of sawmills for March through May and September through November.

The prices for hardwood lumber were obtained from the "Hardwood Market Report" (1970–1995). To correspond with Ohio stumpage price series, market report prices were from the first week of April and October. Although all grades of hardwood lumber for a specific species move in a similar direction in the long run, there is some short-term variation between grade prices. To account for all grades of hardwood lumber that result from sawing hardwood logs, the actual prices used in the analysis were calculated as a weighted average using Eq. (1). The weights used in Eq.
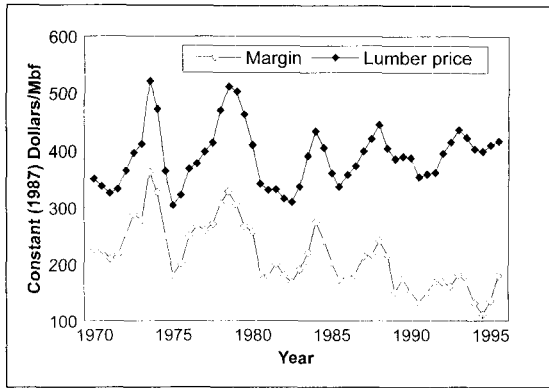
FIG. 3. White oak lumber price and white oak lumber-stumpage market margin 1970–1995 in constant 1987 dollars.
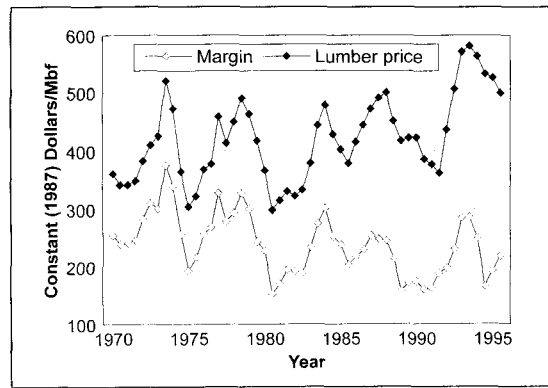

FIG. 4. Red oak lumber price and red oak lumber-stumpage market margin 1970–1995 in constant 1987 dollars.

(1) approximate the proportion grade mix associated with a typical Appalachian sawmill that produces appearance grade lumber:

$$PL_{it} = \{.15 \cdot PFAS_{it}\} + \{.4 \cdot P1C_{it}\} +$$

$$+ \{.25 \cdot P2_{it}\} + \{.2 \cdot p3C_{it}\} \qquad (1)$$

where

PL_{it} = weighted price of species i (i = 1 to 4 for white oak, red oak, yellow-poplar, and hard maple) in period t (t = 1 to 52)

$PFAS_{it}$ = price of plain-sawn FAS lumber for species i in period t

PIC_{it} = price of plain-sawn 1 Common lumber for species i in period t

$P2_{it}$ = price of plain-sawn 2 or 2A Common lumber for species i in period t

$P3C_{it}$ = price of plain-sawn 3A Common lumber for species i in period t except 2B for yellow-poplar.

The lumber-stumpage market margins were calculated by:

$$margin_{it} = PL_{it} - PS_{it} \qquad (2)$$

where

$margin_{it}$ = The lumber-stumpage market margin for species i in period t.

PL_{it} = from Eq. (1).

PS_{it} = price of stumpage for species i in period t (in dollars per Mbf Doyle scale).

Plain-sawn prices were used in this analysis since most of the hardwood lumber is plain-sawn. The intent of this study was to examine trends, so no overrun factor was used in calculation of the hardwood lumber-stumpage market margin. All prices were deflated to constant 1987 dollars using the Producer Price Index for all commodities.

The values of Eqs. (1) and (2) are shown in Figs. 3 through 6. Examination of these figures reveals two trends in the hardwood lumber-stumpage market margins. First, market margins fluctuate with lumber price, increasing when lumber price increases and decreasing when lumber price decreases. Second, the
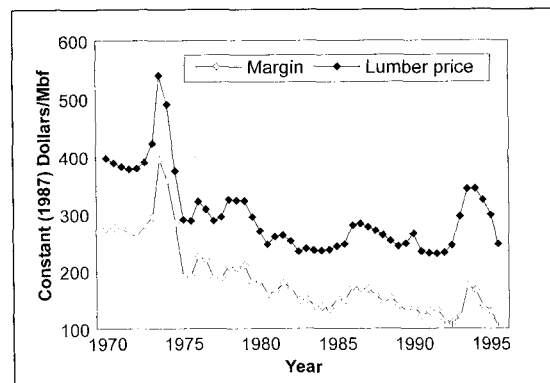

FIG. 5. Yellow-poplar lumber price and yellow-poplar lumber-stumpage market margin 1970–1995 in constant 1987 dollars.
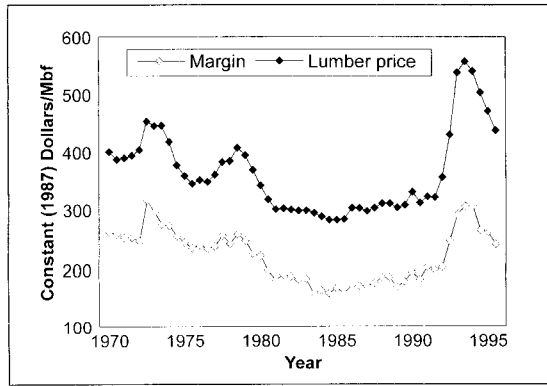
FIG. 6. Hard maple lumber price and hard maple lumber-stumpage market margin 1970–1995 in constant 1987 dollars.

TABLE 1. *Percentage of reported periods in which lumber and stumpage prices moved in the same direction given specified different levels of changes in lumber price.*

Change in lumber price	White oak	Red oak	Yellow-poplar	Hard maple
Less than 5%	27.3	56.3	65.5	56.9
(Number of changes)	(22)	(16)	(29)	(32)
Between 5 and 10	68.4	63.6	69.2	87.2
(Number of changes)	(19)	(22)	(13)	(16)
Greater than 10	63.6	78.6	80.0	75.0
(Number of changes)	(11)	(14)	(10)	(4)

margins are decreasing over time, especially for the oaks.

The fact that market margins fluctuate with lumber price suggests the existence of a percentage margin rather than a fixed margin. Although the percentage margin may be the result of some latent costing process, it does conform with economic theory. Increased lumber price usually causes hardwood lumber producers to increase production. When production is increased, factor demand increases, causing marginal products to decrease and per unit production cost to increase. Similarly, reduced prices lead to reduced production and lower factor demand.

As discussed by Haynes (1977), constant percentage margins are expressed as

$$p^s = p^a + kp^s \qquad (3)$$

$$p^a = (1 - k)p^s \qquad (3a)$$

where

p^s = price in the product or lumber market
p^a = price in the factor or stumpage market
k = percentage margin.

However, Figs. 3 through 6 show that margins have decreased over time, indicating that if there is some percentage market margin, it also may have decreased over time. Therefore Eq. (3) is a naive representation of the market margin model since it does not have a time component.

As stated in the theoretical development section, it is hypothesized that firms with less efficient technology are forced from the market during periods of lower production and price. The remaining efficient firms bid stumpage prices up, causing market margins to decrease. Thus, we should see changes in market margins related to the production cycle. To examine this hypothesis, the following relationship between stumpage and lumber was developed:

$$PS_i = B_{ij}D_j(PL_i) \qquad (4)$$

where

PS_i = price of stumpage of species i (i = 1 to 4)
B_{ij} = 1 − k_{ij} where k_{ij} is the percentage margin for species i in time period j
D_j = 0–1 slope shifter for time period j (j = periods 1 to 5 for 1970 to 1974, 1975 to 1980, 1981 to 1984, 1985 to 1990, and 1991 to 1995)
PL_i = price of lumber for species i.

ANALYSIS

Before estimating the relationship specified in Eq. (4), the stumpage and lumber price data were visually reviewed. This review found that stumpage and lumber price did not always move in the same direction. In the case of white oak, stumpage prices moved in the same direction as lumber prices only half of the time (Table 1). Further examination revealed that the greater the change in lumber price, the greater the likelihood that stumpage prices

would move in the same direction. When lumber prices moved more than 10% in either direction, stumpage prices followed in the same direction and magnitude 75 to 80% of the time. The lack of short-term uniform price movement is probably the result of the fact that most stumpage owners do not have a good source of market information except during expanding markets where competitive factors result in more information being transferred to timber owners.

The visual analysis of lumber and stumpage price also found that large decreases in lumber prices did not always result in large decreases in stumpage prices occurring during the 1974–1975 and 1980 downturns. At the beginning of these downturns, lumber and stumpage prices declined. However, midway through the decline in lumber price, stumpage prices started to increase slightly. This sequence suggests that although lumber prices can continue to decline sharply, there is a point below which stumpage prices stop falling. Such market behavior may be the result of landowner price expectations that cause stumpage owners to withdraw timber from the market until prices rise again.

The second step of the analysis was to estimate the relationship specified in Eq. (4) (Table 2). Initial OLS estimates of Eq. (4) indicated a high degree of positive first-order autocorrelation. Since positive serial correlation deflates standard errors and inflates apparent statistical significance, it was necessary to use the autoregressive procedure. Therefore, the B coefficients and t ratios in Table 2 were estimated using a Cochrane-Orcutt autoregressive estimation procedure described in the SHAZAM 7.0 user's reference manual (SHAZAM 1993). Intercept terms were restricted to zero to conform to the specification of Eq. (3a). Estimations were made using the SHAZAM 7.0 econometric package (SHAZAM 1993).

Essential in the estimation of Eq. (4) is that stumpage and lumber price series are stationary. If nonstationary, the only correct specification of this relation is a cointegrating one (Engle and Granger 1987). If this is the case,

TABLE 2. *Estimated percentage margin between deflated stumpage and lumber prices for white oak, red oak, yellow-poplar, and hard maple in Ohio between 1970 and 1995.*

Statistic	White oak	Red oak	Yellow-poplar	Hard maple
B value Period 1	0.316	0.277	0.288	0.350
(t ratio)	(14.5)	(9.41)	(27.9)	(40.9)
percentage margin	68.4	72.3	71.2	65.0
B value Period 2	0.374	0.351	0.348	0.350
(t ratio)	(17.7)	(11.5)	(24.3)	(36.2)
percentage margin	62.6	64.9	65.2	65.0
B value Period 3	0.419	0.417	0.381	0.405
(t ratio)	(15.7)	(12.7)	(18.5)	(28.3)
percentage margin	58.1	58.3	61.9	59.5
B value Period 4	0.519	0.500	0.423	0.421
(t ratio)	(23.4)	(18.3)	(25.7)	(36.6)
percentage margin	48.1	50.0	57.7	57.9
B value Period 5	0.601	0.551	0.517	0.437
(t ratio)	(23.5)	(19.3)	(28.7)	(46.6)
percentage margin	39.9	44.9	48.3	56.3
R-square	0.885	0.930	0.825	0.926
RHO value	0.494	0.645	0.339	0.253
(t ratio)	(4.10)	(6.08)	(2.59)	(1.88)

the Cochrane-Orcutt procedure produces inconsistent estimates. The large degree of autocorrelation found in the estimate presented in Table 2 may be indicative of the nonstationary lumber price, stumpage price, or both prices. If this is the case, the consistency of the estimates presented in Table 2 is questionable even though an autocorellative adjustment was made. We found that, indeed lumber and stumpage prices were nonstationary, arguing for another approach to estimating Eq. (4) that would produce consistent parameter estimates.

Since an analysis of the cointegration relationship requires the use of time series techniques that most readers may be unfamiliar with, the analysis is presented in Appendix 1. The result of this analysis indicates that lumber and stumpage prices were cointegrated, once production cycles were accounted for. Additionally, further investigation found that the parameter estimates shown in Table 2 were virtually identical to those produced by asymptotically unbiased methods. Also, the sta-

tistical significance of these parameter estimates were also maintained. We further investigated the temporal behavior of prices and learned that, within production cycle, short-run lumber price changes did not precede stumpage price changes, although there was some evidence to support the opposite situation for hard maple.

The more rigorous analysis also supported the findings that, although the percentage margin has decreased for all four species, there are differences in the degree and timing of these decreases. White oak had the largest decline in margin. Although much of this decline probably is a direct result of an increasingly efficient production and distribution system, the veneer log market and log exports also have contributed to margin decline. Red oak and yellow-poplar are two of the most commonly used domestic lumber species (Meyer et al. 1992). Both of these species have similar percentage market margins for Periods 1, 2, and 5. However, red oak showed the greatest decrease between Periods 3 and 4; yellow-poplar had the greatest decrease between Periods 4 and 5.

Hard maple had the smallest decrease in market margin, probably because of the low demand and interest in this species between the late 1960s and the late 1980s. Maple did not experience the rapid rise and fall in price in the mid-1970s. However, data collected since the fall of 1996 indicate that real maple lumber prices have increased to a 30-year high, and the stumpage/lumber market margins have at least temporarily decreased to the level of the other species.

SUMMARY AND CONCLUSIONS

The results of this study support the idea that the decreasing hardwood lumber/stumpage market margin is the result of competitive market forces. We found that stumpage and lumber prices are in long-run equilibrium. However, stumpage and lumber prices do not always follow one another in the short run because owners do not have adequate short-run

market information. The only time that these prices always move simultaneously is the beginning of periods with large changes in lumber prices.

Although stumpage prices do decrease during market downturns, there is evidence that price expectations do not allow stumpage prices to decrease as much as lumber prices during severe recessions. Such behavior aggravates an already poor market situation, causing an indeterminate number of less efficient sawmills to go out of business. When reduced inventory levels are matched with low production capacity, any increase in demand causes lumber prices to rise quickly. The quick rise in lumber prices causes sawmills to bid up the price of stumpage. This bidding war causes stumpage prices and the percentage margin to decrease. As a result, any short-term economic profit due to increased efficiency is transferred to the resource owners.

The findings that short-term increases in economic profit are transferred to the resource has important welfare implications. Any effort by public or private agencies to increase sawmill profitability ultimately will benefit resource owners. Similarly, any effort to impose additional safety and environmental regulations on sawmills that might increase production costs diminishes the potential future value of the resource.

Although this analysis was based on prices in Ohio, it may be relevant to adjacent areas in Indiana, Kentucky, Pennsylvania, and West Virginia. However, additional analyses of stumpage markets in other states are needed to determine whether these findings are valid for other areas that produce hardwood lumber.

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APPENDIX

Because stumpage demand is derived from the production function of lumber, stumpage and lumber prices can be considered codependent, prices being codetermined in equilibrium. One empirical question, therefore, is whether price data are consistent with a hypothesis of codetermination. If both prices are stationary time series, then there is, by definition, a stable relationship between the two: in levels, one can be expressed as a linear function of the other, with deviations from that function due to random, short-run shocks. It is possible, in this framework, for a short-run price change in one series to lead to a similar change in the other series or for there to be some lagged feedback of shocks. However, it should be noted that the time used in this analysis is of minimal size for cointegration analysis.

If both prices are nonstationary, then only a finding of cointegration of the two series can support a hypothesis of codetermination of price. Cointegration suggests that the long-run relationship between the two series is stationary, even though both series are nonstationary.

The market margin hypothesis proposed in this research suggests that one price is a constant proportion of the other. Further, we propose that these proportions are maintained for only five years, wherein the relationship shifts to a new constant proportion. Because all lumber and stumpage price series were found to be nonstationary, the proper method for evaluating the relationships between series was to test for cointegration. Least squares estimates of Eq. (4), which describes this shifting long-run equilibrium between series, produces biased standard error estimates, and the usual methods for correcting for autocorrelation of the residuals cannot be used (Engle and Granger 1987). Under a null hypothesis of cointegration, the residuals in a least squares estimate of Eq. (4) should be stationary. If the residual series is stationary, then the coefficient estimates are consistent, and we have support that Eq. (4) describes the true relationship between prices. If the residual series is nonstationary, then the coefficient estimates describe no durable relationship and are merely sample-dependent values with no theoretical distribution, and the data do not support a hypothesis of a stable (but shifting) long-run relationship between series.

We estimated Eq. (4) without correction for serial correlation and tested for stationarity of the residual series (Appendix Table 1). Equations were estimated in both directions, i.e., stumpage prices as a function of epochal dummies and lumber prices, and lumber prices as a function of epochal dummies and stumpage prices; however, we reported only the stumpage price equations. All dummies were included in the estimate, so Eq. (4) did not have an intercept. Standard errors of coefficients are not shown since they were potentially biased.

Two methods for testing for cointegration are reported in Appendix Table 1. The first, abbreviated ADF, is the Dickey-Fuller test, augmented for lags (Dickey and Fuller 1981). The number of lags used was determined iteratively to avoid over-parameterization of the unit root test and therefore to give the test greater statistical power. We thus began by estimating the test-statistic with four lagged dif-

APPENDIX TABLE 1.   *Estimates of Eq. (4) without correction for serial correlation and tests for stationarity of residuals.*

Left-hand side variable	P_iD_1	P_iD_2	P_iD_3	P_iD_4	P_iD_5	ADF	Johansen
White oak stumpage	0.32	0.37	0.42	0.51	0.61	−3.76[a]	32.14[c]
Red oak stumpage	0.28	0.34	0.40	0.51	0.55	−3.49	41.34[c]
Yellow-poplar stumpage	0.29	0.34	0.37	0.42	0.52	−4.79[b]	28.69[a]
Hard maple stumpage	0.35	0.35	0.40	0.42	0.44	−4.07[b]	20.29

Notes: A.D.F. is the test-statistic of the augmented Dickey-Fuller test of stationarity of the residuals, and Johansen is the test-statistic of a test of the cointegration of prices in an error-correction framework. All equations were also estimated in reverse order, and cointegration was supported for all products. All parameter estimates were statistically significantly different from zero at 1% significance, using methods recommended by Stock and Watson (1993).
[a] Indicates significance of the test-statistic at 10% (adapted from Johansen (1991)).
[b] Indicates significance of the test-statistic at 5% (adapted from Johansen (1991)).
[c] Indicates significance of the test-statistic at 1% (adapted from Johansen (1991)).

ference terms, dropping the fourth if not statistically significant, the third if not statistically significant, etc., to a minimum of one lagged difference term. The second test statistic is from Johansen (1991), in an error-correction framework, assuming no intercept and no trend (besides dummies) in the cointegrating relationship and no trend in the vector autoregression. Because the Johansen test is independent of direction of relationship, only one value is reported per species.

Critical values for the ADF and Johansen test-statistics were obtained from Hamilton (1994), assuming that the effects of epochal dummies on the distribution of test-statistics were the same as the effects of including a linear trend in the cointegrating relationship. In all cases, cointegration is supported at an acceptable level of confidence (except perhaps for hard maple, significant in the Johansen framework only at about 25%). Hence, we can conclude that the coefficients on the dummy-price interactions are estimated consistently and thus accurately describe the long-run relationships between stumpage and lumber prices. We note here, as well, that the estimated equations for stumpage price as a function of lumber prices give nearly identical coefficient estimates as those shown in Table 2. Further investigation of the standard errors of the estimated cointegrating vector, using the methods developed by Stock and Watson (1993), revealed that the statistical significance shown in Table 2 is also maintained. The implications here is that, despite the theoretical inappropriateness of the Cochrane-Orcutt procedure for these equations, producing inconsistent coefficient estimates, compared with the supposedly asymptotically unbiased approach of Stock and Watson (1993), coefficient and standard error estimates were not significantly distorted and showed only relatively tiny differences in magnitude from the asymptotically unbiased estimates.[3]

To supplement our investigation into the relationships between stumpage and lumber prices, we estimated vector error-correction (VEC) models for prices. The purpose of estimating these models was to check whether one price

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[3] The Stock and Watson (1993) method estimates are available from the authors.

leads to the other when subjected to market shocks. As stated above, while significant cointegrating relationships imply that there is a long-run equilibrium relationship between series, cointegration says nothing about short-run deviations from this equilibrium. Therefore, while there may be bidirectional causality between the series, there might also be evidence that one series slightly leads the other in price changes. Accordingly, the VEC, similar to a VAR but in differences, includes the cointegrating equation as a separate term explaining changes in the left-hand-side dependent price variable to account for the long-run tendency of price pairs to remain in equilibrium. Letting Δ symbolize a one-period change and suppressing the species subscript, i, pairs of equations were estimated using OLS:

$$\Delta PL_t = a_L + b_L(PS_{t-1} - B_{j,t-1}D_{j,t-1}PL_{t-1}) + c_{LL1}\Delta PL_{t-1} +$$
$$+ c_{LL2}\Delta PL_{t-2} + c_{LS1}\Delta PS_{t-1} + c_{LS2}\Delta PS_{t-2} + \epsilon_{L,t}$$

$$\Delta PS_t = a_S + b_S(PS_{t-1} - B_{j,t-1}D_{j,t-1}PL_{t-1}) + c_{LS1}\Delta PL_{t-1} +$$
$$+ c_{LS2}\Delta PL_{t-2} + c_{SS1}\Delta PS_{t-1} + c_{SS2}\Delta PS_{t-2} + \epsilon_{S,t}$$

$$(5)$$

The expression in parentheses is, effectively, the residuals from estimates of Eq. (4), the cointegrating relationship.

Estimates of Eq. (5) are reported in Appendix Table 2. The subscript k takes on one of two values, L or S, depending on which of the two equations in (5) corresponds. These estimates indicate that, once the cointegrating relationship between series is taken into account, there is no strong statistical support for a contention that lumber price changes lead stumpage price changes or vice versa. Most statistically significant lags were for own-price terms. Only in one case, hard maple lumber, were stumpage prices found to significantly lead lumber prices. In fact, the t-values for lagged changes in stumpage prices were often greater than one in absolute value for lumber price change equations, hinting that stumpage prices lead lumber prices. The long time between price observations (six months), then, might be a reason why no statistically significant stumpage price leading relationships were revealed across other products. Given that the cointegration equation term in (5) was statistically significant

APPENDIX TABLE 2.   *Vector error correction model estimates for lumber and stumpage prices.*

Left-hand side variable	Const.	C.R.[a]	ΔPL_{t-1}	ΔPL_{t-2}	ΔPS_{t-1}	ΔPS_{t-2}	R^2
White oak lumber	0.19	0.06	0.46	−0.32	0.48	−0.30	0.34
(t ratio)	(0.04)	(0.40)	(2.52)[c]	(2.06)[c]	(1.31)	(0.88)	
White oak stumpage	2.20	0.25	−0.02	−0.05	0.05	−0.09	0.25
(t ratio)	(0.90)	(3.22)[d]	(0.26)	(0.66)	(0.28)	(0.57)	
Red oak lumber	2.43	0.10	0.31	−0.11	0.67	−0.80	0.27
(t ratio)	(0.41)	(0.63)	(1.62)	(0.63)	(1.48)	(1.71)	
Red oak stumpage	3.80	0.23	−0.07	0.00	0.23	−0.12	0.27
(t ratio)	(1.58)	(3.50)[d]	(0.95)	(0.02)	(1.26)	(0.64)	
Yellow-poplar lumber	−0.45	−0.32	0.40	−0.35	0.50	−0.26	0.45
(t ratio)	(0.11)	(1.76)[b]	(2.23)[c]	(2.54)[c]	(1.10)	(0.64)	
Yellow-poplar stumpage	0.20	0.16	0.02	−0.13	0.24	0.04	0.14
(t ratio)	(0.10)	(1.71)[b]	(0.24)	(1.86)[b]	(1.05)	(0.20)	
Hard maple lumber	−1.53	0.38	0.06	−0.26	1.24	0.28	0.44
(t ratio)	(0.50)	(2.03)[c]	(0.24)	(1.41)	(2.95)[d]	(0.79)	
Hard maple stumpage	−0.15	0.35	0.15	0.03	0.30	−0.10	0.45
(t ratio)	(0.08)	(3.26)[d]	(1.01)	(0.28)	(1.22)	(0.50)	

[a] C.R. are residuals from OLS estimate of Eq. (4).
[b] Indicates significance at 10%.
[c] Indicates significance at 5%.
[d] Indicates significance at 1%.

across products, we find that most price adjustments to temporary shocks happen intratemporally. Therefore, we can conclude that within production cycles and within the time between observations, adjustments to price shocks were practically complete for both lumber and stumpage prices. But more frequent observations of prices might have revealed a statistically significant stumpage price leading relationship with lumber prices.