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An Econometric Model of the Hardwood Lumber Market

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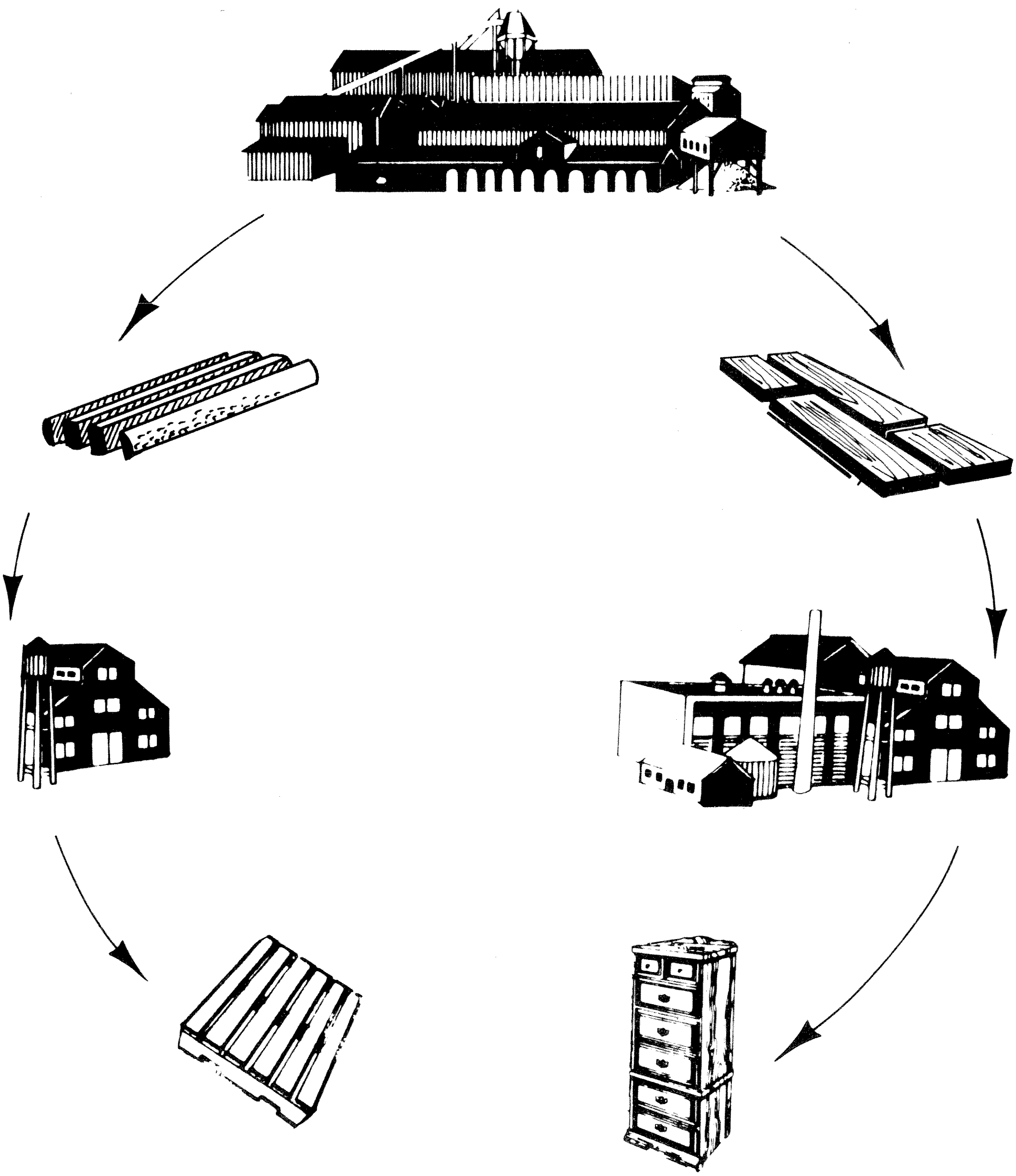

The Author

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Abstract

A recursive econometric model with causal flow originating from the demand relationship is used to analyze the effects of exogenous variables on quantity and price of hardwood lumber. Wage rates, interest rates, stumpage price, lumber exports, and price of lumber demanders' output were the major factors influencing quantities demanded and supplied and hardwood lumber price.

Introduction

The hardwood lumber industry dates back to colonial times, when hardwood lumber was used in the manufacturing of homes, ships, bridges, furniture, and a multitude of other major and minor products. As softwood, steel, plastic, and other industries developed and new technology and production methods were introduced, many of the uses of hardwood lumber changed. Today, hardwood lumber is used primarily by producers of furniture, cabinets, and pallets. Other users of hardwood lumber include manufacturers of rail ties, hardwood flooring, and a variety of specialty items.

Traditionally, the hardwood lumber market consisted of numerous buyers and sellers, trading in a slowly changing market environment. The price of hardwood lumber historically followed an oscillating and slowly upward-trending path. The quantity of hardwood lumber produced and demanded also fluctuated, but did not show any significant trend upward or downward during the last 30 years. However, since 1975, hardwood lumber price has increased dramatically while lumber production remained relatively stable.

Between 1975 and 1979, the price of hardwood lumber increased at an annual rate of 10.4 percent, or about 40 percent above the rate of increase for all crude materials used in manufacturing. Furthermore, the price of higher grade oak, the predominant hardwood species, increased at an annual rate of 18.4 percent. Still, lumber production in the 1970's remained below the average levels of the previous two decades.

The economic behavior of the hardwood lumber market during the late 1970's caused industrial users concern about future price and availability of hardwood lumber. Questions that arose included: what effects have increasing stumpage, labor, and capital costs had on lumber production; and how will lumber users react to increasing lumber prices? Also, what effects have the increased hardwood lumber exports during the 1970's had on the price?

In order for lumber suppliers (producers) and demanders (users) and forest resource planners to address these questions, information is needed on the effects of wage rates, stumpage prices, lumber exports, interest rates, and other important factors on the demand, supply, and price of hardwood lumber. Suppliers and demanders can incorporate such information when making lumber production and usage decisions. More market information will result in better allocation of resources by lumber demanders and suppliers. Such information will also contribute to the stock of knowledge available to resource planners, allowing them to better anticipate the effects of alternative policies on the hardwood lumber market.

To provide this needed information, I developed an econometric model to quantify economic relationships in the hardwood lumber market. The model considered major factors affecting the demand, supply, and price of hardwood lumber. With this model, the impacts of changes in important factors on lumber usage, production, and price can be assessed.

Model Development

The econometric market model uses aggregated yearly production, usage, and price data. Aggregate data that combine all grades and species of hardwood lumber were used because inventory and subsequent lumber usage data were not available by grade and species. Yearly observations were used because monthly observations were not updated. Also, since many firms are vertically integrated in this industry, it was assumed that these firms behaved rationally (maximized profits) at the various levels of their production processes.

The hardwood market model consisted of four relationships—three equations, representing demand, supply, and the price of hardwood lumber, and one equilibrium identity. The overall model was similar in form to the general commodity market model presented by Labys (1975). The model was recursive, with current quantity of lumber demanded being a function of past lumber price. A similar demand equation was presented by McKillop (1969) for the redwood industry. Figure 1 is schematic of the relationships in the model and the causal flow between these relationships.

The major factors assumed to affect hardwood lumber demand, supply, and price and the expected influences of these factors are listed in Tables 1, 2, and 3. The individual equations included in the model are discussed briefly below.

The Demand Equation

The specification of the demand equation was based on the derived demand relationships developed by Mosak (1938). Quantity of hardwood lumber demanded (used) was expressed as a function of lagged quantity demanded, current prices of output, past prices of inputs, and time.

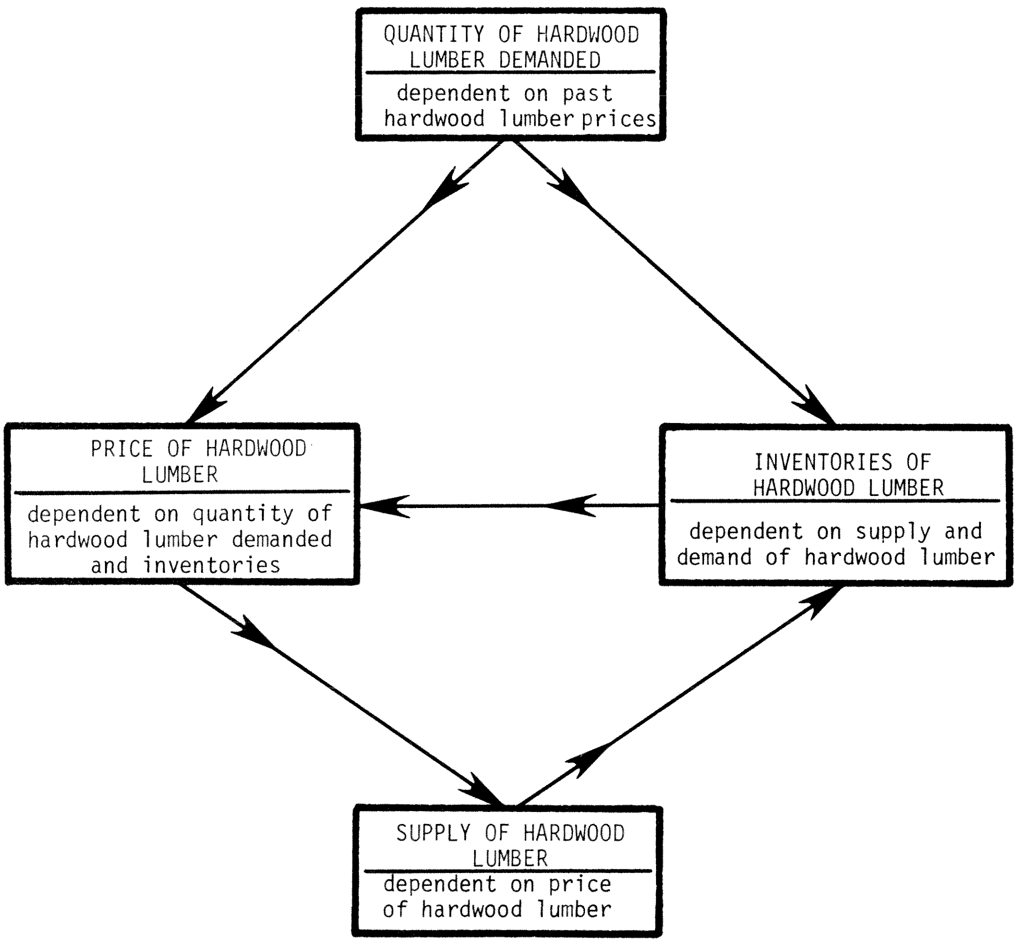


Figure 1.—The directional flow of demand, supply, and price in the hardwood lumber market in the United States.

Table 1.—Major factors, variables, expected relationships between variables, and units included in the hardwood lumber demand equation. The designations in parentheses in the variable column are those used for the same variables in equation 1

Factor	Variable	Expected relationship	Units
Dynamic adjustment variable	Quantity of hardwood lumber, lagged 1 year (lagged quantity demanded)	Positive, but less than 1	Million board feet
Price of output	Weighted price index of wholesale furniture price and price of manufactured goods (output price)	Positive	Index (1967 = 100) in nominal terms
Past price of hardwood lumber	2-year moving average of the price index for hardwood lumber, lagged 1 year (past lumber price)	Negative	Index (1967 = 100) in nominal terms
Past wage rates	2-year moving average of wage rates in manufacturing lagged 1 year (past wage rates)	Negative	Dollars per man-hour in nominal terms
Past price of capital	2-year moving average of interest rate on 4- to 6-month prime commercial paper, lagged 1 year (past interest rates)	Negative	Percentage
Trend removal	Time trend (time)	No a priori expectations	1959 = 1, increasing 1 unit per year

Table 2.—Major factors, variables, expected relationships between variables, and units included in the hardwood lumber supply equation. The designations in parentheses in the variable column are those used for the same variables in equation 2

Factor	Variable	Expected relationship	Units
Dynamic adjustment variable	Quantity of hardwood lumber supplied, lagged 1 year (lagged quantity supplied)	Positive, but less than 1	Million board feet
Lumber price	Price index of hardwood lumber (lumber price)	Positive	Index (1967 = 100) in nominal terms
Stumpage price	2-year moving average of current and past year stumpage price in national forest, plus the cost of borrowing money 1 year (stumpage price)	Negative	Dollars per thousand board feet in nominal terms
Wage rates	Price of labor in sawmills (wage rates)	Negative	Dollars per man-hour in nominal terms
Price of capital	3-year moving average of interest on 4- to 6-month prime commercial paper (interest rates)	Negative	Percentage
Trend removal	Time trend (time)	No a priori expectations	1959 = 1, increasing 1 unit per year

Table 3.—Major factors, variables, expected relationships between variables, and units included in the hardwood lumber price equation. The designations in parentheses in the variable column are those used for the same variables in equation 3

Factor	Variable	Expected relationship	Units
Price expectation variable	Lagged price index of hardwood lumber (lagged lumber price)	Positive, but less than 1	Index (1967 = 100) in nominal terms
Quantity demanded	Quantity of hardwood lumber demanded (quantity demanded)	Positive	Million board feet
Inventory	Quantity of hardwood lumber held in inventory by producers and wholesalers at year's end (inventory)	Negative	Million board feet
Exports	Quantity of hardwood lumber exported (exports)	Positive	Million board feet

The demand equation was specified as a function of past input prices because of the economic behavior of the two major hardwood lumber users, furniture and pallet producers. Furniture manufacturers' usage of lumber and other inputs is a function of past input prices and current output prices because of the process by which furniture is designed and marketed. Design and input mix decisions are made before production and are based on expectations of future input prices. These expectations are usually based on prices during the planning period and previous years.

The quantities of lumber and other inputs used in the production of pallets are also contingent upon past prices because pallet producers cannot constantly change their production processes. Pallet producers do change production processes and equipment, but these changes take time.

The selection of an appropriate output price variable for the demand equation was difficult because furniture is a final product, while pallets are an industrial product. Furniture manufacturers react to wholesale prices of furniture. Pallet producers are usually locked into some formal or informal contractual arrangement with pallet users, so pallet production is usually based strictly on orders. Since pallet cost is a very small part of the pallet user's production and distribution costs, the price of the pallet user's output is relevant in the derived demand for lumber. Therefore, the output price used in the hardwood lumber demand equation was the weighted average of the wholesale price of furniture and a measure of pallet demanders' output price.

Lagged quantity demanded was included in the specification of the demand equation in order to incorporate a distributed lag structure, thus allowing for dynamic adjustment. This method of incorporating a distributed lag was developed by Nerlove (1958) and was based on the idea that dependent variables may adjust to changes in the independent variables over several time periods.

Time was included in the specification to remove any trend that was present in the data. Trend might have been present in the data base because of increases in labor productivity or input utilization. The price of substitute materials was not included in the aggregate demand relationship because a number of substitutes have been developed, implemented, then replaced by yet other substitutes during the period included in the data base.

Imports of hardwood lumber were not used in the final calculation of quantity demanded because there is no adequate price index representing imported hardwood lumber, so misspecification might occur if imports were included in the demand equation. When imports were included in the calculation of quantity demanded, the equation did not explain the turning points as well as the final form of the equation, which excluded imports.

The Supply Equation

Quantity of lumber supplied (produced) was expressed as a function of lagged quantity supplied, price of hardwood lumber, wage rates, stumpage costs, current and past interest rates, and time. The time variable was included to remove some of the trend that might otherwise tend to be picked up by the lagged quantity variable.

The roundwood input used in lumber production may be purchased in the form of stumpage or sawlogs, or both. Stumpage price was included in the supply relationship because stumpage is the basic input, whereas sawlogs are a transitional input. Because stumpage may be held for a period before harvesting, previous stumpage price was hypothesized to influence current quantity supplied. Stumpage is a high-cost input; therefore, interest rates must be considered as part of the cost of purchasing stumpage. Previous purchases of capital equipment also affect current lumber production. Consequently, past and current interest rates were included in the supply equation.

The Price Equation

Price of hardwood lumber was specified as a function of lagged price, quantity demanded, level of inventory, and quantity exported. Although only high-grade lumber is exported, an increase in exports not only leads to an increase in the price of the highest grade of lumber, but also affects all grades of lumber.

Since export demand may be a function of current hardwood lumber price, an argument might be made for domestic price and export demand being jointly determined. However, there is an information lag concerning the volumes of lumber exported, while information about the price of domestically produced lumber is almost instantaneous. Because of the information flows, the causal flow between domestic price and export demand was hypothesized to originate from the export demand relationship and then flow to the domestic price relationship. Similar recursive flows in which all endogenous variables have a time period "t" subscript have been discussed by Wold and Jureen (1953).

Imports may also affect domestic hardwood lumber price; however, much of the hardwood lumber imported is high-value tropical species such as teak, mahogany, and balsa. These high-value tropical species compete with less than 5 percent of the domestically produced hardwood lumber and, thus, should not significantly affect domestic hardwood lumber price. But imports of temperate hardwood species from Canada can affect domestic hardwood lumber price since these species are similar, if not identical, to domestic species. However, the inclusion of Canadian imports into the hardwood lumber price equation resulted in a highly insignificant coefficient of the wrong sign for this variable. The magnitudes of the existing coefficients changed at most by .02 and the R^2 only increased by .0029 percent. In fact, inclusion of Canadian imports into the price model only affected the equation by consuming a degree of freedom that resulted in a 25-percent decrease in the F statistic and increases in the standard errors of the coefficients. Consequently, hardwood lumber imports were omitted from the price equation.

The Equilibrium Identity

The last relationship included in the model was an identity, rather than an equation to be statistically estimated. The identity stated that:

Quantity demanded = (quantity supplied) + (lagged inventory levels) − (current inventory levels) − (exports)

The identity allowed the market model to be in equilibrium with respect to quantities produced, demanded, and held in inventory. Imports were not included in the equilibrium identity since they were excluded from the demand and price equations.

Data Base

All equations were estimated from secondary data. The data base consisted of annual observations from 1959 through 1978, being limited by the stumpage price series that began in 1959. The data series representing quantity of hardwood lumber demanded was calculated using the equilibrium identity presented above. A complete listing of all data used in calculating quantity demanded is listed in Appendix A.

The quantity of hardwood lumber supplied and inventories of hardwood lumber were obtained from *Current Industrial Reports: Lumber Production and Mill Stocks* (U.S. Department of Commerce 1959–1978). Exports of hardwood lumber were calculated from figures presented in *U.S. Exports Schedule B. Commodity by Country* (U.S. Department of Commerce 1959–1978).

The price indexes of manufactured goods, furniture, and hardwood lumber were derived from information published in the *Statistical Abstracts of the United States* (U.S. Department of Commerce 1959–1978). Wage rates in manufacturing, wage rates in sawmills, interest rates of commercial paper, and stumpage price in national forests were also collected from the Statistical Abstracts.

Model Estimation and Evaluation

Since quantity demanded is a function of past lumber prices, the demand equation was estimated by ordinary least squares (OLS); and, since error terms of the price and supply relationships were hypothesized to be independently distributed, the parameters of the price and supply relationships were estimated using OLS procedures. The statistics in parentheses represent standard errors. The "Z" statistic represents "Z" values calculated for the nonparametric runs test, which is a test for serial correlation. This test was used in lieu of a DW statistics since DW statistics are invalid in equations that include lagged dependent variables. All relationships were estimated by taking the natural log of both sides of the individual equations, resulting in a multiplicative form; therefore, the estimated coefficients represent elasticities and flexibilities. The results of the estimate procedure are:

Equation 1:

$$\ln(\text{quantity demanded}) = \underset{(1.68)}{11.19} + \underset{(.151)}{.287}\ln(\text{lagged quantity demanded}) + \underset{(.503)}{1.72}\ln(\text{output price}) - \underset{(.249)}{.961}\ln(\text{past lumber price}) - \underset{(.372)}{1.14}\ln(\text{past wage rates}) - \underset{(.056)}{.076}\ln(\text{past interest rates}) + \underset{(.072)}{.294}\ln(\text{time})$$

Z = .49 F = 21.3 R^2 = .921

Equation 2:

$$\ln(\text{quantity supplied}) = \underset{(1.23)}{.518} + \underset{(.145)}{.256}\ln(\text{lagged quantity supplied}) + \underset{(.124)}{.634}\ln(\text{lumber price}) - \underset{(.097)}{.400}\ln(\text{stumpage price}) - \underset{(.114)}{.676}\ln(\text{wage rates}) - \underset{(.049)}{.185}\ln(\text{interest rates}) + \underset{(.056)}{.344}\ln(\text{time})$$

Z = 1.46 F = 24.0 R^2 = .929

Equation 3:

$$\ln(\text{price}) = \underset{(2.88)}{.810} + \underset{(.108)}{.886}\ln(\text{lagged lumber price}) + \underset{(.243)}{.336}\ln(\text{quantity demanded}) - \underset{(.150)}{.336}\ln(\text{inventory}) + \underset{(.082)}{.161}\ln(\text{exports})$$

Z = .73 F = 82.3 R^2 = .959

In order to estimate the hardwood market model using OLS, it was hypothesized that the supply and price equations were not jointly determined. A likelihood ratio test developed by Anderson (1958) indicated no correlation between error terms since the null hypothesis could not be rejected at the .05 level. Thus, no joint determination appeared to exist between the supply and price equation. A more detailed discussion of the likelihood ratio test employed and the results of the test are presented in Appendix B.

Model Evaluation

The goodness of fit of a particular equation, as measured by multiple correlation coefficient (R^2) and the F statistics, indicated that all equations fitted the data quite well. Most of the estimated coefficients in the model were significant at the .01 level and all variables were significant at the .10 level. Since the resulting Z values of the nonparametric runs tests were all below the critical value of 1.76, the alternative hypothesis (autocorrelation exists) could not be accepted in any of the equations at the .05 level of significance. Thus, autocorrelation did not appear to be present in any of the equations.

The quality of an econometric model is only partially measured by the value of the R^2 or the magnitude of the "t" test on individual variables. In fact, the true strength of a model lies in its ability to account for the fluctuations in the production, use, and price of the commodity. The explanatory abilities of the supply, demand, and price equations are presented in Figures 1, 2, and 3.

The supply equation in Figure 2 performed extremely well, catching five of the six turning points that occurred in the data base. The one missed turning point occurred when the equation showed an upturn in 1967, a year before its actual occurrence. Overall, the explanatory ability of the supply equation was judged excellent.

The demand equation (Fig. 3) accounted for all major turning points that occurred in the data base. Not only were all major turning points accounted for, but so were the magnitudes of these changes. However, the minor turning points, which occurred in rapid succession during the early 1970's, were missed. Thus, the demand equation's explanatory ability was judged as only good, and not outstanding.

Figure 2.—Observed vs predicted of quantity of hardwood lumber supplied, 1961 - 1978.

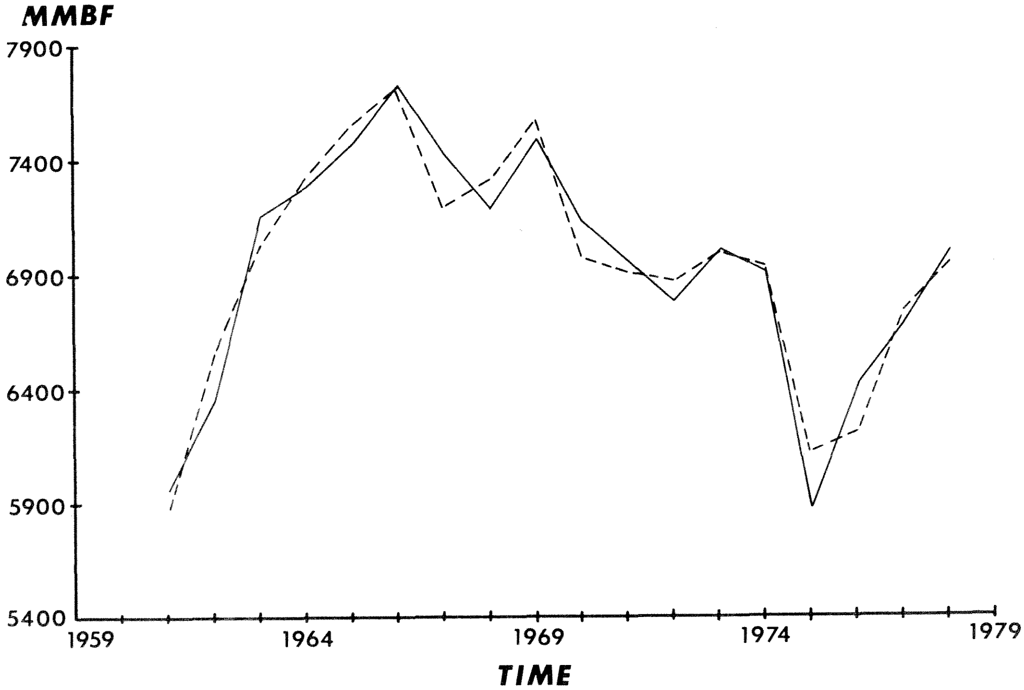
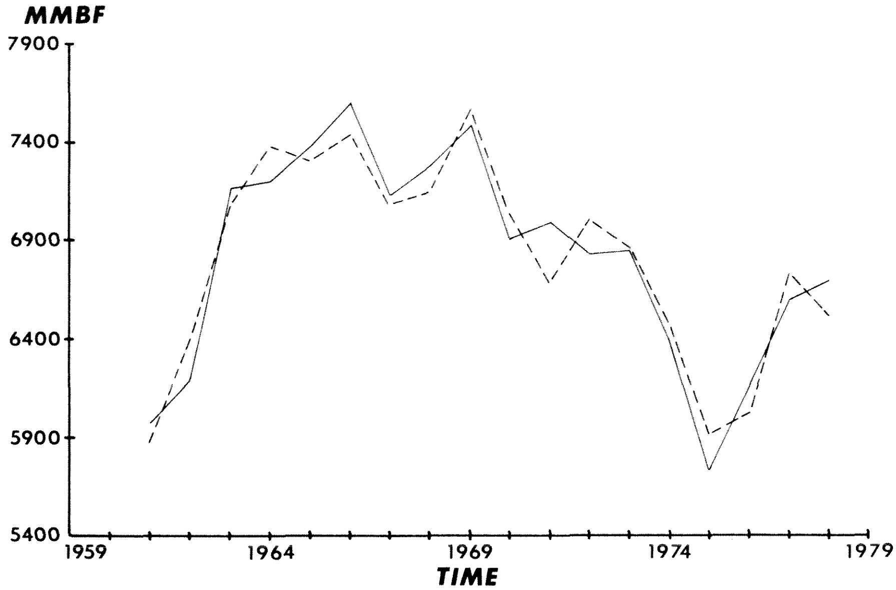


Figure 3.—Observed vs predicted of quantity of hardwood lumber demanded, 1961 - 1978.

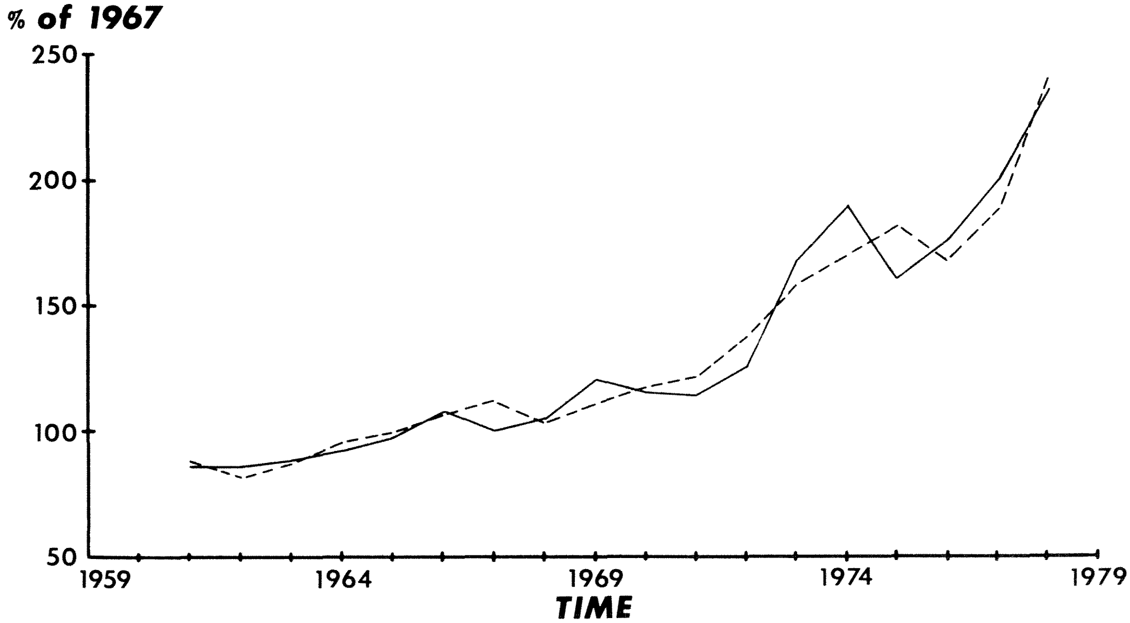


Although the price equation (Fig. 4) had the highest R^2 of all the estimated relationships, the ability of this equation to account for turning points was poor. The inability of the price equation to catch turning points can be attributed to the influence of lagged price. The high estimate for the coefficient of expectation (the coefficient on lagged price) in the price equation caused the estimated turning points to occur a year after the actual turning points. However, the general ability of the price equation to account for price trend implied that this equation could be used for long-term price forecasts with few difficulties.

Model Interpretation

The statistical results presented and discussed in the previous section were not analyzed or interpreted. The purpose of this section is to provide meaning to the statistical results.

Figure 4.—Observed vs predicted of price of hardwood lumber, 1961 - 1978.



Elasticities, Flexibilities, and Net Effects

In the model estimation section, the estimated coefficients of the demand and supply equations represented elasticities, and the coefficients of the price equation represented flexibilities. These coefficients represented the effects of a 1-percent change of an independent variable on a dependent variable without accounting for interactions between equations. The term "net effects" is used in this study to describe the effects of a 1-percent change of an independent variable on the dependent variables of all equations when interactions are allowed to occur between the various relationships in the model. The elasticities, flexibilities, and net effects are discussed in subsequent sections.

Interpreting Elasticities and Flexibilities

Demand and supply elasticities and price flexibilities are presented in Table 4. While elasticities and flexibilities are conceptually simple to understand, the use of these measurements was limited in this study because they do not account for interactions with the other relationships in the model. However, price flexibilities can be used in calculating the effect of changes in exports, quantity demanded, and inventory on price. These price flexibilities are shown in the right-hand column of Table 4. Too, elasticities can be used to determine how much an output price must change to counteract a change in an input price in order for quantity produced or demanded to remain constant. A few examples of the arithmetic used in calculating these counterbalancing changes are demonstrated below. Table 5 is a summary of these counterbalancing changes.

Lumber users can use elasticities to determine how much lumber price must change, given an increase in an input price, in order for lumber production to remain constant. For example, a 1-percent increase in wage rates means that lumber price must increase 1.07 percent for quantity supplied to remain constant. This figure is obtained by dividing wage rate elasticity of supply (.676) by lumber price elasticity of supply (.634). Another way to view this procedure is to say that the .676-percent decrease in lumber production, due to a 1-percent increase in wage rates, is counteracted by a 1.07-percent increase in lumber price since (1.07) × (.634) = .676.

It was slightly more difficult to determine how much lumber price must increase to counteract a 1-percent increase in stumpage price since the stumpage price coefficient was based on a 2-year moving average. Because a moving average was used, a change in the stumpage price was interpreted as affecting lumber production during the year of the change (the first year) and also the year after the change (the second year). Therefore, the number resulting from dividing the stumpage price elasticity of supply (.40) by the lumber price elasticity of supply (.634) must be divided by 2. This can be shown arithmetically as (.40/.634)/2 = .315; so, lumber price must increase by .315 percent during the first year in order to counteract a 1-percent increase in stumpage price. Similarly, a .315-percent increase in lumber price during the second year is also necessary to counteract the initial increase in stumpage price.

The amount lumber price must change to counteract a change in interest rates was developed similarly. However, since the interest elasticity of supply was estimated using a 3-year moving average, lumber price must increase by (.185/.639)/3, or .10 percent during the first, second, and third years in order to counteract a change in interest rates during the first year. Also, since all input price elasticities in the demand equation were based on a 2-year moving average, lagged 1 year, a change in price of one of these inputs affected demand during the subsequent 2 years (Table 6).

Interpreting the Net Effects

The net effects displayed in Table 6 were calculated using a computer program that allowed concurrent changes between the various relationships of the market model. The net effects, obtained from the recursive model, were sequels to impact and interim multipliers obtained from a simultaneous system. However, since recursive systems continually oscillate, the net effects represented changes in production, usage, and price from what would have occurred had there been no change in wage rates, interest rates, etc. The net effects of changes in lumber users' output price, wage rates, interest rates, exports, and stumpage price on quantity demanded (usage), quantity supplied (production), and price are discussed below.

Price of lumber users' output. Lumber users' output price is by far the most influential single force in the hardwood lumber market when measured by net effects. Increases in this variable are usually caused by an increased aggregate demand at the national level. When lumber users' output price increases by 1 percent, quantity of lumber demanded increases by 1.7 percent, production increases by 1 percent, and price increases by almost 1.7 percent. In the second year after the increase in output price, production and usage increase by 1.6 and 1.4 percent, respectively, and price increases by 2.1 percent.

Wage rates. The calculated net effects showed that a 1-percent increase in lumber producers' and users' wage rates initially caused quantity supplied to decrease by .3 percent and price to increase by .58 percent. During the second year after the increase in wage rates, pro-

Table 4.—Elasticities of demand and supply and price flexibilities[a] (in percent)

Variable	Quantity demanded	Quantity supplied	Price
Price of lumber users' output	1.76	NA	NA
Wage rates	− 1.14[b]	− .676	NA[c]
Interest rates	− .076[b]	− .185[d]	NA
Stumpage price	NA	− .400[e]	NA
Exports	NA	NA	.161
Price of lumber	− .961[b]	.634	NA
Quantity demanded	NA	NA	.336
Inventory	NA	NA	.336

[a] Does not include lagged dependent variable. Lagged dependent variables incorporate dynamics into the model, and the coefficients are coefficients of adjustments or expectation.
[b] Calculated from a 2-year moving average, lagged 1 year (t-1, and t-2).
[c] Not applicable.
[d] Calculated from a 3-year moving average (t, t-1, and t-2).
[e] Calculated from a 2-year moving average (t, and t-1).

Table 5.—Using elasticities to calculate the percentage increase in output price necessary to counteract a 1-percent change in input price

Variable that changes by 1 percent in Year 1	Year	Amount lumber price would have to increase for lumber production to remain constant	Amount demanders' output price would have to increase for lumber usage to remain constant
		percent	*percent*
Wage rates	1	1.07	0
	2	0	.32
	3	0	.32
Interest rates	1	.10	0
	2	.10	.02
	3	.10	.02
Stumpage price	1	.32	NA
	2	.32	NA
	3	0	NA
Lumber price	1	NA	0
	2	NA	.27
	3	NA	.27

Table 6.—Net effects of a 1-percent change in exogenous variables on endogenous variables during the year of the change and the year after (in percent)

Exogenous variable	First year			Second year		
	Quantity demanded	Quantity supplied	Price	Quantity demanded	Quantity supplied	Price
Price of lumber users' output	+ 1.72	+ 1.04	+ 1.65	+ 1.39	+ 1.59	+ 2.10
Wage rates	0	− .30	+ .58	− 1.42	− .75	− .01
Interest rates	0	− .08	+ .163	− .16	− .10	+ .161
Stumpage price	0	− .07	+ .20	− .09	− .15	+ .42
Exports	0	+ .08	+ .12	− .06	+ .10	+ .13

duction and usage decreased by .75 and 1.42 percent, respectively, while price decreased by .01 percent. Lumber price actually decreased during the second year after increases in wage rates because lumber users, faced with increases in wage rates and lumber price, decreased their lumber use more than lumber suppliers decreased production. However, increased wage rates at a national level increase aggregate demand and, thus, output prices. Increased output price affects lumber price to a greater extent than it affects lumber production or lumber usage (see lumber users' output price). Therefore, increases in wage rates by themselves may not affect lumber prices, but the effect of increased wage rates and subsequent increased output price can result in increased lumber prices.

Interest rates. The effect of interest rates on usage, production, and price of hardwood lumber appears to be small; however, when interest rates move from 10 to 12.5 percent during the course of a year, the increase is 25 percent. If interest rates increase by 25 percent, lumber production decreases by 2 percent and lumber price increases by 4 percent during the first year. During the second year after the increase, lumber usage decreases by 4 percent, lumber production decreases by 2.5 percent, and price increases by 4 percent.

Stumpage price. As indicated in Table 6, an increase in stumpage price affected lumber price more than it affected either production or usage. A 1-percent increase in stumpage price initially led to a .07-percent decrease in production and a .20-percent increase in price. During the second year after the increase in stumpage price, lumber price increased by .42 percent, while usage and production decreased by approximately .09 and .15 percent, respectively.

Exports. The effects of exports are somewhat understated by the net effects listed in Table 6 because exports changed by as much as 90 percent in 1 year during the 1970's. Given a 10-percent increase in exports, quantity supplied increased by .8 percent and price increased by 1.2 percent during the first year. If exports continued at the high level during the second year, domestic demand would decrease by .6 percent because of the higher price. However, increased exports caused price to increase by 1.3 percent, and thus caused production to increase by 1 percent.

The Results of the Model and Recent Market Behavior

The behavior of the hardwood lumber market during the 1970's and early 1980's was characterized by rapidly rising price and relatively stable production and usage. An examination of why the market behaved in this manner will be of interest to both industry members and resource policymakers and will also demonstrate how information obtained from the previous analysis can be used to explain real-world market behavior. Since the market behaved slightly differently in the 1970's from the early 1980's, each of these time periods is discussed separately.

The 1970's

Hardwood lumber production and usage remained stable, or even decreased, during the 1970's, relative to the 1960's and 1950's. The price of hardwood lumber increased 126 percent between 1970 and 1979, compared to 15 percent from 1960 to 1969. One question that we must address at this point is: how did the factors that affect the hardwood lumber market contribute to the increased price and stable, or even declining, production and usage of hardwood lumber?

One alleged cause of increased price of domestic hardwood lumber is increased lumber exports. Exports increased by more than 250 percent during the 1970's, but the econometric model indicates that increased exports accounted for, at most, 25 percent of the increased lumber price. However, since increased exports have consisted mainly of high-quality oak and ash, the prices of grades 1F and FAS of these species have been more affected by exports.

Domestic demand for hardwood lumber was ruled out as a major contributor to increased lumber price since demand did not increase during the 1970's. This indicates that the large increase in lumber price must have emanated primarily from the supply side; i.e., at the mill level. The fact that price increased 126 percent while production stayed stable supports this hypothesis.

During the 1970's, hardwood lumber producers faced rapidly increasing labor, roundwood input, and capital costs, Wage rates in sawmills increased by 127 percent, stumpage prices increased by 51 percent, and interest rates increased by more than 22 percent. Using the information presented in Table 5, I estimated that lumber prices could increase by 175 percent in order to counteract the increases in production cost. However, better utilization of inputs, as probably represented by the positive time-trend coefficient, partially counteracted increased costs; thus, lumber price increased by only 126 percent.

Increases in production costs also caused lumber demand to remain stable during the last decade. During the 1970's, wage rates in furniture and other types of manufacturing nearly doubled and lumber price increased by 127 percent. According to the information contained in Table 5, output price could increase by 132 percent in order to counteract increases in costs. However, output prices only increased by approximately 90 percent, indicating that gains in input utilization were enough to counteract some of the increased input costs by the end of the decade.

The 1980's

Lumber prices of most hardwood species fluctuated during 1980 and 1981. Although prices of 1F and FAS red and white oak remained high, prices of most other species and lower grades of oak decreased thru 1980 and increased only slightly in 1981.

Lumber production increased in 1980 and 1981, reaching pre-1970 levels, while inventories were at the highest point in the last 30 years. All the while, domestic hardwood lumber demand decreased. These occurrences seem contradictory, since production does not usually increase during periods of increasing inventories and decreasing demand, and lumber price does not usually increase while domestic demand is decreasing and inventories remain high.

The answer to these apparent contradictions can be found by looking at the export market. Exports to Europe remained high during 1980 and 1981, despite devaluation of European currencies against the dollar and slowed economic growth in most European countries. The increases in exports were predominantly FAS and 1F red and white oak. Europeans paid high prices for the best grades, and thus kept these prices high. However, the lower grades did not sell because of decreased domestic demand; thus, inventories increased to the highest levels ever recorded.

Conclusions

One implication of the market model is that the hardwood lumber market is recursive. However, it differs from other recursive markets, such as wheat and other agricultural commodities, because demand, rather than supply, is a function of lagged price. This can cause demand and supply forces to be continually out of synchrony, causing continual fluctuations in production and usage.

A Problem of Uncertainty

A problem in markets with recursive attributes is the uncertainty created by constant fluctuations in quantities demanded and supplied and subsequent fluctuations in price. Uncertainty tends to discourage current and potential demanders from committing themselves to future use of hardwood lumber, and current and potential suppliers may be discouraged from purchasing expensive equipment and incorporating new technology.

Slower implementation of technology affects the price of hardwood lumber on the supply side and contributes to nonincreasing demand. The end result of uncertainty is a potential misallocation of resources, less efficient production practices, and lower production and usage.

Problems Affecting Supply

Increasing production costs forced suppliers of hardwood lumber to increase lumber price or go out of business. In Table 5, the single most influential factor affecting lumber production costs is wage rates. Lumber price can increase by as much as 1.07 percent for each 1-percent increase in wage rates. Given that wage rates have increased more than any other input cost and will probably continue to do so in the future, high priority should be given to ways of increasing labor productivity. It should be remembered that better management and better work incentives may be just as important as labor saving machinery in increasing output per man-hour.

Stumpage costs also contributed to the large increases in lumber prices. Although very little can be done to increase the interim stumpage supply, research in better utilization of existing stumpage would dampen future increases in lumber price, and better maintenance of existing stumpage and growing stock would also help keep lumber production costs down in the long run.

Increasing interest rates increased the cost of capital and, thus contributed to higher production costs. Given the current increases in interest rates, increasing labor productivity by better management and increased work incentives may be, at least, a temporary alternative to increased capitalization.

Problems Affecting Demand

Hardwood lumber users also faced steadily increasing production costs because of increases in wage rates and lumber price. Lumber price increases are not expected to subside in the future; therefore, if lumber costs are to be reduced, lumber users must strive for better utilization and increased use of less expensive, lower grade lumber and timber. Similarly, lumber users must increase labor productivity if future increases in labor costs are to be minimized.

Another problem facing hardwood lumber users is overcapacity. Furniture manufacturers increased production capacity during the 1970's in anticipation of increased demand, but the increase in demand did not materialize. Pallet producers increased production capacity with new equipment, but demand did not increase as fast as production capacity. Given this overcapacity, increasing labor utilization by managerial methods is a viable alternative to increasing production by increased capital expenditures.

Outside Forces Affecting the Hardwood Lumber Market

Much of the economic behavior of the hardwood lumber market is caused by forces that originate outside the market. The hardwood lumber market is small relative to other agricultural and industrial markets; therefore, interest and wage rates are not affected by actions occurring within the hardwood market. Output prices of goods manufactured from hardwood lumber are influenced by aggregate national demand and exports of hardwood lumber are affected by outside forces such as exchange rates and income levels of other countries.

Producers and users of hardwood lumber have had to contend with forces affecting their market and will continue to do so. Thus, timely and accurate information on how these forces are expected to move in the future and the net effects of their movements aid in making more profitable production and usage decisions. Also, because of the effects of outside forces, lumber price cannot simply be assumed to follow some predescribed path in production and usage projections; rather, projections should be based on future movements of the outside forces and the interactions of usage, production, and price.

Future Research Needs

The analysis presented in this study presents an initial framework that can be used to understand the economic behavior of the hardwood lumber market. However, this research is only a starting point, as several important topics were only briefly discussed.

It is crucial to the hardwood lumber industry to better understand and predict the fluctuations in hardwood lumber production, usage, and price. To anticipate these fluctuations, further research is needed to isolate and measure the relative contributions of internal and external forces. Such research should also be extended to simulate future levels of production, usage, and price under various market conditions.

The supply equation presented in this study was based on aggregate data that lumped all species from all regions together. However, lumber demanders usually use specific species of lumber produced in a particular region. Therefore, future research concerned with estimating lumber supply equations by region and species would be highly beneficial to lumber users.

In recent years, exports have increasingly affected domestic lumber price. In order to better anticipate export-induced price changes, the factors that affect exports must be quantified. Information gained by estimating export demand relationships would help in predicting future prices of hardwood lumber.

The estimated price equation was also based on aggregate data. But lumber is produced, marketed, and priced on a species-and-grade basis so quantifying lumber price equations on that basis would be useful to both lumber demanders and suppliers.

Increased labor costs without subsequent increases in labor productivity have contributed to the lack of growth in the hardwood lumber industry. Better labor utilization would help curb these costs increases. Research aimed at increasing labor productivity and improving utilization of all inputs into production and use of hardwood lumber is nesessary to increase the growth potential of this industry.

The research discussed above would provide information that would be beneficial to current and potential lumber demanders and producers in making both short-run and long-run decisions. Since timely and accurate information reduces the amount of uncertainty felt by industry members, the end result of better information will be better planning and better resource allocation.

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Appendix A

Quantity Data Used in Model Estimation

The data representing hardwood lumber exports used in this study do not include products manufactured from hardwood lumber. Products such as rail ties, hardwood flooring, and wood siding are no longer lumber and are not used as lumber. Although an argument can be made for untreated rail ties being considered as lumber, export data did not separate treated and untreated ties until after 1977. Since export information used in this study differed from previously published data, and imports were not used in calculating quantity demanded, a listing of all quantity data used in model estimation is presented below. Imports of Canadian lumber calculated from *U.S. Imports for Consumption and General Imports*, Report FT110 (1960-1963), Report FT125 (1964), and Report FT246 (1965-1978), published by U.S. Department of Commerce, Bureau of Census, are also listed since this series was used in a preliminary estimate of the price model. These import statistics do not include any products manufactured from hardwood lumber.

Quantity data used in the analyses, in million board feet

Year	Quantity supplied	Quantity exported	Inventories at sawmills	Quantity demanded	Canadian imports
1960	6254	113	1265	6100	110
1961	5953	96	1153	5969	95
1962	6359	90	1229	6193	123
1963	7154	85	1139	7159	84
1964	7275	117	1107	7190	123
1965	7467	106	1085	7383	149
1966	7737	130	1101	7591	178
1967	7430	140	1264	7127	146
1968	7188	95	1083	7274	140
1969	7482	90	1001	7474	145
1970	7138	91	1144	6904	137
1971	6949	110	999	6984	136
1972	6770	156	793	6820	144
1973	7009	194	759	6849	147
1974	6904	162	1103	6398	109
1975	5872	153	1093	5729	59
1976	6417	209	1132	6169	79
1977	6679	189	1027	6595	76
1978	6997	358	971	6695	92

Appendix B

Statistical Test for Joint Determination

In estimating the price and supply equations by ordinary least squares (OLS) procedures, it was assumed that these two relationships were not jointly determined. If these relationships are not jointly determined, then the error terms between these relationships will be uncorrelated. The test presented in this appendix indicates that no significant correlation exists between these estimated relationships; therefore, OLS procedures resulted in best, linear, and unbiased estimates.

The Test

The hypotheses to be tested are:

H_o—the disturbance terms are not correlated

H_a—the disturbance terms are correlated

The test statistic is:

$$-K\,Ln(W)\,x^2\,F,\,1-\alpha\ d.f.$$

where:

$$K = (n + 1) - (2P + 11)/6$$

n = degrees of freedom for the system of equations

P = number of equations in the system

W = the determinant of the correlation matrix of the disturbance terms across equations of the model

$$F = P \times (P - 1)/2$$

The correlation matrix of the disturbance terms of the supply and price equation is presented below:

$$\begin{bmatrix} 1 & .03378 \\ .03378 & 1 \end{bmatrix}$$

The system is composed of two equations and there are 24 degrees of freedom for the entire system of equations, therefore:

$$K = (24 + 1) - ((2 \times 2) + 11)/6 = 27.5$$

$$W = .99886$$

$$F = 2 \times (2 - 1)/2 = 1$$

$$-K\,Ln(W) = .0314$$

The critical value of x^2, with 1 degree of freedom at the .05-percent level, is 3.841; therefore, we cannot accept the alternative hypothesis that the error terms are correlated at the .05 level of significance.

Luppold, William G. An econometric model of the hardwood lumber market. Res. Pap. NE-512. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1982. 15 p.

A recursive econometric model is used to analyze the effects of wage rates, interest rates, stumpage price, lumber exports, and output prices on the production, demand, and price of hardwood lumber.

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