Chapter 10

Structure And Efficiency Of Timber Markets

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Perfect competition has long been the standard by which economists have judged the market's ability to achieve an efficient social outcome. The competitive process, unfettered by the imperfections discussed below, forges an outcome in which goods and services are produced at their lowest possible cost, and market equilibrium is achieved at the point at which the cost of the last unit supplied just equals its value in use to the demander. This point maximizes the amount of utility that consumers obtain and the profit that producers procure through the existence of the market. Therein lies the appeal of perfect competitive markets.

Evidence presented in this chapter suggests that timber markets possess certain structural characteristics that may impede perfectly competitive outcomes and thus warrant further scrutiny. Beyond the general concern about the social costs of any form of imperfect competition, why would a policy maker be particularly concerned about the lack of perfect competition in timber markets? The answer lies in the ability of the market to guide society toward an optimal allocation of resources (labor, capital, land) to forestry and forest-based production. If, for example, lack of competition among buyers were to drive down timber prices, the less profitable timber investments would be, and the less profitable forested land use would be. In principle, a lower price for timber causes less land to be in forest base than would otherwise be the case (Hardie et al. 2000). Not only does this diminish the ability of society's forests to provide the efficient amount of timber and other marketed forest outputs, it also reduces the production of nonmarket goods and services provided by forests, such as wildlife habitat, watershed protection, aesthetics, and biodiversity. Thus private market imperfections can have public goods consequences.

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1. MARKET AND EFFICIENCY CONCEPTS

To evaluate timber market structure and efficiency, we must define what constitutes the relevant market for analysis and describe the characteristics by which markets can be deemed efficient. This section first introduces the general concepts of market definition employed in economic analysis and then defines market efficiency in terms of perfect competition.

1.1 Definition of a Market

Aggregate economic analysis depends critically on the definitions used, either explicitly or implicitly, to define a market. For applications ranging from antitrust analysis to the identification of economic sectors for national income accounting, poorly defined markets can generate misleading results. Nobel Laureate George Stigler wrote extensively on the topic of market definition, and offers with colleague Robert Sherwin this particularly clear description of market definition and its implications (Stigler and Sherwin 1985: 555).

> *The market is the area within which price is determined: the market is that set of suppliers whose trading establishes the price of the good. If one draws demand and supply curves that do not represent the traders in a market, the intersection of the curves is economically meaningless. The infrequency with which one encounters actual market size determination outside the antitrust area is surprising and perhaps disquieting.*

Stigler and Sherwin go on to relate the market for a good to "the area within which the price of the good tends toward uniformity, allowances being made for transportation costs" (Stigler and Sherwin 1985: 555). As the passage above suggests, and the empirical work below will show, price is the critical datum for market definition analysis.

It is commonly asserted that commodities are in the same market if their prices move in a parallel fashion. This phenomenon is referred to as the Law of One Price (LOP). The LOP implies that the price of a commodity is equal across all points of production—i.e., there are no opportunities for spatial arbitrage behavior. However, it should be clarified that prices moving together are a necessary but not sufficient condition for firms to be in the same market (McNew and Fackler 1997, Ravallion 1986, Tirole 1988). Commodity prices may move together due to common macroeconomic forces that have little to do with product similarity. Thus another factor to consider in deciding whether products are in the same market is their degree of substitution with each other. Maize from one farm in Iowa is, for all intents and purposes, perfectly substitutable for maize of the same grade on

the farm next door, and thus they are clearly in the same market. We can fully expect their prices to be identical. Whether the maize in Iowa is perfectly substitutable with and in the same market as maize in California is a different matter that requires some empirical analysis to sort out.

Economic theory implies methods for evaluating the extent of the market in the space dimension. Samuelson (1952) described how homogeneous products that are produced in perfectly competitive markets without government intervention should maintain the LOP in that prices in two spatial points of production should differ within the same time period by no more than the cost of product transfer between points. Ravallion (1986) described this as the measure of market integration.

1.2 Perfect Competition and Timber Market Characteristics

The essential structural characteristics of a competitive market are:

1. A large number of buyers and sellers
2. Free entry and exit into and out of the market
3. Products that are identical/homogeneous
4. Buyers and sellers who have perfect information

While economic philosophers since Adam Smith (1776) have argued whether these conditions guarantee perfect competition or, indeed, whether perfect competition guarantees the best possible social outcome, we do not intend to join that debate here. Rather, our emphasis is on whether timber markets possess the procompetitive conditions just referenced and if not, why, and what the implications are. We proceed by briefly evaluating each of the competitive conditions as it relates to the unique characteristics that often pertain in timber markets.

1.2.1 Number of Buyers and Sellers

A large number of buyers and sellers ensures that any one agent cannot deviate from the established market price without either losing their entire market share to the competition or (infeasibly) attracting the entire market from the competition. This fortifies the competitive process to generate a market price that efficiently equates marginal cost on the supply side and marginal benefit on the demand side. Concentrated markets are those with relatively few sellers, buyers, or both. Concentrated sellers (buyers) are more likely to have some power over the price they receive (pay) in the market, because they are large relative to the market and thus can be thought of as

less susceptible to losing their entire customer (supplier) base if they raise (lower) the price.

If we judge competition in timber simply by the absolute number of sellers and buyers at the industry level, then the verdict would often fall on behalf of competition rather than concentration. In the United States, for instance, there are millions of private owners of timber. These owners, most states, and the federal government sell timber on the open market to about 4,400 sawmills, 550 pulp and paper mills (U.S. Census Bureau 1999), and thousands of other wood processing outlets. Given these facts, it is unlikely that any single seller or buyer could exert significant market power at the national level. Large numbers of market participants are the norm in other countries as well. Yet despite these numbers, some questions remain as to whether all or even most timber markets have a sufficient number of participants to ensure something close to perfect competition.

Many forms of timber processing, especially pulp and paper manufacture, exhibit scale economies and therefore need relatively large areas of harvestable timber to meet their minimum efficient scale requirements. The existence of these scale economies and the fact that standing timber is land-intensive and immobile suggest a propensity toward a pattern of spatial dispersion of processors. However, timber is a bulky commodity with transport costs that can be high relative to its production value. Consequently, timber transactions between buyers and sellers may be highly localized, with the spatially dispersed processors having strong locational advantages for acquiring the timber closest to their mills (Lofgren 1985, Lowry and Winfrey 1974, Mead 1966, Murray 1992). Such a pattern works to limit the number of buyers with which a seller can effectively contract, which would seem to violate the first requirement of perfect competition. In the context of markets for harvested timber (logs) as a production input, this type of imperfection is referenced as monopsony or oligopsony power. If geography creates these localized zones of potential buyer market power, this can undermine the LOP referenced earlier, as buyers in different locales will have different abilities to deviate from the perfectly competitive price. In this case, price movements in these markets would be nonparallel.

1.2.2 Free Entry and Exit

Free entry and exit from a market is not the same as costless entry and exit. Free entry instead implies that potential market entrants are assumed to exist and are not impeded from entry or exit by technical or institutional barriers. Unimpeded entry allows potential competitors to impose discipline on the incumbents. If a firm that buys a demanded input to production were

to try to exert market power by offering a price for the input that is below its marginal value as a production input, a profit incentive would be created that would encourage the entry of new producers into the market. As long as the profits for new entry are greater than the entry cost, new entrants would ultimately bid up the price to the competitive (zero profit) level. Unimpeded exit means that potential entrants would still find it profitable to exert their competitive influence even if their entry into the market were only temporary.

A relevant question is whether free entry and exit conditions exist in most timber markets. The construction of a pulp or paper mill, for example, may cost $1 billion (US), but as alluded to previously, cost itself is not an entry barrier (with respect to the four characteristics of perfect competition enumerated). However, the existence of scale economies (declining marginal and average costs) over a wide range of output can make it unprofitable to enter if the entrant cannot attract enough of the market to operate at the cost-efficient scale. With transportation costs limiting the effective size of the market that the entrant can access, significant scale economies can serve as a technical barrier to entry.

An entry barrier would also exist if an incumbent has a property right that the potential entrant cannot readily obtain. This may be an institutionally granted right, such as a government permit to operate, or a competitive asset such as proprietary technology, name recognition, goodwill, or some other firm-specific asset that is not easily replicable. For timber processors, one asset is timberland that may be used to directly supply the mill. If there are certain economies associated with both supplying and processing timber, then only processors vertically integrated into timber supply (timberland holdings) can enjoy those economies of scope. Whether vertical integration constitutes a significant entry barrier is open to debate. Some forest product firms, indeed, have large timberland holdings that they consider a strategic asset, critical to their competitive stance (e.g., Weyerhauser in the United States). Other firms, however, have succeeded with relatively little of their timber procured from company-owned lands. The strategic role of firm-owned timberland is apparently evolving through time, with some large companies spinning off their timberland divisions into separate entities under the firm's umbrella or divesting of timberland altogether. Georgia-Pacific Corporation has employed both strategies in the late 1990s and early 2000s. Thus the role of timberland holdings as a potential entry barrier remains murky.

1.2.3 Homogeneous Goods

When products are homogeneous, one competitor's product is identical to another's. In these situations, there is no scope for the type of product differentiation that can insulate market participants from direct price competition. From a physical content standpoint, timber—once separated into standard commercial grades—is a fairly homogeneous commodity compared, say, to consumer goods such as pharmaceuticals or wine. However, as discussed above, the location of timber relative to its potential buyers may introduce a form of product heterogeneity that can undermine direct competition in the market. Further, if we can define a product as timber of any quality or simply of a similar species on the stump and recognize that harvest costs and timber quality can vary substantially across space due to site and stand conditions, then product homogeneity diminishes.

1.2.4 Perfect Information

All parties to a transaction should have full information about the relevant terms of the exchange (e.g., price, quantity, and quality) for market outcomes to be efficient. When all information is available, buyers and sellers can refuse to deal when they know that an alternative transaction is more attractive. This knowledge enforces the economic concept of Pareto efficiency by eliminating the possibility that market transactions could be rearranged *ex post* to make some parties better off without making other parties worse off.

Information requirements are not trivial in timber markets. When a tract of timber is up for sale, the quantity of harvestable timber is not known with certainty. As a result, both parties to the exchange have an incentive to obtain quantity information by conducting a timber cruise. Timber cruising involves costs, and both parties may not be willing to incur the costs, leaving one party more informed than the other. This may be exacerbated by the fact that many small timber suppliers are relatively infrequent participants in the timber market and thus may not be as effective in obtaining the information necessary to guarantee the best possible outcome. With asymmetric information, one party is systematically more informed than the other on the terms of the exchange and may have the opportunity to use that information to its advantage, thereby eroding the terms of potential Pareto efficiency.

2. EVALUATION OF MARKET POWER IN THE TIMBER SECTOR

This section describes how the spatial dimension within a timber market might produce an environment conducive to localized buyer market power and then reviews the empirical evidence from the literature on whether such market power is empirically evident in actual market settings.

2.1 Pricing Model for Spatially Differentiated Input Market

Because transport costs are a large component of the delivered cost of wood, the markets for wood inputs might best be described as localized or spatially differentiated in the tradition of Hotelling (1929).[1] Here we discuss how the localized nature of these inputs may provide some degree of local market power for the wood processing mills.[2]

Suppose wood processing mill j offers a price of W_j^W for wood delivered to the mill. Timber growers at a distance of d from mill j receive a price for their stumpage (standing timber) of $p^S = W_j^W - h - t(d)$ when they sell to mill j, where h is a per-unit harvest cost of the timber and $t(d)$ is the transport cost as an increasing function of the distance. An individual timber grower will sell $x^s = f(p^s)$ units of timber $(\partial x^s/\partial p^s > 0)$ to the mill from which they receive the highest price. At some distance from mill j in each direction that they face spatial competitors, timber growers receive the same stumpage price from mill j and a competing mill. Thus, if mill j raises the price offered at the mill, two phenomena may occur: the amount supplied to the mill by its inframarginal sources will increase due to the uniformly higher p^s, and, depending on rival mills' responses, it may expand into those rivals' markets by pushing out the distance at which timber growers are indifferent between mill j and its rivals. Thus, the total amount of wood supplied to mill j from all timber growers in its market, X_j^W, is an increasing function of the mill price it pays, $X_j^W = g(W_j^W)$.

The magnitude of the response to a change in the mill's price depends on two factors, the technological nature of the timber grower's unit supply function and the relative intensity of the border competition with rivals. If transport costs per unit distance are high relative to the full delivered cost of the input, the latter, competitive boundary effect is weak, and the technological response of the inframarginal suppliers dominates, thus enhancing the potential for the exercise of local market power. If transport costs are low and/or mills are densely distributed, spatial differentiation is low, and nearly perfect competition might be expected if other product attributes are undifferentiated.

In addition to the wood input, mill j employs other primary factors of production, denoted by the vector, X_j^W, to produce output, Q. We assume price taking in outputs and all other inputs and that firms maximize mill profits:

$$Max \prod = PQ - W^P X_j^P - W_j^W X_j^W \qquad 10.1$$

Here, P is the price of output and W^P is the price vector of nonwood inputs. $W_j^W = g^{-1}(X_j^W)$ is the inverse of the wood input supply function discussed earlier. First-order conditions are:

$$P(\partial Q / \partial X_j^P) = W^P \qquad 10.2a$$

$$P(\partial Q / \partial X_j^W) = W_j^W + \frac{\partial W_j^W}{\partial X_j^W} X_j^W \qquad 10.2b$$

For the nonwood inputs we get the perfectly competitive result: inputs are employed until their value of marginal product (VMP) equals market price. Optimizing with respect to wood use requires accounting for the effect of the firm's wood consumption level on the price it pays. Manipulating the first-order condition for the wood input equates an input's VMP with its marginal factor cost (MFC).

$$P(\partial Q / \partial X_j^W) = W_j^W \left(1 + \frac{1}{E_j}\right) \qquad 10.3$$

where $E_j = (\partial X_j^W / \partial W_j^W)(W_j^W / X_j^W)$ is the delivered price elasticity facing mill j. Also, $E_j = E / \theta_j$, where $E = (\partial X^W / \partial W^W)(W^W / X^W)$ is the elasticity of aggregate timber supply with respect to a uniform change in delivered price and

$$\theta_j = r_j^I / (r_j^I + r_j^B) \qquad 10.4$$

where r_j^I is the inframarginal supply elasticity and r_j^B is the border supply elasticity. r_j^I is determined by the technology of the unit timber supply function, and r_j^B is determined by the intensity of competition at the spatial border between rivals. If there is no spatial differentiation (e.g., transport costs are zero), then r_j^B is infinite and θ_j equals zero, reflecting perfect

competition. At the other extreme, if there is no border competition, then r_j^B equals zero and θ_j is one, reflecting pure spatial monopsony. Thus θ_j, with values in the 0 to 1 interval, can be interpreted as an index of mill *j*'s market power in wood inputs, comparable to Appelbaum's (1982) conjectural elasticity (CE) term.

Under imperfect competition, the firm faces a finite elastic input supply function, presumably positive with respect to price (i.e., $0 < E_j < 1$). Consequently, VMP_j exceeds the input price, W_j^W. Alternatively, under perfect competition ($q_j = 0$), the firm is a price taker ($E_j = 4$) and price equals VMP, as in the case of the nonwood inputs. If the correspondence between price and VMP can be determined empirically, then we can infer how competitive the market is.

2.2 Empirical Evidence on the Degree of Market Power in Timber Markets

The estimation of market power has been a prominent component of empirical industrial organization for years, stemming from the classic work of Lerner (1934) and continuing with the fusion of game theory, producer theory, and econometrics to provide structural measures of market power (e.g., Appelbaum 1982, Bresnahan 1987, Iwata 1974).[3]

Historically, most of the attention in empirical studies of market power has been directed toward the analysis of output markets, but more emphasis has recently been placed on imperfect competition in inputs. Our focus is on timber as a production input. Livestock commodity markets, though, which have some of the same structural features as timber markets (high transport costs, scale economies in processing), have received a fair amount of recent attention in NEIO-based empirical studies of input market power (see the 14 studies referenced in Azzam [1998, table 2] and Muth and Wohlgenant [1999]).

Mead's (1966) study of market power by lumber producers in the U.S. Pacific Northwest marked the earliest comprehensive analysis of timber market structure. Mead employed a combination of an industry case study and structure-conduct-performance methods to examine the competitiveness of both lumber output markets and sawlog input markets. Mead concluded that the lumber markets he studied were competitive, while sawlog markets were moderately oligopsonistic.

Lowry and Winfrey (1974) examined oligopsony in the pulpwood markets of the U.S. South. Using informal methods, they argued that the (assumed) oligopsonistic structure of pulpwood markets both dissuades forest investment by nonindustrial private forest landowners and encourages

vertical integration by processing firms. But Lowry and Winfrey do not formally test the hypothesis that oligopsony exists in the market.

Scandinavian economists have taken up much of the remaining empirical work in timber oligopsony power. Sweden, in particular, has a historically unique institutional structure of roundwood markets—something akin to a bilateral monopoly of buyer and seller cooperatives—that has made the issue particularly relevant there. Johansson and Lofgren (1983, 1985) employed theoretical arguments to explain seemingly irrational responses, such as excess demand for roundwood, via a model of monopsony price discrimination and capacity constraints. Lofgren (1985) uses a spatial oligopsony model and an empirical characterization of roundwood supply functions to explain the outcomes of a roundwood price negotiation process between the buyer and seller cooperatives. Brannlund (1989) measures the social welfare costs of Swedish pulpwood market power under the assumption that the markets are purely monopsonistic and sawlog markets are perfectly competitive. The welfare costs he estimates are large, but monopsony power is assumed rather than tested.

The first studies to use a formal theoretical structure and econometric methods to test hypotheses about timber market oligopsony power were produced concurrently by Murray (1995a) and Bergman and Brannlund (1995). Murray employs a dual profit function approach to determine the degree of oligopsony power within the estimation of a system of output supply and factor demand equations. Using aggregate data for the United States during the period 1958 to 1988, the econometric results suggest that sawlog markets are perfectly competitive throughout the period, while pulpwood markets exhibit some episodes of oligopsony power. The Murray study is examined in more detail in section 2.2.1.

Bergman and Brannlund (1995) estimate the degree of oligopsony in the Swedish pulpwood market. Their methods and findings are similar to Murray's for the United States, suggesting that Swedish pulpwood markets are largely oligopsonistic with varying degrees of market power over time. Bergman and Nilsson (1999) extend the earlier work of Bergman and Brannlund by adding detail on pulpwood inputs from Nordic countries. They find, in contrast, that perfect competition cannot be rejected in Swedish pulpwood markets. Ronnila and Toppinen (2000) test for pulpwood market oligopsony in Finland and, assuming constant market power over time (1965 to 1994), suggest Finnish pulpwood markets have, on average, been competitive over time, with some evidence of market power in the wood chip market.

2.2.1 Empirical Example: Estimation of Oligopsony Power in U.S. Timber Markets

This section briefly describes in more detail Murray's (1995a) study of oligopsony power in U.S. sawlog and pulpwood markets. Murray's study combines modern production theory (duality) with econometric methods to test hypotheses in their structural form. The basis of Murray's model is a timber processor's restricted profit function:

$$\prod_t = \prod (P_t, W_t^L, W_t^M, Z_{Kt}, Z_{Wt}, t) \qquad 10.5$$

P_t is the price of the processed output (e.g., lumber, paper) in period t, W_t^L is the labor wage, W_t^M is the price of a composite material input, Z_{Kt} is the quantity of capital used as a production input, and Z_{Wt} is the quantity of wood processed. With an unrestricted profit function, only prices would occur as arguments in the function, indicating that input quantities can freely move to their optimal level in response to changes in prices. A restricted function, though, imposes constraints by replacing the input price with an input quantity, the Z variables in equation 10.5, which are referred to as quasi-fixed factors (QFFs) of production.

The QFFs typically are often imposed on time series models, such as the one employed by Murray, in recognition of rigidities in the ability of capital to optimally adjust in the short run. That is the nature of Z_{Kt}'s role as a QFF in Murray's model. However, wood is employed as a QFF by Murray (1995a) for a different reason. One of the problems hindering the estimation of input market power in the studies predating Murray was the inherent difficulty in measuring the VMP of the input in question. Under perfect competition, the market price of the input is assumed to equal VMP. However, as indicated above, the market price does not equal VMP under imperfect competition. Thus, the analyst must use some other information to estimate VMP. Studies prior to Murray (Azzam and Pagoulatos 1990, Schroeter 1988) either used production functions, with the attendant econometric problems, or impose symmetry between input and output market power, which may not be appropriate for evaluating the forest products sector, to estimate VMP. Murray's solution was to specify wood, the oligopsonized input, as a QFF in the restricted profit function, Z_{Wt}. This specification enables the computation of a shadow price for wood by taking the derivative of the restricted profit function with respect to the wood QFF.

$$\lambda^W = \frac{\partial \prod}{\partial Z_W} \qquad 10.6$$

Using t to index the time period, the shadow price, λ_t^W, provides an estimate of wood's VMP in the production process, thereby providing a means around the VMP estimation described earlier. Taking together equations 10.6 and 10.3, Murray imposes an oligopsony condition to be estimated econometrically:

$$W_t^W\left(1+\frac{\theta_t}{E}\right)=\lambda_t^W \qquad 10.7$$

where W_t^W is the market price of wood, E is the wood supply elasticity, and θ_t is the CE parameter which, as described earlier, serves as the market power index bounded by zero and one. The CE parameter is specified as a function of several exogenous variables, X_t:

$$\theta_t=\theta(X_t) \qquad 10.8$$

The market power index can be written in terms of the markdown between the shadow price and the industry wood price:

$$\theta_t=E\left(\frac{\lambda_t^W-W_t^W}{W_t^W}\right) \qquad 10.9$$

Estimating the gap between the shadow price and the industry price lies at the heart of empirically revealing the structural parameter, θ.

The bracketed term above is the input analog to the well-known Lerner's index of the magnitude of the monopoly price distortion, [(P–MC)/P], so that the relationship between the CE parameter and the Lerner input index is:

$$L=\frac{\theta}{E} \qquad 10.10$$

Equations 10.6 through 10.10 are combined by substitution and estimated jointly with an output supply function and input demand functions for labor and materials. The econometric system is estimated to determine the aggregate degree of oligopsony power in wood markets for the two largest wood processing sectors in the United States: the sawmilling sector, which processes sawlogs, and the combined paper and paperboard mill sectors, which process pulpwood. The system of equations is estimated using an iterative nonlinear variant of a seemingly unrelated regression system.

Among the parameter estimates presented by Murray, the CE parameters are of most interest to this study. The values for the sawlog and pulpwood

markets are presented separately in table 10.1. CE values are computed for 5-year intervals throughout the sample period. The parameter covariance matrix is used to compute standard errors and t-statistics for each CE value. Computing t-statistics provides a test of the price-taking assumption by suggesting acceptance or rejection of price taking ($\theta = 0$) at a specified level of significance. For the entire period, the average degree of oligopsony power in sawlog markets is relatively low, as indicated by a mean θ estimate of 0.042. The highest mean value of approximately 0.10 is found in the earliest years of the sample. The value of θ declines throughout the period and falls below typical levels of significance after 1978, as indicated by the low t-statistics. The t-statistic at the sample mean is approximately 2.2, indicating rejection of the price-taking hypothesis, $\theta = 0$, at the 5% level for the sample period as a whole.

Table 10.1. Market power indicators 1958 through 1988 (from Murray 1995a)

Industry or Period	Conjectural Elasticity (θ)	T-statistic	Lerner Index (L)
U.S. sawmilling (sawlogs)			
1958–62	0.0977	3.3463	0.5229
1963–67	0.0696	3.2442	0.3713
1968–72	0.0432	2.6896	0.2669
1973–77	0.0252	1.9052	0.1662
1978–82	0.0149	1.3985	0.1061
1983–88	0.0102	0.9193	0.0637
1958–88	0.0424	2.2076	0.2435
U.S. paper/paperboard (pulpwood)			
1958–62	0.4146	3.6957	0.7083
1963–67	0.2621	3.3382	0.4322
1968–72	0.1169	2.1975	0.1806
1973–77	0.0686	1.4423	0.0892
1978–82	0.0553	1.3264	0.0857
1983–88	0.1342	2.2990	0.2296
1958–88	0.1740	2.3805	0.2857

The degree of market power is higher for pulpwood than for sawlogs. The sample mean value of θ is 0.174, with a t-statistic of 2.4, indicating statistical significance at the 5% level. Statistical significance at 5% is maintained throughout most of the period, as implied by the periodic mean values for the t-statistic. The exception is the two periods spanning 1973 through 1982, where t-statistics are well below 2. The mean value of θ is highest in 1958 through 1962 at 0.415 and declines from 1978 through 1982 to a statistically insignificant level of 0.055, at which point the trend reverses to a statistically significant value of 0.134 for 1983 through 1988.

The estimates of higher oligopsony power in pulpwood markets than in sawlog markets are not surprising, given the presence of larger, relatively

isolated mills in the pulp and paper sector and smaller, more densely distributed sawmills. These findings are consistent with other commentaries on the structure of timber input markets referenced in the preceding section.

The prevalent decline in market power over time indicated by the results is intuitive as new entrants and capacity expansion eat away at the bargaining strength of incumbent processors. This is consistent with the erosion in output market power over time found by Appelbaum (1982). However, the late period reversal of the declining trend in pulpwood market power is a curious phenomenon, which Murray speculates might be explained by the time pattern in the use of wood chips by pulp mills.

The low but statistically significant values of θ for sawlogs in the earlier years of the sample indicate near price-taking behavior. However, even a small amount of market power corresponds with nontrivial price distortions, as evidenced by L values in excess of 0.25 for the early years. This occurs because of the relatively limited short-run price responsiveness of sawtimber growers, which is reflected in low price elasticity for sawlogs. Consequently, even the intense border competition implicit in the low values of θ afforded the capture of some oligopsony rents by sawlog processors in the earlier time periods of the study. Those rents more or less dissipated over time.

In a related paper, Murray (1995b) uses the results from table 10.1 to estimate the magnitude of social welfare costs from the pulpwood market distortions in the later years of the sample (when sawlog markets are held to be competitive). Applied to data from the southern United States, the study finds that the primary welfare effects of the oligopsony distortion are a sizeable transfer of wealth from open market timber suppliers to the pulp and paper industry, but relatively small absolute welfare efficiency costs. Murray (1995b) also examines the implications of assuming *a priori* that pulpwood markets are purely monopsonistic (i.e., setting $\theta = 1$) rather than using the econometric estimates of θ in table 10.1. Under that assumption, absolute welfare estimates are of similar magnitude to Brannlund's (1989) estimate for Sweden, using the same monopsonistic assumption.

3. EMPIRICAL EVIDENCE ON TIMBER MARKET EFFICIENCY

Economic theory of market efficiency (Fama 1970, 1991; Muth 1961) implies methods for evaluating the degree of market perfection in the time and space dimensions. Recall from section 1, that products produced in different places or by different firms are identical, and that buyers and sellers have perfect information regarding factors that shift supply and demand. Together these factors imply that time series of market prices for a good

should not contain predictable changes between periods (LeRoy 1989) and that time series of prices of the same good produced in different places should move together (the LOP). Otherwise, economic agents would be able to exploit opportunities for arbitrage across locations and time, and thus the market would not be in equilibrium.

Several empirical analyses have tested the statistical and economic importance of spatial separation and product homogeneity on the functioning of wood product markets. These studies start with the contention that if spatial separation or product distinctions generate conditions for imperfect markets, then statistical analyses of prices should reveal the effects of these factors. Notable examples span a range of forest products and include studies by Buongiorno and Uusivuori (1992), Jung and Doroodian (1994), Hänninen et al. (1997), Murray and Wear (1998), and Nagubadi et al. (2001). These studies broadly conclude that LOP holds across the spatial dimension, albeit over broadly aggregated areas and time periods.

As in studies of spatial market price behavior, empirical studies of prices in the time dimension are partly motivated by a desire to better understand the effects of policies and shocks on markets. Analyses of timber markets in North America and Europe showed mixed results with regard to price behavior. Washburn and Binkley (1990, 1993), Hultkrantz (1993), and Prestemon and Holmes (2000) tested the price behavior of timber in the southern United States. Most of these studies were simply tests of the theory of efficient markets (that all available information is reflected in the current price, thus no intertemporal arbitrage opportunities exist), not perfect markets (see section 1.2 of this chapter). Williams and Wright (1991) and Deaton and Laroque (1992, 1996) offer one set of critiques in the context of storable products about whether efficiency can even be evaluated using univariate time series tests when a commodity is storable.

Market efficiency research also addresses the applicability of alternative harvest timing rules. An active area of research in resource economics since the mid-1980s has been the development of harvest timing rules in the presence of stochastic prices (Abildtrup et al. 1997, Brazee and Bulte 2000, Brazee and Mendelsohn 1988, Clarke and Reed 1989, Forboseh et al. 1996, Gong 1999, Haight and Holmes 1991, Lohmander 1988, Norstrøm 1975, Plantinga 1998, Thomson 1992, Yin and Newman 1996). A key question arising from the harvest timing literature is how observed price behavior, harvest timing rules, and market efficiency are related. For instance, if prices are predictable, then harvests can be timed to take advantage of high price periods. This would imply unexploited opportunities for intertemporal arbitrage and thus inefficient markets.

The harvest timing research has implications for optimal resource allocation. If prices are mean-reverting (stationary), then the applicable

harvest timing rule, such as that developed by Brazee and Mendelsohn (1988), implies that timber can yield much higher profits than previously supposed (e.g., compared to profits from a static Faustmann harvest timing rule), because suppliers can capitalize by harvesting more (less) when prices are above (below) the stationary mean. This finding, derived from simulations, implies that many timber producers may not be using all available information to time timber sales and harvests, leading to lower than possible profits. The result is an aggregate misallocation of resources toward alternative uses of land and away from timber production. Harvest timing rules based on integrated (e.g., random walk) price behavior (e.g., Haight and Holmes 1991), on the other hand, imply no significant misallocation of resources. If prices are indeed nonstationary and producers time harvests according to such price expectations, then all the available investment strategies and options for land use are being appropriately evaluated, indicating an efficient market. Haight and Holmes (1991) quantify through simulation that timing with nonstationary prices offers small or insignificant extra advantage over the profits and hence equilibrium land values yielded by using a Faustmann approach. In the section that follows, we evaluate whether all useful information is being used to determine the current market price, a measure of how well characteristic 4 of the perfect market is being met. In this analysis, if prices are found to be stationary processes, then substantial misallocation of resources may be occurring in land-intensive production. If prices are found to be nonstationary, then perhaps no substantial misallocation is occurring. The example is applied to the U.S. South, one of the world's primary timber producing regions, where private production dominates and where markets are largely left to themselves to determine going prices and production levels.

3.1.1 Time Series Behavior of U.S. Southern Pine Stumpage Markets

To illustrate the empirical work in understanding market efficiency in the time dimension, we describe results of tests of whether prices are stationary or nonstationary. In previous work on the topic, tests of timber price behavior have been mainly limited to procedures with nonstationarity as the null hypothesis, which have been shown to be weak for near-unit root processes (e.g., Schwert 1989), which timber prices might be.[4] These include Dickey-Fuller type tests (Dickey and Fuller 1979, Said and Dickey 1984). But there are tests that take the opposite null, for example, that the series follows a stationary AR(p) process. Those developed by Kwiatkowski et al. (1992) and Leybourne and McCabe (1994) are examples of these. Use of these might add greater confidence to conclusions or dampen our certainty about the true nature of timber price processes. In fact, the principal

contribution of the price behavior research presented below is the assessment of price behavior using alternative testing procedures.

In our empirical example, we apply augmented Dickey-Fuller (ADF) and Leybourne-McCabe (Leybourne and McCabe 1994) approaches. The timber price series evaluated are for southern pine sawtimber and pulpwood stumpage from the U.S. South. These include 18 series that emanate from substate regions. Although species may differ in characteristics across the region, the southern pines (especially *Pinus taeda, P. elliottii,* and *P. echinata*) are quite uniform in appearance and application. The lumber deriving from them is classified using a common set of grading rules (Forest Products Laboratory 1987:1-17), and few differences exist among these primary species in the quality of their fiber for pulp. Together, pulp and lumber comprise over 80% of their demands (Prestemon and Abt 2002). Southern pine timber prices have been the subject of a large part of the timber price research occurring in the United States, given that this market is so active and dominated by private producers and thus sheds light on the market efficiency question.

The ADF test is conducted by regressing the current change in price (dy_t) on lagged changes in prices and a single lag (y_{t-1}) of the current price:

$$dy_t = \alpha y_{t-1} + \sum_{i=1}^{I} \beta_i dy_{t-i} + \gamma + e_t \qquad 10.11$$

where $dy_t = y_t - y_{t-1}$, the size of I may be determined by a model selection procedure (e.g., Hall 1994), and γ is a constant. The existence of a unit root can be determined by whether an estimate of α in OLS estimation of equation 10.11 differs significantly from one.

The Leybourne-McCabe method evaluates the null hypothesis that a series is a stationary autoregressive of order p [AR(p)] process against an ARIMA (p,1,1) alternative. In terms of market efficiency testing, the Leybourne-McCabe test seeks sufficient empirical evidence to support an alternative hypothesis that market prices are consistent with an efficient market (prices are *not* stationary). This is in contrast to the ADF, whose alternative is that prices may be consistent with market inefficiency (prices *are* stationary). In other words, the Leybourne-McCabe test is powerful against the hypothesis for which the ADF is weak. This score-based stationarity test begins with the maximum-likelihood estimate of the parameters $\phi = (\phi_1, \phi_2, \ldots, \phi_J)$ obtained by fitting the ARIMA model:

$$dy_t = \beta + \sum_{j=1}^{J} \phi_i dy_{t-j} + \varsigma_t + \theta \varsigma_{t-1} \qquad 10.12$$

and then constructing the series,

$$y_t^* = y_t - \sum_{j=1}^{J} \phi_j^* y_{t-j} \qquad 10.13$$

where the ϕ_j^* are estimates of ϕ_j from equation 10.12, and the size of J in equations 10.12 and 10.13 are set beforehand. Two possible least-squares regressions can be estimated: regressing y_t^* on an intercept (no-trend case), or regressing y_t^* on an intercept and a trend (deterministic time trend case). The test is conducted on the residuals, $\{\varepsilon^*\}$, from either of these two possible regressions, in the following manner:

$$s^* = \sigma_\varepsilon^{*-2} T^{-2} \varepsilon^{*\prime} V \varepsilon^* \qquad 10.14$$

where $\sigma_\varepsilon^{*2} = \varepsilon^{*\prime}\varepsilon^* / T$ and V is the covariance matrix of a nonstationary series, where the elements v_{jk} of V are the min(j,k). Critical values for the statistic s^* are tabulated for both the no-trend and the deterministic time trend case by Kwiatkowski et al. (1992) and are applicable to the Leybourne-McCabe test. Leybourne and McCabe showed in simulations how the number of lags (J) of differenced prices in equation 10.12 does not appreciably affect the outcome of the test. In our analysis, we use the deterministic time trend case, since a time trend, consistent with the stationary null, can exist in an inefficient market. Thus, if we find that the value obtained from equation 10.14 is greater than that expected, then sufficient evidence exists that prices are not stationary and support nonstationarity. That result would be consistent with an efficient market.

Price data used in the analysis are the quarterly price data available from Timber Mart-South (Norris Foundation 1977 to 2002). Timber Mart-South is a report for timber submarkets throughout the U.S. South including prices for up to 22 price regions, two regions per state. The periods of monthly reported prices (1977 to 1987) were converted to quarterly by mid-month sampling. Our results rely on a kind of temporal aggregation of price series likely to be present in the Timber Mart-South data, which could lead to power reduction in tests for a unit root (e.g., Haight and Holmes 1991, Taylor 2001). This should be kept in mind when evaluating the following results. In states where region redefinitions occurred in 1992, the weighting correction approach recommended by Prestemon and Pye (2000) was applied to the pre-1992 series. A few series had missing data, so the ADF and Leybourne-McCabe tests were conducted only for 18 of the 22 series. The southern pine sawtimber and pulpwood stumpage prices were deflated by the consumer price index for all urban consumers. The ADF was

conducted using the Hall (1994) general-to-specific procedure, beginning with $I = 16$ lags, finding the specification with the minimum of the Schwarz Information Criterion, holding the number of usable observations constant at 85. The Leybourne-McCabe included $J = 4$ lagged difference terms.

Results (table 10.2) show that both the ADF and the Leybourne-McCabe tests concur that southern pine sawtimber stumpage prices are nonstationary.

Table 10.2. Results of Leybourne-McCabe and ADF tests for southern pine sawtimber stumpage prices deflated by the consumer price index (1977:1-2002:2)

Submarket	Leybourne-McCabe Test		ADF Test			
			Statistic		Obs.	Lags
Alabama-1	1.74	***	-2.43		85	0
Alabama-2	1.45	***	-2.44		85	0
Arkansas-1	1.83	***	-2.65	*	85	0
Florida-1	1.51	***	-2.19		85	1
Florida-2	0.82	***	-1.57		85	5
Georgia-1	0.84	***	-1.54		85	11
Georgia-2	0.12		-1.07		85	5
Louisiana-1	1.78	***	-1.40		85	6
Louisiana-2	1.85	***	-2.44		85	0
Mississippi-1	1.38	***	-2.27		85	0
Mississippi-2	1.63	***	-1.59		85	2
North Carolina-1	1.73	***	-1.29		85	4
North Carolina-2	1.89	***	-0.86		85	5
South Carolina-1	1.45	***	-1.47		85	11
South Carolina-2	1.69	***	-2.30		85	0
Texas-1	1.78	***	-2.39		85	0
Texas-2	1.78	***	-1.35		85	5
Virginia-2	0.08		-3.07	**	85	0

Asterisks = rejection of tests' respective nulls, at 10% (*), 5% (**), and 1% (***) significance.

Two exceptions, at 5% significance, are those reported for Georgia (region 2), where the Leybourne-McCabe test could not reject the null of a stationary AR(p) process, and Virginia (region 2), where the Leybourne-McCabe and the ADF (at 5% significance) favored the AR(p) process over a nonstationary process.

For pulpwood (table 10.3), both the Leybourne-McCabe and the ADF tests agreed that series are stationary in two cases, with the former not rejecting the null of an AR(p) process (at 1% significance) and the latter rejecting the null of a nonstationary price (at 10% significance) in favor of an AR(p) process for Louisiana's two price regions. The tests appear at odds for North Carolina (region 2) and Texas (region 1). We can conclude, however, based on these results, that intertemporal arbitrage has worked successfully to eliminate much predictability of both southern pine

pulpwood as well as sawtimber stumpage prices, with perhaps slightly more evidence of unpredictability and thus efficiency in the sawtimber market.

Table 10.3. Results of Leybourne-McCabe and augmented ADF tests for southern pine pulpwood stumpage prices deflated by the consumer price index (1977:1 to 2002:2)

Submarket	Leybourne-McCabe Test		ADF Test			
			Statistic		Obs.	Lags
Alabama-1	0.70	***	-2.24		85	12
Alabama-2	0.76	***	-1.35		85	0
Arkansas-1	0.45	***	-1.45		85	1
Florida-1	0.59	***	-1.89		85	0
Florida-2	1.02	***	-0.68		85	8
Georgia-1	0.92	***	-2.39		85	15
Georgia-2	0.76	***	-0.96		85	12
Louisiana-1	0.11		-2.65	*	85	0
Louisiana-2	0.10		-3.90	***	85	0
Mississippi-1	0.70	***	-2.42		85	13
Mississippi-2	0.87	***	-1.43		85	6
North Carolina-1	0.72	***	-1.47		85	11
North Carolina-2	0.35	***	-3.02	**	85	11
South Carolina-1	0.97	***	-1.56		85	4
South Carolina-2	0.76	***	-1.50		85	7
Texas-1	0.34	***	-3.00	**	85	4
Texas-2	0.38	***	-2.52		85	0
Virginia-2	0.07		-2.30		85	12

Asterisks = rejection of the tests' respective nulls, at 10% (*), 5% (**), and 1% (***) significance.

This analysis carries several conclusions. First, southern pine sawtimber and pulpwood stumpage prices appear to be broadly nonstationary, suggesting intertemporal efficiency in the U.S. South timber sector. An implication of this finding is that southern timber prices tend to retain the effects of market shocks, so that a nonstationary price harvest timing rule (e.g., Thomson 1992) would also seem most applicable to landowners managing southern pine.

4. SUMMARY

This chapter examines several key issues related to the structure and performance of private timber markets. It starts by introducing key aspects of market definition, perfect competition, and market efficiency, then describes how these conditions are met in typical private timber market settings, and then presents empirical evidence on timber market structure and efficiency. Two key features of timber markets are that (1) high transportation costs for timber and processing scale economies mean that the

distance between suppliers and demanders matters, and (2) timber's role as both capital and product implies complex interaction between market price expectations and harvesting behavior. These technical and spatial factors play an important role in determining the efficiency of and movement of prices in timber markets.

The chapter presents empirical evidence on the extent of buyer market power (monopsony) in timber market settings in the United States and Scandinavia, which largely addresses the first two components of a competitive (efficient) market defined in section 1 (numerous buyers and sellers, free entry and exit). The findings broadly suggest that these timber markets function closer to perfect competition than to pure monopsony, especially sawtimber markets. There is some evidence of oligopsony power in pulpwood markets, though the degree has varied over time.

The chapter also presents some empirical evidence on the spatial and temporal efficiency of timber markets, using data from the U.S. South, which largely addresses the third and fourth efficiency conditions (product homogeneity and perfect information). The evidence, while mixed, broadly supports the notion of temporal efficiency of timber prices. Page constraints preclude a full assessment of spatial market integration here, though much of the literature suggests a higher degree of integration at the final product (i.e., lumber and paper) than at the timber stage, as the latter are more spatially constrained than the former.

Despite the substantial research advances outlined here, much remains unknown about the structure, function, and efficiency of timber markets in North America, Scandinavia, and other major producing regions. Better understanding of these markets could enable better government policies, more efficient investment strategies, and greater aggregate benefits for producers and consumers. Fortunately, enhancements in economic theories of the firm and the market, improvements in econometric methods, and increased availability of more disaggregated and longer time series of price and production data all bode well for the research required to advance this understanding.

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[1] The data used in this study indicate that the stumpage price paid to timber growers, which is net of transport and harvest costs, is on average roughly one-fourth the delivered (mill) price for pulpwood and two-thirds the delivered price for sawlogs.

[2] A more formal presentation of the spatial input market and local market power determinants can be found in Murray (1992).

[3] The more modern empirical methods have been referred to as the new empirical industrial organization (NEIO) methods (Bresnahan 1989).

[4] An ARIMA(p,d,q) is an autoregressive integrated moving average time series process, where p is the lag order of the autoregression, d is the order of integration, and q is the lag order of the moving average. "Near unit-root processes," such as a pure first-order autoregressive process, ARIMA(1,0,0), with an autoregressive parameter approaching 1.0, are mean-reverting. In these, a portion of each period's price change is predictable, tending toward the long-run mean price level. In contrast, certain unit-root processes, such as the random walk, an ARIMA(0,1,0) process, have changes from one period to the next that are not predictable using previous price levels or innovations.