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Research Directions

in the Study of Timber Markets and Forest Policies

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ABSTRACT

Research on the economics of forest production and timber supply has been prolific, especially over the past 10 years. A synthesis of this literature defines research progress to date and also defines research directions. Research is proposed under four topic areas: (1) aggregate production functions for forestry, (2) wood products technologies and derived demands for timber products, (3) timber market models, and (4) market imperfections, including industrial organization, externalities, and risk.

KEYWORDS: Forest production technology, timber markets, market structure.

Introduction

Research in forest economics has long been dominated by questions regarding timber availability and long-term timber supply. This focus is logical, as government and individual firms attempt to form policies and production plans for a long-lived renewable resource in a dynamic world. Much of the early work was driven by the fear of "timber famine" and the obvious economic dislocations that would follow. Some feel that these fears were borne out at the turn of the century in the Lake States and in the 1930's in the South, when many firms shut down operations and left communities stranded with little industrial base. As a result, early researchers attempted to assess the potential for national and regional forest development and to predict the effects of government policies on timber supply.

The first models to assess timber supply were "gap" models which compared rates of harvest against standing timber inventories and rates of growth (e.g., USDA Forest Service 1920, 1933, 1965). These models generally predicted horrific consequences from then current practices with a quick exhaustion of inventories and destitute timber-dependent communities. However, many critics noted that these overly simplified models gave biased results. They felt that better predictions would be possible only with the inclusion of economic and other dynamic forces in the estimation of future timber supplies (Clawson 1979; Vaux and Zivnuska 1952; Zivnuska 1964).

In the 1980's, the emphasis of forest economics shifted from stand-level problems and physical views of timber supply to regional timber markets and variable timber supply. Three outstanding contributions were published in 1980: Hyde's "Timber Supply, Land Allocation, and Economic Efficiency" and Jackson's "The Microeconomics of the Timber Industry," provided the theoretical bridge from the financial analysis of timber stands to the microeconomic analysis of timber supply, while Adams and Haynes' Timber Assessment Market Model (TAMM) brought together many developments in econometric approaches to market modeling. TAMM incorporated an economic model of timber supply in national assessments required by the Resource Planning Act. Since 1980, a substantial body of related research has extended and broadened their coverage.

Our paper surveys and synthesizes this literature, emphasizing developments since 1980. We also discuss emerging research issues and directions in the microeconomic study of timber supply and forest policies. We frame our study with two concerns: (1) understanding and projecting timber market activities, and (2) estimating the influence of policies on timber producers and timber markets where markets do not lead to the desired quantities or allocations of resources. Our discussion of these concerns is structured around four major topics: (1) production technology in the timber-growing sector, (2) the structure of timber demand, focusing on the use of timber as an input into downstream production, (3) regional timber market models, and (4) timber market imperfections and their effects. In each section, we outline the basic theory, survey the literature, and identify major research issues and directions.

This paper's primary emphasis is placed on the Southern United States. We therefore deemphasize important national and stand-level applications, discussing them only where they contribute directly to regional studies. Where germane, we refer to recent surveys in these uncovered areas. Our intent is not to list all the relevant research that has gone on in the past decade but to focus on research that shows the greatest promise for improving analysis of forestry supply issues or that departs significantly in its approach to these issues.

The Timber Production Function and Timber Supply

Timber supply is defined by combining a biological model of forest production and a behavioral model of timberland owners. The forest production process translates physical inputs such as light, water, nutrients, and air and management inputs such as capital, labor, and entrepreneurial skills into forest products. The products considered here are pulpwood, sawtimber, and fuelwood. While other products or benefits such as forage, water quality, wind protection, and recreation may also be considered, for reasons of simplicity we ignore these possibilities here. Joint production of different forest products, however, is an important field of research (see Peterson and Sorg 1987 for a recent survey of attempts to include all forest products into a valuation scheme). The behavioral model assumes that timberland owners are rational decisionmakers and that they use efficient land management methods. The general economic model of production, the production function, is:

$$y = f(\mathbf{x}, \mathbf{t}) \tag{1}$$

where $\mathbf{x}$ is a vector of inputs and y is a vector of outputs.[1] For the forestry case, $\mathbf{x}$ includes biophysical, land, labor, and capital inputs to timber growing and y includes products such as pulpwood and sawlogs, t refers to the amount of time used to grow trees.

Aggregate regional production functions translate these forestry inputs into forest products and permit powerful analysis of timber supply. For example, the production function translates an incremental change in land availability into a physical output response. In addition, changes in production function estimates over time measure technological progress in terms of changes in input productivity. Conversely, productivity declines that may be associated with cultural influences such as acid rain and CO_2–induced climate changes can also be examined.

With few exceptions, however, estimating production functions in forestry has proved very difficult. Two measurement problems are especially troublesome: (1) the temporal separation of forestry inputs and forest products, and (2) a lack of data on input quantities. These problems, while unique in their degree, are similar in form to those in other fields of study. In other sectors, progress has been made in estimating production technology indirectly by studying the behavior of producers faced with various market situations. These procedures allow the analyst to use observations of profit-maximizing behavior to discover the underlying production technology. This approach shows promise for applications to forestry. To illustrate this connection or duality between production technologies and decisionmaking, we consider two models of producer behavior: (1) revenue maximizing with constrained budgets and (2) cost minimizing with constrained output. For revenue maximization, if we assume that individual timberland owners control what they produce but not the price they are paid for their output, then optimal production can be defined by the production function and a budget constraint. Timberland owners will seek to maximize revenue, subject to limits on their production budget:

$$\begin{aligned} R &= \max_x \sum_{j=1}^{M} p_j f(x) \\ & s.t. \sum_{i=1}^{N} w_i x_i = B \end{aligned} \tag{2}$$

Where p and w are the prices of the M outputs and N inputs respectively, R is revenue, and B is the budget level. Knowledge of f and solutions to (2) define the set of input demand functions. These functions are obtained by solving the N first order maximization conditions of the system for x as function of prices.

$$x_i^* = g_i(p_1 \ldots p_m; w_1, \ldots, w_n) \tag{3}$$

If these functions are substituted for x_i in the production function, the optimal output for specified prices or the supply function is defined:

$$y_j^* = S_j(p, w) \tag{4}$$

For the cost minimization problem total cost C is defined as the sum of input bills for the forest sector.

$$C = \sum_{i=l}^{N} w_i x_i \tag{5}$$

If we assume that producers minimize the costs of attaining their production goals, then the cost function defines the set of cost-minimizing inputs necessary to reach this goal:

$$\begin{aligned} C &= \min_x \sum_{i=1}^{N} w_i x_i \\ & s.t. y^* = f(x) \end{aligned} \tag{6}$$

Output supply and input demand functions may also be derived from the actual expenditures of firms. The

[1] With regard to all sections on theory, the uninitiated reader should refer to standard microeconomic texts. A basic reference is Hirshleifer (1980); a more complete theoretical treatment can be found in Russell and Wilkinson (1979) or Silberberg (1978).

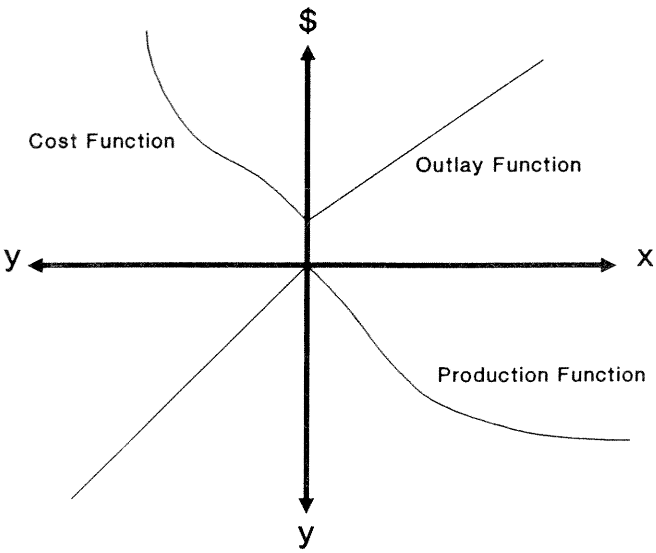

Figure 1: The relationship between the shapes of production and cost functions.

purchase of various combinations of inputs and the returns to production reveal the production possibilities or production function. Because the cost function:

$$C = g(y, w) \tag{7}$$

reflects the minimum-cost combination of inputs to produce y, it can be used to derive all the essential elements of the production technology.

A cost function can describe a production technology because cost and production are dual, or mirror image, problems. This duality for the case of one input and one output is displayed in figure 1. In the lower right-hand quadrant, the production function defines the transformation of input x into output y. The 45-degree line in the lower left-hand quadrant transfers output (y) from the production function to the cost function in the upper left-hand quadrant. The outlay function (upper right-hand quadrant) is simply the price of the input (w) times volume of the input used, and the cost function (upper left) relates output to these total outlays. For this simple case it is easy to see that the shape of the cost function is determined exactly by the shape of the production function.

The cost function can be used to reveal the input:output possibilities for an individual producer. If we aggregate across individual producers within a region, we can examine regional input demands and output supply. At the regional level, it may be inappropriate to consider the level of output as an exogenous variable.[2] If so, it may be necessary to incorporate variable output, using a profit function.

In summary, a forestry production function provides an analytical framework for studying the supply of forest outputs. It is an empirical means of fusing biological and management inputs and a convenient mechanism for examining the influence of land use and other shifts on timber production. The same information can also be derived from an aggregate cost (or profit) function.

Previous Research

Regional models of forest production have been slow to evolve in the forestry literature. Rather, much of the modeling work has focused on stand- and forest-level models. However, a precedent for this aggregate work exists in the rich body of production function research developed in the agricultural economics literature (see Woodworth 1977 for a review). Several factors explain why these models have found more expression in agriculture. For major agricultural crops, ownership and management types are relatively homogenous and crop production cycles are annual or semiannual in nature. These factors allow for the greater accumulation and richer analysis of compatible data.

These advantages are not generally present in the forest sector. The extended production period has been particularly vexing. As Hirshleifer (1976) emphasizes, standing timber is both a product and a factor of production. As plant, timber is a form of capital that appreciates "on-the-stump." It is, however, different from other factors because the firm cannot adjust growing stock as freely as it can other inputs such as forestry workers and skidders. In this sense, growing stock is similar to large structures and other forms of capital that may be fixed in the short run. This fixity of growing stocks must be considered in an aggregate timber production or cost function model.

In addition to this basic problem regarding the nature of forest production, some severe data problems discourage the direct estimation of a forestry production function. Broad tree specie, ownership,

[2]In this case, being exogenous indicates that the variable is not totally controlled by local decisionmakers. A variable which is locally controlled is an endogenous variable in this context.

and management classes pose serious aggregation problems, and strong annual or cross-sectional data for regions are typically lacking. Finally, information about important factors of production such as labor inputs is typically not collected. Forest economists have attempted to get around some of these problems to answer basic questions about productivity and technological change. They have examined such topics as the specification of production relationships for industrial wood products, returns to research and technical change in the forest products industry, and the development of micro- and macro-level biological forest production functions. However, these functions have generally been developed for stand-level problems. Regional studies have relied on proxy variables in lieu of missing data on input use.

Stand production function research in forestry has developed at two different levels. Most recent studies focus on the stand-level effects of only biological inputs and time (see Alig and others 1984a, 1984b for a review). Production functions have been estimated for individual species in which site productivity responds to management as well as physical inputs (Chang 1984; Couto and Nautiyal 1984; Nautiyal and Couto 1981, 1984; Rawat and Nautiyal 1985). This allows the effects of management controlled factors such as fertilization and planting density, to be merged with exogenous site and biological factors in describing total forest production.

Functional forms for these models vary across studies to increase precision and tractability for particular species and uses. Couto and Nautiyal (1984), for example, examine only fertilizer and rotation age for ***Eucalyptus grandis*** and compare six functional forms ranging from a simple Cobb-Douglas model to quadratic models with interaction terms. Their chosen model used logarithmic-reciprocal function, setting timber yield ($V, m^3/ha$) equal to a function of nitrogen N, phosphorus P, potash K, and time T:

$$\begin{aligned} lnV &= 5.752 - 5.778T^{-1} + 45.766(TN)^{-1} \\ &\quad -432574.6(TPK)^{-2} \\ &\quad -43957079.3(NPK)^{-2} \end{aligned} \tag{8}$$

Chang (1984) estimated loblolly pine yield (ft^3/acre) as a logarithmic-reciprocal function of age, planting density M, and site index S:

$$\begin{aligned} lnV &= 9.7501 - 34.013(T)^{-2} \\ &\quad -3418.106(TM)^{-1} \\ &\quad -740.820(TS)^{-1} \\ &\quad -1527.667(S)^{-2} \end{aligned} \tag{9}$$

Optimal management plans can be derived using these specifications of forest production with generalized forest rotation models. These plans should increase the economic efficiency with which planted forest stands are managed; they can also improve our understanding of the effects of management inputs on production. Since they cannot be aggregated in meaningful ways, however, they are useful only for micro-level decisions.

Recent studies have measured regional biological forest production directly (Wallace and Newman 1986; Wallace and Silver 1984). In these studies, forest survey data ownership and species distribution, along with average biological characteristics, were used to assess the effects of policy variables and variations in ownership and forest type inputs on total forest productivity. The basic model is quite simple. Productivity V is set as a homothetic function of biological characteristics and total acreage in forest production. The full model in Wallace and Newman (1986) is a log-linear function of average tree diameter D, average stocking percent B, and average site quality S times a nonlinear combination of acreage A in ownership class (public P, nonindustrial private forest N, and industrial I) and species type (loblolly pine L, other softwood M, oak-pine O, and other hardwood H). The general formula is:

$$\begin{aligned} logV &= log\beta_0 + \beta_1 logD \\ &\quad +\beta_2 logB + \beta_3 logS \\ &\quad +\alpha log(A_L\gamma_2(A_M \\ &\quad -A_L) + \gamma_3(A_0 - A_L) \\ &\quad +\gamma_4(A_H - A_L)) \\ &\quad +(1-\alpha)log(A_p + \omega_2(A_N \\ &\quad -A_P) + \omega_3(A_I - A_P)) \\ &\quad +log\epsilon \end{aligned} \tag{10}$$

where the β's, ω's, and γ's are estimated parameters, the α is an exponential term between 0 and 1, and ω's represent other unspecified variables and measurement error. In addition, the model is restricted so that $\sum\omega_i = \sum\gamma_i = 1$ (thus, for instance, $\omega_1 = \omega_2 + \omega_3 + \omega_4$). The model is estimated using nonlinear estimation techniques.

Interpretation of the coefficients for this model proceeds in two manners. The biological coefficients signify partial derivatives of growth with respect to the particular variable. The acreage coefficients, because of the summation constraint, signify only relative impacts between acreage types and not direct impacts. Still, substantial new information is generated about aggregate productivity and numerous conceptual experiments can be performed vis-à-vis the acreage breakdowns.

This type of production model has not explicitly considered time or growing-stock effects. It does offer substantial promise for applying available resource inventory data to the assessment of policy, technical, and environmental changes in the region. Its utility would be greatly enhanced with the incorporation of temporal effects.

Research Directions

Estimating an aggregate forest production technology will require advances in several areas. The most important is data quality. Forest survey data have been used for several previous analyses, but this source is limited in its breadth. These studies have relied on proxies for much of the management inputs to the production function. Actual measures of these inputs are needed to explicitly identify production functions. This can be accomplished, on a limited level, by tying the forest types described in the forest inventories with capital and labor inputs necessary to create them. These inputs may well have been tabulated for other purposes, but they have rarely been brought together in a single analysis.

Time can be directly incorporated into a regional production model by measuring the lags between the inputs and outputs of forest management. Incorporating these lags could enhance our understanding of such topics as returns to research, tax, and other incentive programs for nonindustrial private forest (NIPF) owners, etc. A basic problem with this approach is the lack of compatible annual data over long time periods, which would allow the econometric interpretation of relevant lags.

An alternative way to handle production lags is to directly incorporate growing stock in the production model. Growing stock represents the accumulated investment of physical and management inputs in the stand. The price of growing stock then reflects the opportunity costs of these inputs and can be viewed as rent on the standing timber capital. Timberland owners adjust levels of growing stocks by harvesting and through timber stand improvement and regeneration. The amount of growing stock held at any time should reflect its capitalized value relative to product prices.

Recent developments in applied duality theory have enhanced our ability to examine the production technology through cost/profit analyses. These dual models have yet to be used to estimate biological production technologies, but the approach is promising. Cost/profit function analysis requires input and output price data which are often more readily available and more reliable, and avoids some of the measurement problems cited earlier. In addition, recent studies in partial equilibrium analysis suggest ways of incorporating growing stock as a quasi-fixed factor of production in a cost function model (e.g., Berndt and others 1981).

Reliable production functions for timber growing would permit direct, analytical means of generating timber supply functions. To date, timber supply has been modeled in two different ways. One is through the use of simplified models of the timber market. These studies (discussed in detail later in this paper), are highly aggregated and do not distinguish between ownership and site groupings, or between short- and long-term supply effects. Short-run effects are limited because of the relative fixity of timber stocks, and long-run results must be defined by a stock-adjustment mechanism.

The other approach to timber supply modeling is through the mechanical simulation of a production function. This engineering approach has been applied to long-run questions but has not yet been used to study short- versus long-run stock adjustments. Supply models derived from a properly specified production function would incorporate these important aspects of supply behavior.

Wood Products Industries and Timber Demands

This section examines the demand side of timber markets and its derivation from production technologies for wood products. This technology is described using the same constructs described above: production functions and cost functions. Here however, the demand for inputs, such as timber, rather than the supply of outputs is emphasized.

Wood products technologies provide the efficient combination of inputs such as timber, labor, and capital, and wood product outputs such as plywood, lumber, and paper. By applying the same analytic technique we used for the timber-growing production function, the wood products production function can yield timber demand functions:

$$y_j^* = D(P, W) \tag{11}$$

where y_j^* is the demand for stumpage of class j, P is a price vector for wood product outputs, W is the price vector for raw material and other inputs, and D is a function. Knowledge of these production relationships allows for the direct estimation of changes in timber demands as product mixes and levels shift.

The application of dual production models is much more straightforward for wood products manufacturing than for forest production, and research activity in this area has been prolific. While these models have yielded valuable information about timber demand and substitution possibilities between timber and other inputs, their results have not been consistent across regions and model forms. Important questions therefore remain about the specifications of the production model. In addition, the measure of timber inputs has been highly aggregated. Both concerns suggest needs for future investigations.

Previous Research

In the past 15 years, extensive research into the structure of manufacturing technologies has been fueled by concurrent advances in duality theory and in the estimation of flexible functional forms for both production and cost/profit functions. The result is a much more direct bridge between the theoretical constructs of microeconomics and the statistical estimates of its parameters.

Humphrey and Moroney (1975) pioneered the application of dual models in natural resource economics, analyzing several natural resource-using industries in the United States, including the solid-wood products industries. In their estimates of production technologies they used both cost function and production function approaches and considered labor, capital, and raw materials inputs. They applied their models at the national level, but they imposed fairly restrictive assumptions. Subsequent studies generalized this basic model by considering fixed and variable inputs, more refined definitions of outputs, and production at the regional level.

These studies have assessed the production structure of the major wood products industries, usually by two-digit, sometimes four-digit, Standard Industrial Classification (SIC) code. They generally used the production function dual, the cost function, to investigate such concerns as technological bias, substitution in production, and derived demands for inputs, including timber. The transcendental logarithmic, or Translog, model has been the most popular specification for cost models. This versatile model allows direct estimation of elasticities of substitution between the primary inputs of production: labor, capital, and wood (and sometimes energy), input demand and output supply elasticities, and time or technological change effects.

The general approach in these studies is to define a second-order approximation to a cost function for the industry. The derivative property of cost functions then defines the demand function for inputs to production. Either the cost functions, the derived demand equations, or both are estimated by a technique that accounts for the error structure between equations. For example, the constant-returns-to-scale, n-input, translog cost function is:

$$lnC = \beta_0 + \sum_{i=1}^{N} \beta_i lnp_i + \sum_{i=1}^{N}\sum_{j=1}^{N} \beta_{ij} lnp_i lnp_j \tag{12}$$

Where C is cost, p's are input prices, and β's are coefficients. In addition, scale effects can be incorporated by including output levels, and technological change can be addressed with a time variable. The partial derivative of (12) with respect to the logarithm of input price defines the cost share of that input:

$$\frac{\partial lnC}{\partial lnp} = \frac{\partial lnC}{\partial C}\frac{\partial C}{\partial p}\frac{\partial p}{\partial lnp} = \frac{p_i X_i}{C} = g(p) \tag{13}$$

Share equations sum to 1, so only n-1 equations are independent. Once estimated, (12) and (13) describe the salient characteristics of the production technology using various demand, substitution, and scale elasticities.

Applications of these models to the wood products industry have yielded contrasting conclusions about the production technology. Most notably, analyses have disagreed about the relative substitutability of stumpage for the other inputs into the production process. Abt (1987), Stier (1980), and de Borger and Buongiorno (1985) generally agree that stumpage, capital, and labor are gross substitutes in production in both the lumber and pulp and paper industries. Merrifield and Haynes (1983), however, found stumpage and labor to be complements in lumber production, while stumpage was a substitute for capital in production. In later studies of lumber and plywood production, Merrifield and Singleton (1986) and Wear (1987) found stumpage and capital to be weak complements and all other inputs substitutes. Finally, Humphrey and Moroney (1975) found stumpage and capital to be strong complements in the pulp and paper industry (SIC 26), with stumpage and labor being substitutes.

These differences likely arise from different levels of aggregation of both inputs and outputs in these models. On the input side, all timber is typically lumped into a single quantity variable. Some studies separate softwoods from hardwoods; some do not. Even softwood timber is composed of a wide variety of tree species and qualities. Constantino and Haley (1988) have shown that these attributes greatly influence the value of a tree in production. On the output side, it is common to lump lumber, plywood, and other solid-wood products as a single aggregate output. These different products are made with very different technologies. In both cases, it is reasonable to question the validity of aggregating materials of variable quality.

In addition to the horizontal aggregation of product classes, production technologies have also been aggregated on the vertical scale (for example, across logging, hauling, and milling). Production/cost models of the solid-wood products industries have defined timber input at the stumpage level because price data are generally available for stumpage but not for delivered logs. However, use of stumpage input prices requires the analyst to include logging contractors and log transportation as well as lumber and plywood manufacturers in a model of the wood products technology. Assumptions underlying this kind of aggregation are that the quality of the labor and capital used in the lumber industry is identical to that in the logging industry and that the degree of substitution between capital and labor is the same in the two industries.

Studies examining returns to research and technical change in forest production focus on two major concerns: technical change bias, and economic returns. Early work focuses on the former using methods developed by Solow (1957). These studies show wood product industries exhibiting positive growth in productivity over the past 30 years. The technological bias of this growth is generally labor saving (Greber and White 1982; Robinson 1975; Stier 1980). Recent investigations have shown large positive economic returns arising from the research that has fueled this productivity growth (Bengston 1984; Seldon 1988; Seldon and Newman 1987).

Demand information from these aggregate production models has also been integrated in timber market assessments. Wear (1988) used factor demand equations from an aggregate cost function model in a simple partial equilibrium analysis of wood products and regional stumpage supply markets. His results suggest that the use of these highly specific demand models in lieu of commonly applied fixed-factor-proportions models significantly changed stumpage market projections. Further work is needed to apply these derived demand relationships in timber market models.

Research Directions

Research into the production structure of wood products sectors has been prolific. Research in this area will continue to refine and generalize production models and should focus on translating this information into timber market models. Production models can be refined by considering more output and input detail. On the output side, the separability of product groups is unclear, and the vertical as well as horizontal integration of production has not been adequately addressed. In addition, emerging technologies may shift demands for products. A related topic is the presence and extent of "economies-of-scope," or cost-advantages of producing a diversified set of outputs. On the input side, recent research suggests that results are highly sensitive to the specification of fixed versus variable inputs. This indicates a need for more careful study of capital investment dynamics in individual wood products sectors.

These models can also be extended to incorporate more detailed timber information. Distinctions between tree species and producing regions can be made and the separability of various species groupings tested. This approach can be used to develop regional demand models for timber. In addition, the point of valuation of timber should be examined. The precision of production and demand models may be improved by considering log and stumpage markets separately. Another area of concern is the timber data used. Many studies use the prices paid for USDA Forest Service timber as a proxy for prices paid for private timber. Jackson (1987) has compared Forest Service against other price series and has shown that stumpage prices vary greatly between Federal and State ownerships in Montana. He attributes these differences to the complexity of Federal timber sales and an extensive roads program on Federal lands. Additional contractual obligations may also reduce stumpage prices for Forest Service timber. In contrast, Cubbage and Davis (1986) found no significant differences between the prices reported for Forest Service and State timber sales in Georgia. Econometricians hope that if a bias occurs, it is in level and not in trend, but the issue remains as an important research question.

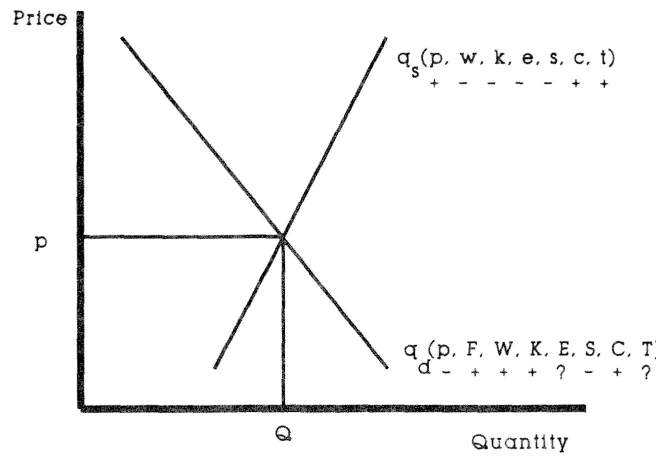

Figure 2: Stumpage supply and demand.

Timber Market Modeling

Timber market models define the interaction of timber supply decisions of individual producers with timber demands. Timber demand depends directly on the economy's consumptive demands for wood products such as lumber, plywood, paper, and paperboard. Accordingly, we can view the timber stumpage market as the interface between timber growers and wood products industries. Research in this area focuses on the mechanics that simultaneously determine the level of timber production and timber prices.

Timber market models are a way of sorting input and output price effects on market prices and quantities of timber produced. In theory, supply and demand can be analytically derived from production constructs for the wood growing and wood using sectors, respectively. In reality, specific data have not been available to fully develop market models in this way. Instead, the theory has been used as a heuristic guide to variables that should influence supply and demand. These variables have been used to specify "impressionistic" market models. These models typically contain a correct complement of variables, but coefficients are not constrained to reflect the basic tenets of microeconomic theory.

The basic structure of a market model for stumpage derives from equations of supply and demand and a market equilibrium condition. We earlier described the theoretical foundations for timber supply and stumpage demand through their respective production functions. With the assumption of competitive markets and profit maximization, the application of Hotelling's lemma defines the firm's input demand function and producer's stumpage supply function (Varian 1984). The resulting system of equations can be represented by:

$$Q^s = q_s(p^*, \mu) \tag{14}$$

$$Q^d = q_d(p^*, \phi) \tag{15}$$

$$q_s(p^*, \mu) = q_d(p^*, \phi) \tag{16}$$

where Qi is the stumpage quantity supplied or demanded; $p*$ is the equilibrium market price; and μ and ϕ represent other factors that shift supply and demand such as final goods prices, capacity, price expectations, technology, government policies, and the availability of land, energy, and capital.

The equilibrium condition (16) allows straightforward estimation of the coefficients of these functions. Figure 2 depicts this system with linear functions and gives the predicted signs of the coefficients. For demand, prices of other inputs into the production process–capital (k), labor (w), energy (e), etc.–are expected to show substitution effects as firms adjust input mix in line with relative input prices. These coefficients would thus be expected to have positive coefficients, although factors such as energy could be complements and their signs are uncertain. Final goods prices (f) for wood products and complements to wood products (c) would also positively increase stumpage demand while the price of substitute final goods–other building materials, plastics, etc. (s)–would negatively affect stumpage demand. Technical change occurring in the forest products industry causes uncertain shifts in the demand function, depending on the type of change that occurs. At one level, technical change can reduce costs and lead to increased production and therefore greater stumpage demands. At another level, technical change can increase production efficiency, reducing the need for stumpage in production. Therefore, the sign on a demand technology coefficient must be empirically determined.

The supply coefficients are constructed in a similar manner to demand coefficients. Increases in input costs (w, k, and e) decrease supply as production costs increase. Since forests create multiple outputs (e.g. wildlife, recreation, sawtimber, pulpwood) these outputs may act as substitutes or complements in production and thus may negatively or positively shift supply. Finally, technical change works to lower production costs and thus positively shifts supply.

Figure 2 presents an idealized estimated model. Severe data limitations frustrate the complete delineation of market models such as that proposed in the figure. On the supply side, the lack of strong cost data limits the delineation of direct supply effects from input price changes. As a result, many researchers have used the standing timber inventory as an inverse proxy for input costs. The rationale for the use of this proxy is that production costs are reduced as inventory builds up because economies of scale are introduced.

An understanding of the benefits derived from expanding the production capabilities of the southern forest requires identification of the characteristics of forest output markets. Policy analysis demands precise models of timber markets and investment behavior. This has been an area of active research, and several studies have examined timber markets in the Southeast. Results may be improved as promising developments from other areas of study are applied to southern timber markets.

Previous Research

Most modeling has focused on national markets for lumber, paper, plywood, or other products. These models often leave the raw material input as an exogenous or predetermined variable (Adams and Blackwell 1973; McKillop 1967; Mills and Manthy 1974). Possible reasons for favoring industry studies are the general availability of homogeneous market data and the seemingly greater application of the analytical results to macroeconomic policy decisions.

Several studies are available that either focus on an aspect of southern timber supply and demand or have an aggregate southern regional component as part of a national market assessment. Robinson (1974) examined regional stumpage and lumber markets for the South and the Pacific Northwest for the period 1947-1967. He used two-stage least squares (2SLS) regression to estimate an eight-equation linear system. However, he was unable to characterize the southern lumber market because the own-price coefficient for lumber was not significantly different from zero. To arrive at a solution for southern stumpage, he ultimately assumed a predetermined southern pine lumber consumption level and solved for the equilibrium stumpage demand price as a function of lumber production, chip production, and time. His estimates showed a stumpage demand elasticity of -0.5 and a supply elasticity of 1.06. The supply elasticity was higher than expected, and he discounted the relatively large value as being related to the use of a nonsimultaneous estimation method. He found a more theoretically consistent short-run supply elasticity of 0.32 when both quantity and price were endogenized in the estimation method.

As part of their national Timber Assessment Market Model (TAMM) Adams and Haynes (1980), specified southern sawtimber stumpage supply functions by region and ownership type. The South was divided into two regions, and supply functions for forest industry and NIPF were estimated. They used 2SLS with stumpage supply modeled for each region/group as a linear function of two variables: own price and standing timber inventory. Solid-wood stumpage demand was driven only by demand in the final goods market and product conversion factors, so the own-price demand elasticity was effectively assumed to be 0. The estimated supply elasticities for the two regions ranged from 0.3 to 0.47 for own price, with forest industry being slightly more elastic. The inventory elasticities ranged from 0.41 to 0.72, with NIPF being more elastic. In a similar earlier study, Adams (1977) estimated somewhat lower elasticities of 0.24 and 0.13 for own price and inventory, respectively. This model was for the entire southern region and for all private ownerships and was not disaggregated.

Daniels and Hyde (1986) applied a regional supply and demand model suggested by Jackson (1983) to the total (both softwood and hardwood) North Carolina forest sector. They used an indirect least-squares formulation to estimate their coefficients. The model posited supply as a log-linear function of own price and standing inventory. Demand was a function of own price and final goods price. The estimated supply price and inventory elasticities, 0.27 and 0.16, were very similar to those found by Adams (1977). Their demand function was virtually perfectly inelastic with a price response of -0.03 and final goods price elasticity of 0.52.

Newman (1987) used a profit-maximization approach to derive timber demand and supply equations to model the southern pulpwood and solid-wood (lumber and plywood) stumpage markets. The three-stage least-squares estimation method, which simultaneously determined coefficients in both markets, was based on work done in Scandinavia by Brannlund and others (1985) and Kuuluvainen (1986). The major innovation of these modeling efforts was that both pulpwood and solid-wood production possibilities were included in the supply specification, allowing for the delineation of substitution possibilities by stumpage producers. Newman found solid-wood timber to be a weak complement to pulpwood supply as owners jointly produce both goods. Pulpwood stumpage was a substitute for solid-wood supply.

Recent work in Sweden and Finland has a strong potential for use in econometric supply modeling in the South. Loikkanen and others (1986) combined survey and market data in a three-step estimation procedure: (1) the decision to harvest is simulated using all observations and a profit model; (2) the amount of timber expected from NIPF owners who do sell is estimated, using a linear model; and (3) the total production expected from all owners, is projected using results from (2) and a tobit model. The important value of these models is that they use repeated sampling of NIPF owners to gauge the intertemporal effects of market and institutional variables on timber supply behavior. Similar models have examined positive questions such as responses to subsidies, tax changes, and other market and nonmarket occurrences in Finland and Sweden (Carlen and Lofgren 1986).

Engineering production models of long-term timber supply were developed first for California by Vaux (1954) and later, more formally, by Hyde (1980). Long-term models of timber supply in individual Southern States were performed for Georgia by Montgomery and others (1975), for East Texas by Hickman and Jackson (1981), for Mississippi by Bullard and others (1984), and for Louisiana by Hotvedt and Thomas (1986). These models assume that landowners efficiently guide their management behavior in response to prices and costs, and that landowners maximize the present value of the timber production on their land.

The advantage of this method is that it considers only timberland that is economically productive in the sense of being able to produce a positive financial return at a given market price. As market price increases, new acreage is brought into production and acreage already in production may increase in output as new productivity-enhancing methods become feasible.

As one would expect, these models generally show a highly elastic supply potential in the range of current prices and quantities. The elasticity indicates that much of the current timberland produces much less stumpage per acre than is technically feasible. Thus, in the long run, the timber production in a region could greatly increase with little change in price. The much lower short-run elasticities derived in econometric analyses reflect the timber supplier's difficulties in responding to new prices and costs, and the fact that timberland is often not managed at its technical optimum. Thus, while the results of normative analyses made from policy tests are useful for comparative purposes, welfare analysis of the benefits from these tests are severely limited by the design of the model.

Engineering approachs and their rich supply specifications can be fused with econometric demand analysis through a linear or quadratic programming sector model. This modeling technique has already been used in agricultural and industrial sectors (Hazell and Norton 1986; Takayama and Judge 1971) and on a limited level in the forest sector. Greber and Wisdom (1985) developed a static model for solid-wood products markets in the coastal plain of Virginia, and Gilless and Buongiorno (1987) applied the methodology to the U.S. pulp and paper industries.

The advantage of this technique is that it allows high specificity of timber inventories and other technical inputs. In this way it is similar to the engineering approaches. It departs from a purely normative assessment by incorporating econometric demand models in a market-simulating objective function. This specificity allows the direct analysis of a wide variety of questions about optimal investment levels under varying condition for various classes of ownerships. Another important aspect of this modeling approach is that, unlike econometric models, it provides a framework for simulating production in new policy environments. Application to forestry has likely been hampered by the intertemporal nature of timber production. However, decomposition methods and recursive programming offer possibilities for coping with this problem (Duloy and Norton 1975).

Research Directions

Although the southern timber market has been modeled, important research is still needed to fully use these market models. One research task is to develop models that explicitly assimilate the lags from policy implementation to supply shifts. Incorporating these lags is critical for developing true measures of the economic efficiency of various efforts. A major shortcoming in attempts to measure welfare benefits of policies designed to shift supply is the *ad hoc* nature with which the shifts are implemented (Adams and others 1977; Brooks 1985; Newman 1987). More extensive testing of lag structures will be helpful in future policy analysis.

The specification of timber supply models needs to be expanded beyond a simple function of price and inventory variables and towards a complete microeconomic model of supply behavior. This model form, while being pervasive in previous studies severely limits policy analysis. Binkley (1985) discusses how the inclusion of an inventory variable places severe restrictions on the size of estimated price elasticities, depending on the product of concern. However, it is theoretically clear that inventory responds to changes in harvest levels. This relationship suggests that inventory adjustments should be estimated simultaneously with prices and quantities in order to avoid simultaneity bias in estimation.

Another possibly fruitful avenue of research is to expand market models to simultaneously incorporate the market for land. In current models the use of land is either inextricably tied up with the inventory variable, or land markets are modeled separately (Alig 1986). In reality, land and growing stock adjust through different mechanisms and land is an endogenous variable for timber producers, and thus should be directly incorporated in timber market analyses. These adjustments are especially important in the Southern United States where competing land uses will have an important bearing on future forestry production.

Timber Market Structure

Competitive market models assume several "perfects." The competitive market equilibrium requires perfect and symmetric information for sellers and buyers, perfect competition, and perfect compensation. When competition is imperfect and some parties have influence over price or when information is asymmetric between buyers and sellers, a market agent may have market power. If market power exists, it needs to be incorporated in our models of economic behavior. In addition, market power generally suggests an inefficient allocation of resources and often forms the basis for government intervention. Suboptimal investment may also arise if producers are not properly compensated for their outputs or are uncertain about future returns. These kinds of market imperfections are often associated with timber production.

The most familiar counter-structure to the competitive market is a monopoly, in which a single producer can determine market price by adjusting output levels. The classical result of this market structure is that the profit-maximizing producer keeps outputs lower and prices higher than the competitive case. Total social welfare decreases as returns to the monopoly increase. Thus, monopoly is seen as an obvious case for market regulation.

Between competition and monopoly is a gray area, where there are sufficiently few producers (or consumers) to shift the market away from the competitive solution. The mechanism for this departure may not be clear. Collusion among a few producers, as in the case of the OPEC cartel, can sometimes be shown but other models of price leadership or collusion are also plausible. In these gray areas it is difficult to test for market power, because accurate production and cost data must be obtained from the producers. If market power can be shown, it is not always clear that the prospective returns justify regulation. In addition, a regulatory mechanism is often difficult to define.

An especially interesting market structure is created when the Federal Government participates in a market as a producer. Timber production by the USDA Forest Service is such a case. While the Forest Service does not act as a profit-maximizer in these markets, its actions can influence timber prices and the harvesting and investment behaviors of other owners. The Forest Service likely provides some sort of leadership in timber markets, especially in places like the Pacific Northwest and the Rocky Mountains.

In southern forestry, monopsony or oligopsony may be more important than the oligopoly and monopoly cases discussed above. That is, market power likely rests with the purchasers of stumpage rather than its producers. Large timbersheds are needed to justify the very large capital investments in mills, especially paper and plywood mills. As a result, there are often few purchasers of raw material in an area. In this kind of market, price information processes need to be considered when modeling timber markets.

In addition to market structure, a commonly cited market failure in forestry is the presence of externalities in production. If they exist, the timber price will generally not fully compensate the timber producer for the extra-market, perhaps amenity, goods that are derived from forests. Society benefits from the production of these goods, but producers will generally not produce optimal quantities of them without financial incentives.

Risk and uncertainty in timber production are often cited as causes of suboptimal investment in timber and a reason to provide government support for practices such as planting and site preparation (Adams and others 1982). While these types of incentives would be unnecessary in a well-functioning market with perfect information, analysts argue that forest owners have imperfect knowledge of the relative profitability of forestry investments. This lack of information has led to suboptimal investment levels and reduced productivity in the southern forests. Many reasons for this market failure have been proposed, but the length of the forest investment and the level of risk aversion of forest owners are felt to be primary contributors.

Previous Research

The importance of externalities in timber production has received the most attention in the literature, with most of this work completed at the stand management level. Hartman (1975), Calish and others (1978), Nguyen (1979), Berck (1981), Bowes (1983), and Strang (1983) all have examined the effects on optimal forest rotations when these nonmarket values are included in the rotation decision. The ultimate effects on stumpage supply are uncertain, depending on the form of the revenue function and the tradeoffs involved between land, timber, and extra-market goods.

The analysis of externalities is important at the regional as well as at the stand or forest level. Apparent regional growth declines in nonindustrial pine forests in the Southeast, for instance, have caused great concern and external market factors such as acid rain are being investigated as possible contributors (Sheffield and others 1985). Substantial modeling is needed to understand the regional supply effects of such factors and how policy inputs can modify potentially deleterious effects.

In other regions, researchers have studied situations where purchasers of timber exert market power. Monopsonistic or oligopsonistic market structures can arise in forestry from the relatively high costs of transporting unprocessed logs and the spatially concentrated nature of the wood products industries. The effects of monopsony on stumpage supply in specific markets have been analyzed by Mead (1966, 1968) in the Pacific Northwest of the United States and by Johansson and Lofgren (1983, 1985) in Sweden. As expected, results suggest that lack of competition depresses stumpage prices and reduces total production. The South is generally considered to have the most active timber markets in the country, but there is a great need to understand the extent to which market power is expressed there.

A problem related to imperfect market structures is the imbalance of information between buyers and sellers of timber. Many NIPF owners are infrequent participants in the stumpage market and thus may be unfamiliar with market prices. Timber buyers, on the other hand, follow market conditions closely and are able to take advantage of perceived changes. To correct this perceived market failure, price reporting services have been provided by individual States and organizations. The best known service is Timber Mart-South (TMS), begun in 1977. Wallace and Silver (1980, 1981) assessed the quality of TMS data, and Boyd and Hyde (1989) assessed TMS's efficiency. The latter study showed that TMS has produced measurable social benefits. It has reduced price variation and facilitated planning by both buyers and sellers.

Of special importance to researchers is the highly detailed listing of stumpage and delivered mill prices for different timber species and products. Although there is some debate about the quality of these data and their compatibility with other sources (Cardellichio and Binkley 1983), they offer the possibility for greatly improved regional supply and price forecasting. Prior to the advent of TMS, the only data sources were annual reports of Forest Service timber sales and those from some State such as Louisiana and Arkansas (Ulrich 1987). There is substantial concern that Forest Service data are not representative of private timber sales and thus give biased elasticity estimates when used in econometric supply and demand analyses (Jackson 1987). Bias is especially likely in the South, where Federal timber sales make up such a small percentage of the total timber transactions. The TMS regional prices have been used in the most recent Forest Service projections (USDA Forest Service 1988). More extensive testing of different price scenarios and other questions relating to market structure will be possible in the future as more data points are accumulated.

The analysis of risk and uncertainty in investment decisions is generally based on the work of Von Neumann and Morgenstern (1953). This theory assumes that investors use expected returns from an investment to guide their decisions and invest in the projects that maximize their expected wealth. The method for deriving this return involves the calculation of probabilities for the potential outcomes of an investment and then calculating the mean (or expected) value of the return. If all outcomes are possible, the risk-neutral investor should be indifferent between investing in the project or receiving a certain payoff equal to that expected return. A risk-averse individual would demand a higher return than a risk-neutral individual might accept. The implications of these results have been discussed in the forestry context by Chang (1980), Kao (1982, 1984), and Johansson and Lofgren (1985) and in a generalized agricultural setting by Antle (1985).

The implications of this analysis are quite important. In the presence of risk, it is not optimal to attempt to maximize output as this will increase the level of investment and thus create a greater potential loss (Daniels 1984). Since NIPF owners have smaller landholdings than public and industrial owners, they are unable to spread their risk level. For them, reducing forest investments is a reasonable response. Thus, research that assesses methods to reduce NIPF risk may prove useful in increasing aggregate forest productivity.

Timber insurance is one method to reduce the risk perceived by NIPF owners. Public and private organizations have attempted to provide timber insurance programs in the South over the past 70 years, but no program currently exists. Efforts have been hampered by the lack of adequate actuarial data on natural hazard losses and the expense of obtaining it (McAndrew 1984). As a result, owners are unable to insure themselves against the small probability of a catastrophic loss and have likely reduced their investment levels accordingly.

Another method to reduce the effects of risk is through portfolio diversification. Owners of real assets, such as timber, can decide on the level of risk that they wish to carry by the combination of assets that they own (Cass and Stiglitz 1970). Thus, individuals who are more risk adverse can balance the relatively risky asset, timber, with more secure assets such as long-term bonds. A number of recent studies have examined the riskiness of returns from growing timber in the South using the Capital Asset Pricing Model (Redmond and Cubbage 1988; Thomson 1987; Zinkhan 1988). The riskiness of returns from forest investments, as measured by the variance of stumpage prices was compared with those of other assets such as common stocks. Although there is some question as to whether these assets can be meaningfully compared, the results show timber returns to be less risky than stocks.

The major risks associated with growing timber come from natural agents such as fire or insects. These risks alter management behavior in two ways. First, since the expected revenues from timber management are reduced by the potential devastation of these agents, forest investments are either not made or they are reduced. Second, rotation lengths are shortened because risk of loss is an increasing function of the harvest age (Martell 1980; Reed 1984). The regional consequence of both of these effects is to lower standing inventory. The effect on total productivity is uncertain because shortened rotations lead to higher growth rates. The importance of these results for research is that aggregate models which use inventory as an independent variable may misstate the actual timber supply effects from inventory changes.

Risks and uncertainty create substantial problems in modeling decisionmaking. Often the standard methodological assumptions needed to make problems tractable become untenable. For example, experimental evidence indicates that individuals may systematically violate key behavioral assumptions of the utility model (Machina 1987). A related question is the manner in which landowners perceive changes in their environment. Nonpermanent policy changes apparently have different supply effects than those that are perceived as permanent (Carlen and Lofgren 1986; Lofgren 1987). Differentiating these types of uncertainty makes policy analyses more difficult. In addition, computational problems arise because it becomes necessary to model investment decisions over an extended number of time periods (Kao 1984). Nevertheless, stochastic modeling is an area of research that has received extensive attention and offers important possibilities for future productivity assessments.

Research Directions

Many questions remain regarding the influence of market imperfections on markets for timber. While these markets have been modeled as competitive cases, incongruous results have led researchers to cite market failure as reason for policy action. However, the finding of a market failure also invalidates the model upon which the original analysis is based. Where imperfection is suspected, its existence, cause, structure, and influence need to be understood. Rejection of the competitive case is only the first step towards policy actions. An understanding of the alternative structure is required to build policy instruments and to forecast their costs and benefits.

Difficulties in regional analysis of market structures arise because the degree of oligopsony/monopsony necessarily varies over space. This poses serious aggregation problems for assessing the regional market. Research at a theoretical level is needed to address, in effect, the separability of market structures in a regional analysis. Ultimately, the question is: How meaningful is a regional price/quantity equilibrium or, conversely, what is the appropriate scale for regional market analysis?

Studies of market structure will need to focus on the concentration of firms at a local level. In contrast to many natural resources such as copper, coal, and iron, which have few supply centers relative to demand sites, the demand for timber is local and prices are very low relative to unit transportation costs. Processing centers are necessarily close at hand, and there are often few within a reasonable hauling distance from a forest stand.

Research is needed on the influence of risk and uncertainty on investments in timberlands. First, however, the linkage between these investments and timber supplies needs to be explicitly modeled. The market changes caused by these investments must simultaneously be incorporated into these analyses. Mathematical programming techniques already discussed can be produced to simulate a host of important policy-related scenarios. Issues such as tax and other financial and policy changes, environmental disturbances, land use changes, and similar concerns can be specifically addressed using these techniques. Stochastic modeling which has been applied more to forest growth and yield modeling than to landowner decisionmaking, offers good opportunities to investigate the manner in which landowners act upon new information about investment potentials. Stochastic models also provide a good conceptual framework to assess the acceptance of policy and technical innovations. In addition, incorporation of risk into landowner decision models should help to explain investment behavior.

Research on methods for reducing investment risk is needed. Insurance as a means for reducing risk has been studied but was abandoned when USDA funding for the programs and research was withdrawn. A need for timber crop insurance may exist, however, to keep Conservation Reserve plantings from reverting to agricultural use. If so, research is needed into the many difficulties in instituting timber insurance programs.

A final promising research area deals with the assessment of policy innovations that attempt to reduce the effects of market imperfections on timber supply. These studies would help policymakers estimate program efficiency. Research could characterize timber markets and measure welfare gains, providing important information on the costs and benefits of programs. A subsidy that reduces the costs of production and shifts supply, for example, should be considered a cost. The direct shift in supply resulting from the subsidy cannot at the same time be considered a benefit. Only the addition to supply that would not be incurred if the subsidy had not been made can be considered a benefit.

Summary and Conclusions

In this paper, we have attempted to review the literature and evaluate research needs in four different areas of microeconomic analysis of timber production. Research in forest economics has been prolific over the last 10 to 15 years, as views of timber markets and forestry have moved away from a biophysical paradigm and adopted a socioeconomic model. Still, while the state of knowledge has advanced, several areas remain for researchers. These areas are summarized below.

The Timber Production Function and Timber Supply. This area of study, which is the basis for the supply side of timber markets, is relatively underdeveloped. Evidence rests in the simple form of contemporary timber supply models. Advances in timber supply modeling will come from basic research into the timber production technology and a rigorous derivation of supply from these production models.

Wood Products Technologies and Timber Demand. Research into the production technologies for wood products has been prolific in recent years. Further research into levels of technological and input/output aggregation is needed to fully understand the effects of shifts in production technologies on timber demands. In addition, models which use market data at the delivered log level, and which therefore separate logging and processing sectors, will likely improve the precision of demand estimates. Basic research into the relationship between Federal and private timber price trends is also needed, not only for the demand side, but for market modeling in general. That is, we need to know if the commonly used Federal price data are an adequate index of private timber prices.

Timber Market Modeling. The development of precise market models is essential for undertaking policy analysis in the timber sectors. Many of the suggestions made above logically apply to this area as well. That is, better grounded models of timber supply behavior, information on the reliability of timber price data, and appropriately aggregated structures are needed. The actual use of these models will determine the desired model structure. For example, if the model is to be used to study a new policy, then a programming-type market model with econometric demand equations and a mechanistic, rather than econometric, supply side may be best. This type of programming model, with investment dynamics included, has not been developed. Means of incorporating the detailed supply and demand information discussed in the previous sections into a market framework is another important area for future research.

Timber Market Imperfections. Further research lies in three distinct areas: market structure, externalities, and risk and uncertainty. Understanding the effects that oligopsony and monopsony may have on price formation (and on the appropriate form of market models) is critical to conducting accurate policy analysis. The effects of externalities, both with regard to the valuation of nontimber products from forest management, and the effects of pollutants on growth and yield, need to be studied from a regional timber supply perspective. Risk and uncertainty is inextricably tied up with the investment calculus of individual landowners and will have an extremely important bearing on future timber supply from the South.

References

Abt, Robert C. 1987. An analysis of regional factor demand in the U.S. lumber industry. Forest Science 33:164-173.

Adams, Darius M. 1977. Effects of National Forest timber harvest on softwood stumpage, lumber, and plywood markets: an econometric analysis. Res. Bull. 15. Corvallis, OR: Oregon State University, Forest Research Laboratory. 50 pp.

Adams, Darius M.; Haynes, Richard W. 1980. The 1980 softwood timber assessment market model: structure, projections, and policy simulations. Forest Science Monograph 22. 64 pp.

Adams, Darius M.; Haynes, Richard W.; Darr, David R. 1977. A welfare analysis of long-term forest products price stabilization. American Journal of Agricultural Economics 59:662-673.

Adams, Darius M.; Haynes, Richard W.; Dutrow, George F. [and others]. 1982. Private investment in forest management and the long-term supply of timber. American Journal of Agricultural Economics 64:232-241.

Adams, F. Gerard; Blackwell, John. 1973. An econometric model of the United States forest products industry. Forest Science 19:82-96.

Alig, Ralph J. 1986. Econometric analysis of the factors influencing forest acreage trends in the Southeast. Forest Science 32:119-134.

Alig, Ralph J.; Lewis, Bernard J.; Morris, Paul A. 1984a. Aggregate timber supply analysis. Gen. Tech. Rep. RM-106. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 49 pp.

Alig, Ralph J.; Parks, Peter J.; Farrar, Robert M., Jr.; Vasievich, J. Michael. 1984b. Regional timber yield and cost information for the South: modeling techniques. Gen. Tech. Rep. RM-112. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 28 pp.

Antle, John M. 1985. Technical and allocative efficiency under uncertainty. Discuss. Pap. RR85-07. Washington, DC: Resources for the Future, Renewable Resources Division. 32 pp.

Bengston, David N. 1984. Economic impacts of structural particleboard research. Forest Science 30:685-697.

Berck, Peter. 1981. Optimal management of renewable resources with growing demand and stock externalities. Journal of Environmental Economics and Management 8:105-118.

Berndt, Ernst R.; Morrison, Catherine J.; Watkins, G. Campbell. 1981. Dynamic models of energy demand: an assessment and comparison. In: Berndt, Ernst R.; Field, Barry C., eds. Modeling and measuring natural resource substitution. Cambridge: MIT Press: 260-289.

Binkley, Clark S. 1985. Long run timber supply: price elasticity, inventory elasticity, and the capital output ratio. WP-85-10. Laxenburg, Austria: International Institute for Applied Systems Analysis. 26 pp.

Bowes, Michael D. 1983. Economic foundations of public forestland management. Discuss. Pap. D-104. Washington, DC: Resources for the Future, Quality of the Environment Division. 80 pp.

Boyd, Roy G.; Hyde, William F. 1989. Forestry sector intervention: the impacts of public regulation on social welfare. Ames, IA: Iowa State University Press. 295 pp.

Brännlund, Runar; Johansson, Per-Olov; Löfgren, Karl Gustaf. 1985. An econometric analysis of aggregate sawtimber and pulpwood supply in Sweden. Forest Science 31:595-606.

Brooks, David J. 1985. Public policy and long-term timber supply in the South. Forest Science 31:342-357.

Bullard, Steven H.; Weaver, G.H.; van Hees, W.W.S. 1984. Mississippi's long-run softwood timber potential: private nonindustrial influences. Inf. Bull. 56. Mississippi State, MS: Mississippi Agricultural and Forestry Experiment Station. 6 pp.

Calish, Steven; Fight, Roger D.; Teeguarden, Dennis E. 1978. How do nontimber values affect Douglas-fir rotations. Journal of Forestry 76:217-221.

Cardellichio, Peter A.; Binkley, Clark S. 1983. Stumpage prices in the hardwood assessment market model. Work. Pap. New Haven, CT: Yale University, School of Forestry and Environmental Studies. 26 pp.

Carlen, Ola; Lofgren, Karl Gustav. 1986. Supply consequences of subsidizing thinning activities in Sweden. Scandinavian Journal of Forest Research 1:379-386.

Cass, David; Stiglitz, Joseph E. 1970. The structure of investor preferences, assets returns, and separability in portfolio allocation. Journal of Economic Theory 6:122-160.

Chang, Sun Joseph. 1980. Discounting under risk: comments on adjusting discount rates. Journal of Forestry 78:634-635.

Chang, Sun Joseph. 1984. A simple production function model for variable density growth and yield modeling. Canadian Journal of Forest Research 14:783-788.

Clawson, Marion. 1979. Forests in the long sweep of American history. Science 204:1168-1174.

Constantino, Luis F.; Haley, David. 1988. Trends in wood quality for the British Columbia Coast and the United States, Pacific Northwest, Westside. Forest Science 34:176-189.

Couto, Laercio C.; Nautiyal, Jagdish C. 1984. A nutrient-related time-dependent timber production function for *Eucalyptus grandis* Hill ex Maiden in southeastern Brazil. Australian Forestry Research 14:37-47.

Cubbage, Frederick W.; Davis, Jerry W. 1986. Historical and regional stumpage price trends in Georgia. Forest Products Journal 36(9):33-39.

Daniels, Barbara; Hyde, William F. 1986. Estimation of supply and demand elasticities for North Carolina timber. Forest Ecology and Management 14:59-67.

Daniels, Steven F. 1984. An introduction into the use of stochastic theory in silviculture. Durham, NC: Duke University. 31 pp. M.S. thesis.

de Borger, Bruno; Buongiorno, Joseph. 1985. Productivity growth in the paper and paperboard industries: a variable cost function approach. Canadian Journal of Forest Research 15:1013-1021.

Diewert, W.E. 1974. Applications of duality theory. In: Intriligator, M.; Kendrick, D., eds. Frontiers in quantitative economics. North Holland. Vol. 2.

Duloy, J.H.; Norton, R.D. 1975. Prices and incomes in linear programming models. American Journal of Agricultural Economics 57:591-560.

Gilless, J. Keith; Buongiorno, Joseph. 1987. PAPYRUS: A model of the North American pulp and paper industry. Forest Science Monograph 28. 37 pp.

Greber, Brian J.; White, David E. 1982. Technical change and productivity growth in the lumber and wood products industry. Forest Science 28:135-147.

Greber, Brian J.; Wisdom, Harold W. 1985. A timber market model for analyzing roundwood product interdependencies. Forest Science 31:164-179.

Hartman, Richard. 1975. The harvesting decision when the standing forest has value. Economic Inquiry 14:52-58.

Hazell, Peter B.R.; Norton, Roger D. 1986. Mathematical programming for economic analysis in agriculture. New York: Macmillan. 502 pp.

Hickman, Clifford A.; Jackson, Ben D. 1981. Economic outlook for the East Texas timber market. MP 1478. College Station, TX: Texas A&M University, Texas Agricultural Experiment Station. 14 pp.

Hirshleifer, Jack. 1976. Sustained yield versus capital theory. In: Dowdle, B., ed. The economics of sustained yield forestry: a Symposium. University of Washington, Seattle. unnumbered.

Hirshleifer, Jack. 1980. Price theory and applications, 2d ed. Englewood Cliffs, NJ: Prentice-Hall, Inc. 620 pp.

Hotvedt, James E.; Thomas, Charles E. 1986. Impacts of changes in the commercial forest land base on the long-term pine timber supply potential in Louisiana. Res. Pap. SO-230. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 18 pp.

Humphrey, David Burras; Moroney, J.R. 1975. Substitution among capital, labor, and natural resource products in American manufacturing. Journal of Political Economy 83:57-82.

Hyde, William F. 1980. Timber supply, land allocation, and economic efficiency. Baltimore, MD: The Johns Hopkins University Press. 225 pp.

Jackson, David H. 1980. The microeconomics of the timber industry. Boulder, CO: Westview Press. 136 pp.

Jackson, David H. 1983. Sub-regional timber demand analysis: remarks and an approach for prediction. Forest Ecology and Management 5:109-118.

Jackson, David H. 1987. Why stumpage prices differ between ownerships: a statistical examination of state and Forest Service sales in Montana. Forest Ecology and Management 18:219-236.

Johansson, Per-Olov; Löfgren, Karl Gustaf. 1983. Monopsony, conjectural equilibria, and the Swedish roundwood market. Forest Science 29:439-449.

Johansson, Per-Olov; Lofgren, Karl Gustaf. 1985. The economics of forestry and natural resources. New York: Basil Blackwell Inc. 292 pp.

Kao, Chaing. 1982. Optimal stocking levels and rotation under risk. Forest Science 28:711-719.

Kao, Chaing. 1984. Optimal stocking levels and rotation under uncertainty. Forest Science 30:921-927.

Kuuluvainen, Jari. 1986. An econometric analysis of the sawlog market in Finland. Journal of World Forest Resource Management 2(1):1-19.

Lofgren, Karl Gustav. 1987. Effects of permanent and non- permanent forest means on timber supply. Silva Fennica 20:308-311.

Loikkanen, Heikki A.; Kuuluvainen, Jari; Salo, Jorma. 1986. Timber supply of private nonindustrial forest owners: evidence from Finland. Res. Rep. Nr. 50. Institute of Economics, University of Helsinki. 56 pp.

Machina, Mark J. 1987. Decision-making in the presence of risk. Science 236:537-543.

Martell, Dennis L. 1980. The optimal rotation of a flammable forest stand. Canadian Journal of Forest Research 10:30-34.

McAndrew, Joan. 1984. Timber insurance: problems and prospects. Durham, NC: School of Forestry and Environmental Studies, Duke University. 45 pp. M.S. Project.

McKillop, William L.M. 1967. Supply and demand for forest products: an econometric study. Hilgardia 38:1-132.

Mead, Walter J. 1966. Competition and oligopsony in the Douglas-fir lumber industry. Berkeley, CA: University of California Press. 276 pp.

Mead, Walter J.; Hamilton, Thomas E. 1968. Competition for Federal timber in the Pacific Northwest–an analysis of Forest Service and Bureau of Land Management timber sales. Res. Pap. PNW-64. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 63 pp.

Merrifield, David E.; Haynes, Richard W. 1983. Production function analysis and market adjustments: an application to the Pacific Northwest forest products industry. Forest Science 29:813-822.

Merrifield, David E.; Singleton, William R. 1986. A dynamic cost and factor demand analysis for the Pacific Northwest lumber and plywood industries. Forest Science 32:220-233.

Mills, Thomas J.; Manthy, Robert S. 1974. An econometric analysis of market factors determining supply and demand for softwood lumber. Res. Pap. 238. East Lansing, MI: Michigan State University, Agricultural Experiment Station. 59 pp.

Montgomery, Albert A.; Robinson, Vernon L.; Strange, James D. 1975. An economic model of Georgia's long-run timber market. Ga. For. Res. Rep. 34. Macon, GA: Georgia Forest Research Council. 20 pp.

Nautiyal, J.C.; Couto, Laercio. 1981. Use of production function analysis in forest management: eucalypts in Brazil, a case study. Canadian Journal of Forest Research 12:452-458.

Nautiyal, J.C.; Couto, Laercio. 1984. The nature and uses of the timber production function: *Eucalyptus grandis* in Brazil. Forest Science 30:761-773.

Newman, David H. 1986a. An econometric analysis of aggregate gains from technical change in southern softwood forestry. Durham, NC: Duke University. 179 pp. Ph.D. dissertation.

Newman, David H. 1986b. Changes in southern softwood productivity: a modified production function analysis. SCFER Work. Pap. 29. Research Triangle Park, NC: Southeastern Center for Forest Economics Research. 54 pp.

Newman, David H. 1987. An econometric analysis of the southern softwood stumpage market: 1950-1980. Forest Science 33:932-945.

Newman, David H. [In press]. Shifting southern softwood stumpage supply: implications for welfare estimation from technical change. Forest Science.

Nguyen, D. 1979. Environmental services and the optimum rotation problem in forest management. Journal of Environmental Management 8:127-136.

Peterson, George L.; Sorg, Cindy F. 1987. Toward the measurement of total economic value. Gen. Tech. Rep. RM-148. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 44 pp.

Rawat, J.K.; Nautiyal, J.C. 1985. An application of a production function for juvenile hybrid poplar to intensive forest management. Forest Science 31:143-156.

Redmond, Clair; Cubbage, Frederick W. 1988. Portfolio risk and returns from timber asset investments. Land Economics 64:325-337.

Reed, William J. 1984. The effects of risk of fire on the optimal rotation of a forest. Journal of Environmental Economics and Management 11:180-190.

Robinson, Vernon L. 1974. An econometric model of softwood lumber and stumpage markets, 1947-1967. Forest Science 20:171-179.

Robinson, Vernon L. 1975. An estimate of technological progress in the lumber and wood-products industry. Forest Science 21:149-154.

Robinson, Vernon L.; Montgomery, Albert A.; Strange, James D. 1978. GASPLY: a computer model for Georgia's future forest. Ga. For. Res. Rep. 36A. Macon, GA: Georgia Forest Research Council. 21 pp.

Russell, Robert R.; Wilkinson, Maurice. 1979. Microeconomics: a synthesis of modern and neoclassical theory. New York: John Wiley and Sons. 459 pp.

Seldon, Barry J. 1988. A nonresidual estimation of welfare gains from research: the case of public R&D in a forest product industry. Southern Economic Journal 54:64-80.

Seldon, Barry J.; Newman, David H. 1987. Marginal productivity of public research in the softwood plywood industry: a dual approach. Forest Science 33:872-888.

Sheffield, Raymond M.; Cost, Noel D.; Bechtold, William A.; McClure, Joe P. 1985. Pine growth reductions in the Southeast. Resour. Bull. SE-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 112 pp.

Silberberg, Eugene. 1978. The structure of economics: a mathematical analysis. New York: McGraw-Hill. 543 pp.

Solow, Robert M. 1957. Technical change and the aggregate production function. Review of Economics and Statistics 39:312-320.

Stier, Jeffery C. 1980. Estimating the production technology in the U.S. forest products industries. Forest Science 26:471-482.

Strang, William J. 1983. On the optimal forest harvesting decision. Economic Inquiry 21:576-583.

Takayama, T.; Judge, George G. 1971. Spatial and temporal price and allocation models. Amsterdam: North Holland Press.

Thomson, Thomas A. 1987. Financial risk and timber portfolios for some southern and midwestern species. In: Busby, R. L.; Kurtz, W. B.; deSteiguer, J. E., eds. Proceedings of the 1987 Joint Meeting of the Southern Forest Economics Workers and the Mid-West Forest Economists.

Ulrich, Alice H. 1987. U.S. timber production, trade, consumption, and price statistics, 1950-85. Misc. Publ. 1453. Washington, DC: U.S. Department of Agriculture, Forest Service. 81 pp.

U.S. Department of Agriculture, Forest Service. 1920. Timber depletion, lumber prices, lumber exports, and concentration of timber ownership. Rep. on S. Res. 311, 66th Cong., 2d sess., Washington, DC. 71 pp.

U.S. Department of Agriculture, Forest Service. 1933. A national plan for American forestry. S. Doc. 12, 73d Cong., 1st sess., Washington, DC, 2 vols. 1677 pp.

U.S. Department of Agriculture, Forest Service. 1965. Timber trends in the United States. For. Resour. Rep. 17. Washington, DC. 235 pp.

U.S. Department of Agriculture, Forest Service. 1988. The South's fourth forest: alternatives for the future. For. Resour. Rep. 24. Washington, DC: U.S. Department of Agriculture, Forest Service. 512 pp.

Varian, Hal R. 1984. Microeconomic analysis. 2d ed. New York: W.W. Norton and Co. 348 pp.

Vaux, Henry J. 1954. Economics of young growth sugar pine resources. Bull. 78. Berkeley, CA: University of California Division of Agricultural Sciences.

Vaux, Henry J. 1973. How much land do we need for timber growing? Journal of Forestry 71:399-403.

Vaux, Henry J.; Zivnuska, John A. 1952. Forest production goals: a critical analysis. Land Economics 28(4):318-324.

Von Neumann, John; Morgenstern, Oscar. 1953. Theory of games and economic behavior. 3d ed. Princeton, NJ: Princeton University Press. 641 pp.

Wallace, T. Dudley; Newman, David H. 1986. Measurement of ownership effects on forest productivity: North Carolina 1974-84. Canadian Journal of Forest Research 16:733-738.

Wallace, T. Dudley; Silver, J. Lewis. 1980. An evaluation of Timber Mart South price data. [Mimeo] Contract Research Report to the USDA Forest Service. 44 pp.

Wallace, T. Dudley; Silver, J. Lewis. 1981. Price variations for southern timber markets. [Mimeo] Contract Research Report to the USDA Forest Service. 48 pp.

Wallace, T. Dudley; Silver, J. Lewis. 1984. Public cost sharing and production in nonindustrial private forests: the case of FIP in Coastal Georgia. In: Royer, J. P.; Risbrudt, C. D., eds. Nonindustrial private forests: a review of economic and policy studies. Durham, NC: Duke University, School of Forestry and Environmental Studies: 165-180.

Wear, David N. 1987. The structure of production in the U.S. solid wood products industries and the derived demand for sawtimber. Missoula, MT: University of Montana. 151 pp. Ph.D. dissertation.

Wear, David N. 1988. Modeling stumpage and wood products markets using applied general equilibrium techniques. In: Abt, R., ed. Proceedings of the 1988 southern forest economics workshop. Orlando, FL. pp. 99-106

Wear, David N. 1989. Structural change and factor demand in Montana's solid wood products industries. Canadian Journal of Forest Research 19(5):645-650.

Wear, David N.; Hohenstein, William G.; Alig, Ralph J. 1989. Investment in forest management in the Southeast: effects on future inventories and prices. In: Potter, R. ed. Proceedings of the 1989 southern forest economics workshop, San Antonio, TX. pp. 116-127.

Woodworth, Roger C. 1977. Agricultural production studies. In: Judge, G. G. [and others], eds. A survey of agricultural economics literature. Minneapolis: University of Minnesota Press: 128-157. Vol. 2.

Zinkhan, F. Christian. 1988. Forestry projects, modern portfolio theory, and discount rate selection. Southern Journal of Applied Forestry 12:132-135.

Zivnuska, John A. 1964. The 1964 timber trends study in perspective. Proceedings, Society of American Foresters, pp. 84-88.

Newman, David H.; Wear, David N. 1990. Research directions in the study of timber markets and timber supply. Gen. Tech. Rep. SE-62. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 20 pp.

Research on forest production and timber markets is reviewed and directions for future research are suggested.

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