Chapter 9

BIOECONOMIC AND MARKET MODELS*

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Abstract: The United States has a century of experience with the development of models that describe markets for forest products and trends in resource conditions. In the last four decades, increasing rigor in policy debates has stimulated the development of models to support policy analysis. Increasingly, research has evolved (often relying on computer-based models) to increase understanding of consumer demands, producer behavior, landowner behavior, and conditions of the timber resource. Greater computational power available since the mid 1970s has allowed the evolution of bioeconomic models that combine economic and resource models. These are used in the United States to provide the basis for forecasting future resource and market trends and to inform policy analysis. These more complex models have also extended options for policy analysis using approaches such as scenario planning to help decision makers gauge uncertainty.

Key words: Forest sector modeling, policy analysis; supply; demand.

1. INTRODUCTION

For the past century, forest policies of the United States have been influenced by information about economic efficiency and equity developed increasingly from models of various economic and biological processes. In the past four decades, these models have grown in size and complexity, enabled by rapid developments in computational power. The purpose of this Chapter is to describe the development of both market and bioeconomic models, and to

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describe their use in policy analysis. Needless to say, the impact of this information on strategies for land management and forest policies has been evocative.

This chapter will proceed in several steps. First, given that models need to reflect local conditions, the U.S. forest context is briefly summarized. Second, the evolution and structure of market models are summarized. Thud, three uses of these models are discussed: forecasting, policy analysis, and scenario planning (strategic assessments). Finally, lessons learned are discussed, including inferences about the importance of frameworks for an integrative assessment as a basis for policy analysis.

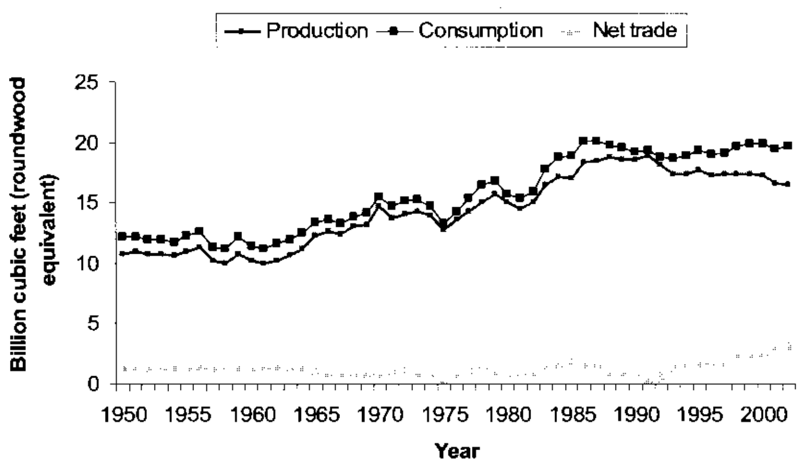

Figure 9-1. Production, consumption, and net trade of timber products, 1950-2002

The forest situation in the U.S. provides a rich setting for analysis of the forest sector. Powell et al. (1993) and Smith et al. (2001) provide a detailed description of the U.S. timber resource. Briefly, the U.S. forestland base is 298.3 million ha that includes 197.9 million ha of timberland defined by productivity and availability for harvest. The U.S. forestland per capita is roughly a third higher than the world average. The United States accounts for 7.4% of world resources hut 27% of consumption and production of industrial wood. Growth in consumption and slower growth in production (and as a proxy for harvest) is shown in Figure 9-1. The United States is a net importer of forest products and its largest trading partner is Canada. These trends reflect a multitude of underlying trends including growth in population, disposable income, and consumer preferences for forest products.

Unlike most other countries, the largest share of timberland (73%) in the United States is privately owned 28.5 million ha by forest industries, and 116.3 million ha by a variety of owners including farmers and others who do not operate wood-using plants. Publicly owned timberland accounts for the reminder, with the federal government being the largest public owner. Federal lands comprise about 20% of all U.S. timberland and 34% of all forestland. The federal government plays a dual role. First, it regulates markets and environmental conditions and, second, it is a major land manager. These dual roles have led to a range of U.S. forest policies that address issues such as terms of trade, performance and quality standards, safety regulations, pollution abatement, as well as policies for the management of federal lands.

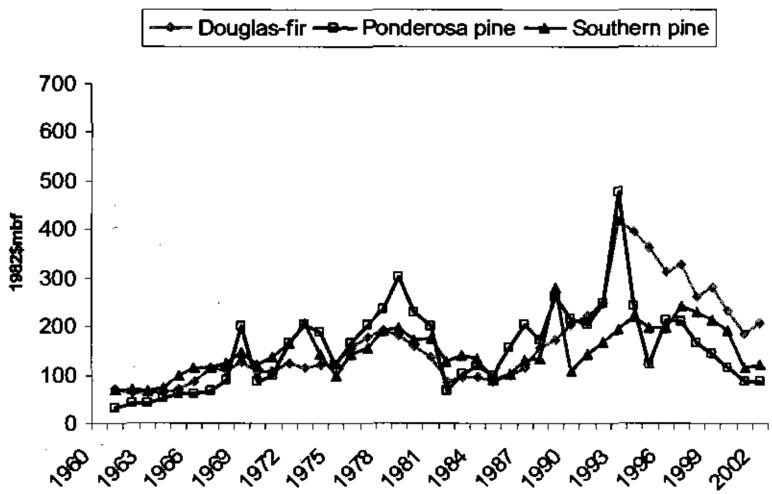

Figure 9-2. Stumpage prices for Douglas-fir and ponderosa pine softwood sawtimber, 1910-2004,

Private timberlands have fostered the development of functional markets for forest products. Figure 9-2 illustrates the dynamic nature of markets for stumpage (a factor of production) in the Pacific Northwest and South. It also shows the persistent differences in regional stumpage prices. Both the highly dynamic nature and regional differences among markets challenge the development of empirically based models.

Finally, the United States has a rich tradition of science-based policy development. Research information plays three roles in this context: (1) providing specific information needs of managers and policy makers; (2) development of systematic approaches to complex problems; (3) and provision of more rigorous understanding of processes for which management has often relied on intuitive approaches.

2. QUESTIONS LEADING TO MODEL DEVELOPMENT

There are several types of questions that compelled the development of computer-based bioeconomic models. The first type focuses on understanding market forces and understanding market performance. The second type deals with models used to understand the impacts of policies. The third type deals with attempting to estimate relative uncertainties associated with various policies.

The theoretical and methodological roots of these models owe much to developments in the economics and agricultural sectors. In the economics sector, Samuelson (1952) conceptualized the equilibrium conditions in spatially distinct markets leading to efforts to use programmatic approaches to solve for the prices, quantities, and trade flows that maximize the sum of consumer and producer surplus. In the agricultural sector, the development of macro-econometric models in the late 1960s and their use in policy simulation experiments (see for example Naylor 1972, who described the form of the policy simulation approach still used today) served as examples for forestry research. McKillop (1967) is often credited with the first comprehensive econometric analysis of forest-product demand using a theoretically complete specification.

The ability to develop policy-relevant market models expanded rapidly in the 1970s, enabled by access to modem computers, more rigorous empirical training of researchers, and the evolution of time-series data for a number of key variables. Policy analysis, that in the past had been based on hypothetical relations, was now based on empirically developed frameworks that proved to be robust in an array of applications.

One outcome of this expanded research capacity was the development of models that represented the complete forest sector.[11] The development of a forest-sector model for the United States was supported by the USDA Forest Service who needed a comprehensive planning framework to meet the requirements of the Resources Planning Act (RPA).[12] This forest-sector

[11]See Haynes, 1993 for a synthesis ofthe development and uses of forest sector analysis.

[12]The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 as amended by the National Forest Management Act of 1976 directs the Secretary of Agriculture to prepare a Renewable Resource Assessment. The purpose of this Assessment is to analyze the timber resource situation in order to provide indications ofthe future cost and availability of timber products to meet the Nations' demands.

model (the Timber Assessment Market Model [TAMM] (Adam and Haynes 1980, Haynes and Adams 1985, Adams and Haynes 1996) provided an integrated structure for considering the behavior of regional prices, consumption, and production in both stumpage and product markets. TAMM has been used for the past two decades to provide forecasts of market activity and to explore the need for, and the consequences of, various policy actions.

3. THE U.S. TIMBER ASSESSMENT MODEL

Figure 9-3 shows the bioeconomic modeling framework used to develop projections for timber assessment. This structure has evolved over the past 25 years to fill needs for greater geographic, owner, resource, and product specificity in the projections. The framework consists of four submodels or modules:

TAMM embraces the solid wood-products sector and also provides the linkage between product markets (solid wood and pulpwood) and timber inventory.

The Aggregate TimberLand Analysis System (ATLAS) is a biological modeling structure for projecting timber growth and inventory over time given timber harvest.

The North American Pulp And Paper model (NAPAP) is an economic model of the pulp, paper, and paperboard sector with detailed treatment of fiber supply (recycled, roundwood, and short-rotation woody crops) used to project markets for pulpwood stumpage.

The AREACHANGE model explains the shifting of timberland between forest and nonforest uses and among forest types.

The system shown in Figure 9-3 is an example of a bioeconomic model, because it combines explanations of both biological and economic processes. Figure 9-3 also shows the major links between modules. Harvest estimates lead to adjustments in timber inventories (and broad-scale vegetation conditions) given changes in forest growth and losses and gains in timberland. The volume of available timber inventory is then fed back to both the solid wood and paper and paperboard models as a major determinant of stumpage supply. The economic models are built on spatial

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The analysis also identifies developing resource situations that may be judged desirable to change and it identifies developing opportunities that may stimulate both private and public investments.

equilibrium concepts that solve for simultaneous equilibrium in both regional product and stumpage markets.

These models were developed to support national assessments of supply and demand trends for timber. Starting in the 1950s, the USDA Forest Service developed an assessment framework, based on a trend analysis of future demands for forest products and the availability of timber resources as separate entities (USDA Forest Service 1958, 1965, 1974, 1982). Policies and emerging trends were discussed in the context of the gap between the trajectories of the demand for forest products (expressed in roundwood equivalents), and the prospective availability of timber. Prices were not explicit in this analysis. Computer models were used in projecting demand and inventory, the latter by means of a stand-table-based inventory projection called TRAS (Larson and Goforth 1974, Alig et al. 1982).

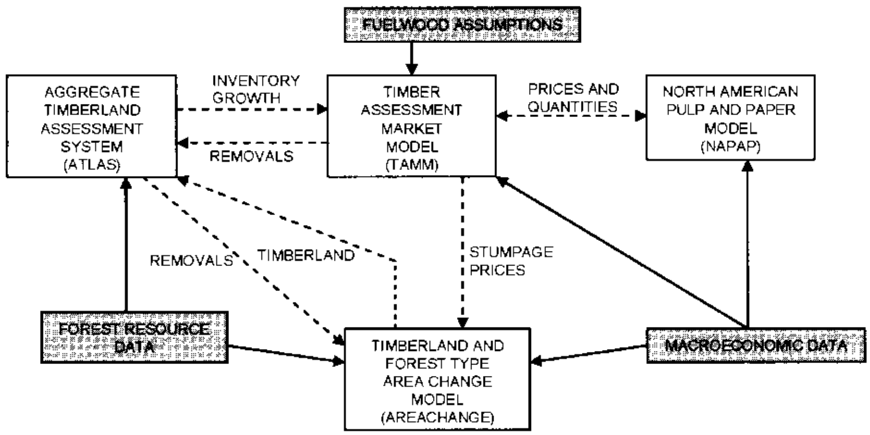

Figure 9-3. Bioeconomic modeling system for the Timber Assessment.

The development of more elaborate computer-based models was strongly influenced by changes in the ways in which timber policy issues were characterized, shifting from potential shortfalls in future quantity toward a focus on future price trends and impacts. Starting in 1977, the USDA Forest Service undertook the development of a forest-sector model designed to explicitly describe regional stumpage price behavior as required by RPA. The resulting model was called TAMM (Adams and Haynes 1980, Haynes and Adams 1985, Adams and Haynes 1996). It produced regional price trends in both product and factor (stumpage) markets that recognized simultaneous market interactions and differences in regional timber resources.

Subsequent refinements of these models continue to provide useful policy-relevant information. The modeling approaches are especially apt in light of ongoing debates about resource sustainability, because many of these discussions revolve around notions of balancing timber demands and supplies with changes in resource conditions.

3.1 The timber assessment market model

Since its initial development in the late 1970s, TAMM has undergone a number of extensions and revisions designed to improve the behavioral models underlying its projections and the utility of its output to resource analysts and policymakers. Details about the various input assumptions used in TAMM are described in the 1989 assessment (Haynes 1990), the 1993 assessment (Haynes et al. 1995), and model features in Adams and Haynes (1996).

TAMM is a spatial model of the solid wood and timber inventory elements of the U.S. forest products sector, and of softwood-lumber and oriented-strand-board (OSB) production in Canada (Adams and Haynes 1980, 1996; Haynes and Adams 1985). TAMM provides annual projections of volumes and prices in the solid wood-products and sawtimber-stumpage markets and estimates of total timber harvest and inventory by geographic region for periods of up to 50 years. Projections of pulp and paper products are derived from the NAPAP model (Ince 1994), which is linked to TAMM through the quantities and prices of roundwood and residues. Endogenous trade flows in TAMM are limited to softwood lumber and OSB/waferboard shipments between the United States and Canada. All other flows, including sawlog imports and exports, are established externally.

The major modules in TAMM are outlined in the following sections.

3.1.1 Product demands

There is one set of product demand relations for each of the major products modeled in TAMM: softwood lumber, softwood plywood, OSB/waferboard and hardwood lumber. These relations explicitly recognize the opportunities for substitution among these classes of products, and so are interdependent in product prices (contemporaneous price-based substitution).

The demand module for softwood solid wood products uses Spelter's diffusion analysis of demands for U.S. softwood lumber, softwood plywood, and OSB/waferboard (Spelter 1984, 1985, 1992). Spelter's model considers the demand for each product category in various end uses (several components of single-family home construction, residential upkeep and alteration, multifamily and mobile units, nonresidential construction, manufacturing, and shipping, a total of 18 uses in all). Demand for hardwood lumber is disaggregated into eight end-use categories (furniture, millwork, flooring, ties, pallets, mining, containers and dunnage, and miscellaneous). Demand relations employ an “end-use factor” form and, as in the case of softwoods, are dependent on prices of substitute materials in the current period. In general, aggregate product demands have been found to be inelastic with respect to changes in price in the short term. Sustained price increases, however, lead to consumers making adjustments in consumption patterns, and act to increase effective demand elasticities two to threefold or more (depending on the end use) over a 5-year period.

3.1.2 Product supplies

In RPA timber assessment projections, it has been customary to treat trends in the technology of wood-products processing and logging by means of specific scenarios of future technical developments and associated impacts on use of the wood (log) input. Efficiency of wood use in milling is represented by “product recovery factors:” product output-log input ratios (for example, board foot lumber tally output per cubic foot log input). To explicitly incorporate these projections in the representations of product supply, the module for solid wood-products supply assumes that product output is obtained in fixed proportions to log input (the product recovery factor linkage), but in variable proportions to all other factors. This implies that logs are separable from other inputs in production. Details of the derivation of relations in this module are described in Adams and Haynes (1996). These are econometric relations with parameters estimated using historical time-series data. Canadian supplies of softwood lumber and OSB/waferboard are explicitly represented in this module and are integral, price-sensitive elements. Estimated product supply elasticities with respect to product price differ markedly across regions and products. Although most are inelastic, many, including those for the largest producing regions, are close to unit elasticity.

3.1.3 Log demands

Given the assumptions of fixed log input-product output relations in TAMM, the derived demand for logs is simply the product of recovery factors times output. This same accounting allows the model to track residues generated in the production process and their disposition. Estimated residues generated in milling depend on projections of product recovery, size of logs processed, and the size mix of products.

3.1.4 Log and timber supplies

The supply of wood to processing facilities is modeled as a mixture of price-sensitive relations and exogenous flows describing the volumes of timber available for immediate harvest and the volumes of logs delivered to mills. Harvests from public lands are set outside the projection model as a policy input. Private relations for timber supply derive from explicit theories of multi-period harvest behavior for industrial and nonindustrial owners (Adams and Haynes 1996). The resulting relations link harvest to prices, inventory, interest rates, and, for nonindustrial private forest owners, income from nonforest sources. Price sensitivity for both softwood and hardwood supplies has been found to be low (inelastic) for all regions and owner groups.

3.1.5 Timber harvest and inventories

TAMM also includes a program module that provides linkage to the ATLAS timber-inventory system described below (Mills and Kincaid 1992) for the solid wood, paper and board, and fuelwood models. Product volumes are aggregated, converted to amounts derived from live growing stock, and adjusted for additional removals owing to logging residues and cultural treatments. This module also allows estimation of timber harvest in Canada, although it does not attempt to model Canadian timber inventories. Canadian harvest estimates are derived from projected softwood lumber, paper and hoard, and OSB/waferboard production, with adjustments for softwood plywood, hardwood lumber, noustructural panels, miscellaneous products, and log trade, which are not explicitly modeled.

3.2 The aggregate timberland assessment systems timber inventory

The biological projection system, ATLAS, was developed to model timber inventories at multiple geographic scales[13]. Its function is to simulate growth, harvest, changes in land use and forest type, and shifts in timber management for approximately 144.1 million ha of private timberland and 55.5 million ha of public timberland in the conterminous United States. Inventory projections depend on the development of inputs under several assumptions regarding the stratification and aggregation of the basic timber-resource data. These data were derived from approximately 180,000

[13]The ATLAS system evolved from earlier work by Beuter et al. (1976) and Tedder et al. (1987).

permanent ground plots maintained by the Forest Inventory and Analysis (FIA) programs within the USDA Forest Service.

At its most basic level, ATLAS uses an even-age representation of the timber inventory. That is, the area and standing volume of the inventory arc aggregated into a series of age classes that advance over time to simulate the development of forests. Original field inventory data relate to the stand level, whereas the linkage between TAMM and ATLAS recognizes a highly aggregated regional (multistate) level. Aggregating inventory from the stand level to the regional level combines a broad mix of conditions, and the even-age characterization used by ATLAS gives way, in effect, to a multi-age model in which age classes represent a collection of stands on a similar growth trajectory.

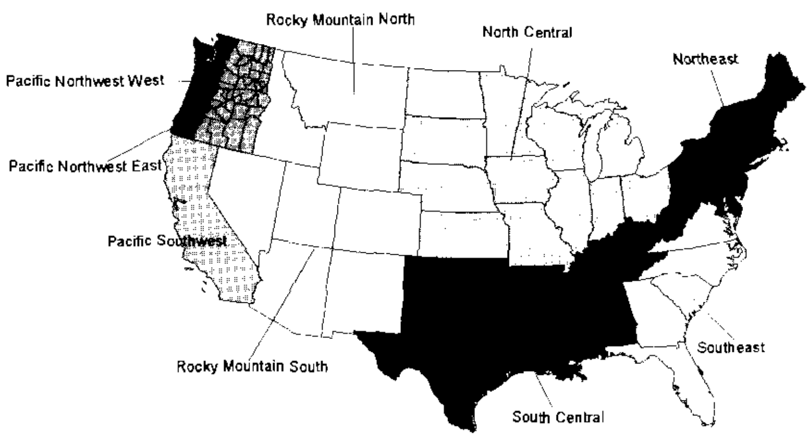

Figure 9-4. RPA assessment regions for the United States.

For the timber assessment, the resource data were divided into nine timber-supply regions (see Figure 9-4). Within each region, timberland was stratified by up to five ownership groups, up to 10 forest types, and up to 26 age classes. Five-year age classes were used in the South and 10-year age classes were used in all other regions. Resource data in the South and the Pacific Northwest West were further stratified by three classes for site productivity and by up to 12 classes for management intensity. Timber-resource data for national forests and other public forests were stratified into three management classes.

The set of attributes used to identify a unit or cell of the ATLAS inventory is region, owner, forest type, site-productivity class, management-intensity class, and age. The area and timber volume within each cell can be identified by these attributes throughout the projection. Weighting within and among cells is dependent on the area associated with each stratum. Given that the stratification scheme depends upon regional aggregations that are sometimes rather broad categories, cells can range in size from several thousand to several million hectares (or acres). The projection mechanism in ATLAS moves each cell along a yield trajectory, dependent on coefficients that adjust volume relative to the user-defined yield of the stratum. This process projects cell volumes forward by age class using a time-step consistent with the length of the projection period. Yield tables for each stratum were derived from either established growth models, or were empirically derived from timberland inventory plot data collected by the various USDA Forest Service FIA units (see Mills, 1990). The various management regimes were derived through cooperative research and consultation with private forest landowners, and from previous studies. The inventory data inputs are summarized in Mills (1989, 1993) and Haynes (2003).

Over time, as an inventory cell advances in age, it can change management-intensity class, shift forest type, receive a harvest treatment, or be lost from the forestland base to nonforest uses such as developed uses (Alig et al. 2003). Upon final harvest, the cutover area within the cell returns to a regeneration pool in which the area is combined with all other land available for regeneration and assignment to a new cell. Depending on the type of harvest, this could he a single cell, several cells, or portions of several cells. The harvested area is combined following final harvest and the area to be regenerated is distributed among the available management classes based on both endogenous and exogenous parameters assigned. A new cell is created at that time. This re-pooling of regenerated area and loss of the original identity is known as a “model II” formulation, as described by Johnson and Scheurman (1977). Cells cease to exist when their inventory is completely harvested, or they are removed due to area loss, or when inventory grows into the oldest age class, and they are added to a larger pool.

In the 2005 Assessment Update, the stratified timberland data occupied over 9,000 cells at the start of the projection. To avoid introducing ambiguous errors to the initial FIA plot data, inventory values were not adjusted to a common starting point in time. The starting year represents roughly the average year the data were collected: 1995 in the South, and 1990 in the seven remaining U.S. regions. To reach 2050, the South was projected for eleven 5-year periods, and all other regions are projected for six 10-year periods. By the end of the projection, some concentration of age and management groups had occurred and the inventory resource was distributed among 7,100 cells.

In each simulation period, changes in the inventory result from growth, area change, and harvesting. Periodic change in inventory volume is the sum of four components: net growth (+), volume lost owing to area loss (–), harvest (–), and volume gained owing to area gain (+). Net growth is the sum of growth (net of mortality) calculated for all inventory present during any portion of the projection period. Normal inventory growth is calculated when cells advance in age, simply moving from one time step to the next, and are present for whole period. A partial period of growth is calculated on the timber volume removed by harvesting and on the volume inventory gained or lost because of additions or subtractions of timberland area.

Changes in forest type and management intensity are governed in part by externally developed scenarios of prospective future private management decisions. Enrollment of area into various regimes of management intensity is also endogenously sensitive to price and other market elements. The market response has been recently incorporated by using costs and returns to generate a series of economic returns to guide the model's investment decisions. In the past, adjustments in management intensity were made using judgments and a series of successive projections to gauge possible price impacts.

While growth is simulated for each cell independent of all other cells, the amount of harvest or area change occurring in a particular cell most often depends on the cell's weight relative to other cells. That is, the amount of harvest allocated and removed, or the amount of area lost, will depend on a cell's relative available volume or relative area among a targeted group of cells. For changes in forest area, this typically occurs within a forest type and for harvest this occurs among the forest types that are grouped together for harvesting. The harvest volumes in the RPA were derived from product demand for hardwood or softwood. Demand was balanced against the available ATLAS inventory in the TAMM portion of the model. Between TAMM, NAPAP, and ATLAS, the inventory and harvest were aggregated to the same region, owner, and fiber type. ATLAS apportions the harvest across all forest types within the harvest group based on available volume among the types and available volume among the cells within each type.

3.3 North American pulp and paper model

The NAPAP model applies conventional techniques for modeling regional markets to compute annual market equilibria, based on optimization of consumer and producer surplus in the pulp and paper sector (Zhang et al. 1993 and 1996, Ince 1999). The model computes market equilibria over a 65-year period, extending historically from 1986 through the present and out to the year 2050. The overlap of model projections with 15 years of actual historical data allows for extensive testing and calibration of model performance (average errors between historical data and projected equilibrium product demands, pulpwood supply, and recycling rates over the historical period are less than 1 percent per year). Changes in regional production capacities for pulp and paper manufacturing processes, including shifts between virgin fiber and recycling technologies, are simulated in the model as economic responses to projected market conditions, and in turn, projected market equilibria are influenced by shifts in capacity and embodied changes in technology. The introduction in the 1990s of somewhat more sophisticated economic modeling techniques, based on market analysis and technology forecasting, resulted in projections of pulpwood market trends lower than those in previous timber assessments, largely because the NAPAP model accurately simulated the impact of increased paper recycling (Ince 1994, 1999).

Whereas TAMM produces projections for solid wood industries and sawtimber markets, the NAPAP model produces projections for the pulp and paper industry, pulpwood markets, and recovered paper markets. The NAPAP model uses linear programming to solve for annual market and production equilibria. Equilibria are adjusted over time by endogenous changes in production capacity and exogenous changes in supply and demand. The NAPAP model shows how markets for pulpwood and recovered paper are expected to evolve in response to changing market conditions, including changing technology (shifts in production capacity embody shifts in technology). The model includes regional supply functions for pulpwood and recovered paper, and a detailed representation of regional production capacity and production volume for all principal grades of paper, paperboard, and market pulp produced in the United States and Canada. The model also includes demand functions for all end products, with separate demand functions for U.S. domestic demand, Canadian domestic demand, and demand for exports outside of the United States and Canada.

The current NAPAP model is an extended and revised version of the original NAPAP model used in the 1993 assessment (Ince 1994, Haynes et al. 1995). Details of NAPAP model methods and results can be found in Ince (1994, 1999) and Zhang et al. (1996). NAPAP model methods are an application of the price endogenous linear programming system (PELPS), an economic modeling system developed primarily for modeling the pulp and paper sector aver the past decade (Gilless and Buongiorno 1985, Calmels et al. 1990, Zhang et al. 1993). Commodities in production and demand in NAPAP model are listed in Table 9-1.

In the NAPAP model, there are three demand regions (United States, Canada, and Other World). Separate United States and Canadian demand functions are included for each principal paper and paperboard grade. U.S. demands for paper and paperboard grades are defined by estimated elasticities with respect to product price, per capita U.S. GDP, U.S. population, and price of capital. Equilibrium prices are derived endogenously within the model, whereas other independent variables are projected exogenously. U.S. demands for communication paper grades include also elasticities with respect to price indexes of television or radio and computers. Econometric analysis has shown that demands for communication paper grades and electronic media are complementary, so declining real prices for media such as computers exert a positive influence on demand for paper (Zhang 1995). U.S. demands for packaging paper and paperboard grades include also elasticities with respect to a price index of plastic substitutes and the all-commodity Producer Price Index (PPI). Econometric analysis has shown that plastics are weak substitutes for paperboard grades, and prices of plastic substitutes are not expected to decline significantly (Zhang 1995). Canadian demands for paper and paperboard grades include only elasticities with respect to price and Canadian GDP.

Table 9-I. Commodities in production and demand in NAPAP model

Paper grades	Paper grade market pulps	Paperboard grades and other
Newsprint	Softwood kraft	Linerboard (unbleached kraft and recycled)
Uncoated free sheet paper	Hardwood kraft	
Coated free sheet paper	Recycled	Cormgating medium (semichemical and recycled)
Uncoated groundwood paper	Chemithermalmechanical Pulp (CTMP)	
Coated groundwood paper		Solid bleached paperboard
Tissue and sanitary paper products		Building paper
Specialty packaging and industrial paper		Recycled board (other than cormgated boards)
Unbleached kraft packing paper		Dissolving pulp

Projected growth rates in U.S. demands for most paper and paperboard commodities were also adjusted downward in the period from 2000 to 2005, to more accurately reflect the impact of the current economic recession on the pulp and paper sector. Although domestic GDP growth did not slip into a recession until the third quarter of 2001, US. paper and paperboard consumption has been receding from a recent peak of over 341 kg per capita in 1999 to around 318 kg per capita in 2001, and domestic paper and paperboard production has dropped by about 7% in that period. This is the most significant drop in consumption and production since the period of the energy crisis in the early 1970s. Thus, projections of U.S. demand in the NAPAP model incorporate a period of slow growth in the near term, with partial recovery to modest expected rates of growth in demand after 2005.

There are eight pulpwood-supply regions in the model (U.S. North Central, Northeast, South Central, Southeast, West, Canada East, Canada West, Other World), six production regions (U.S. North, South Central, Southeast, West, Canada East, Canada West), and five regions for recovered paper supply (U.S. North, South, West, Canada East, Canada West).

Pulpwood supplies for Eastern U.S. supply regions include supplies from harvests on forest industry lands, harvests on non-industrial private forest lands, harvests on public forest lands, and wood residues supply (from sawmills and plywood mills), for both hardwoods and softwoods (eight distinct sources of pulpwood supply in each Eastern U.S. region). Pulpwood supplies for U.S. West and both Canadian supply regions include supplies from timber harvests and wood residues, for both hardwoods and softwoods (four distinct sources of pulpwood supply).

Functions for supply of pulpwood stumpage were estimated for pulpwood harvest from forest industry and non-industrial private forest lands in Eastern U.S. regions (separately for hardwoods and softwoods). Stumpage supply functions have unitary elasticity with respect to timber inventories, projected by TAMM and ATLAS. Pulpwood supplies were estimated to have relatively low elasticity with respect to stumpage price of pulpwood (less than 0.5 in most cases). Harvest quantities for pulpwood from public forest and total harvest of roundwood pulpwood in the U.S. West are projected exogenously. Supplies of pulpwood residue are determined by lumber- and plywood-production activities projected in the TAMM model. Equations for supply of Canadian roundwood pulpwood are elastic with respect to delivered pulpwood price, sawtimber price, and labor wage rates in Canada (projected exogenously). Supplies of Canadian pulpwood residue are elastic with respect to delivered pulpwood price and Canadian lumber-production activities; the latter are projected in TAMM.

In the NAPAP model, supply of recovered paper is modeled for five categories of recovered paper including old newspapers, old corrugated containers, mixed paper, pulp substitutes, and high-grade de-inked paper. For U.S. supply regions, supply of recovered paper consists of two elements, long-term contract and spot market supply. Large quantities of recovered paper are collected and transferred to mills under long-term negotiated contracts (particularly in the domestic sector). The remainder of the market is an open or spot market (particularly for exports). For purposes of estimating supply of recovered paper, volume of domestic supply was used as a proxy for supply under long-term contract, and volume of export supply was used as a proxy for spot market supply. Supply under long-term contract is modeled as unresponsive to price, hut increasing gradually over time in relation to consumption of paper and paperboard commodities (recovery is increasing but at a declining rate over time). Spot-market supply is elastic with respect to price, landfill tipping fees, and consumption of paper and paperboard commodities. Total supplies of the various categories of recovered paper are each limited by assumed maximum feasible recovery rates.

Trade flows are modeled separately for all pulp, paper, paperboard, and fiber input commodities in which there have been significant trade volumes in the past decade. The market equilibria for U.S. pulp, paper, and paperboard imports from Canada are modeled endogenously by the NAPAP model, as influenced by regional production costs and assumptions about rate of currency exchange. Other significant trade flows (total exports from Canada to Other World, total U.S. exports, and total imports from Other World to the United States and Canada) are projected by using trend analysis with significant adjustments for the assumed impacts of expansion of global capacity and rates of currency exchange. In particular, the current outlook for U.S. export of paper and paperboard is more pessimistic than in past assessments because of the observed negative impacts of the strong dollar on U.S. competitiveness in recent years, weakened growth in domestic capacity, and continued expansion of overseas capacity.

3.4 Timberland area change model

The land-area projection system, AREACHANGE, was developed to project changes in land use and forest type at regional and national scales. The system was linked to the ATLAS and TAMM models in the 1989 assessment (Haynes 1990), and the study of "The South's Fourth Forest" (USDA FS 1988). A projection by the system operates in two phases. In the first phase, area changes in major land uses are projected to provide regional estimates of total timberland area by ownership, e.g., non-industrial private forest. In the second phase, the system projects area changes for major forest types (e.g., planted pine) on each ownership. Price projections from other parts of the timber-assessment modeling system are used as one of the inputs in the first phase of the projections, and projections of changes in class of management intensity from the ATLAS model are used as an input in the second phase (Figure 9-3) (Alig and Butler 2004).

For the first phase, econometric analyses of the determinants of land use by region (e.g., Mauldin et al. 1999, Plantinga et al. 1999, Ahn et al. 2002) were used in developing simulation models to project changes in regional area in timberland by private ownership (Alig et al. 2003). Land-use competition between forestry and other sectors is modeled by using statistical relations between changes in timberland area and determinants such as population, per capita income, and income from land-based enterprises such as forestry or agriculture.

In the second phase, area changes for forest types on a particular ownership can result from four basic sets of activities: afforestation, deforestation, shifts among forest types on retained timberland, and ownership exchanges. In contrast to ecological processes, land-use changes and disturbances can differ significantly by type of private ownership. Changes in land use involving afforestation and deforestation affect areas of forest type over time. Deforestation is most often caused by conversion to other land uses. This contrasts to timber harvests as part of typical forestry activities, because timber harvests are most often followed by regeneration back to forest. Land exchanges between ownerships are largely driven by financial, strategic, and other socioeconomic factors (Alig 1985).

Transitions in forest type on timberland are based on data from remeasured FIA survey plots. Projections of such area changes for major forest types take into account likelihood of final harvest and forest successional forces (Alig and Wyant 1985). Forest-type transitions for an aggregate grouping of timberland (by a stratum representing a specific region and ownership) are conditional on three types of timber harvest–no harvest, final or clearcut harvest, and other harvest types and miscellaneous natural disturbances. Projected harvest information is provided by the overall TAMM/ATLAS/NAPAP/AREACHANGE modeling system.

3.5 Linkage among modeling of area changes, timber management intensity, and economic timber supplies

Solution of the integrated modeling system shown in Figure 9-3 involves an iterative approach. Starting estimates of land use and forest cover from the AREACHANGE system are fed into the ATLAS model, which also accounts for changes in intensity of timber management. Resulting impacts on forest growth are reflected in ATLAS, which adjusts timber inventories. The adjusted physical measures of available timber inventories are used to shift curves for supply of timber stumpage in the economic models of timber supply embodied in the TAMM and NAPAP models. Price projections from the latter models are then fed back to the AREACHANGE system to account for the impacts of any altered timber-harvest levels and timber prices on projections of land use and forest cover. The revised land-use and forest-cover projections are then input into new ATLAS runs, and so on. This iterative running of models proceeds until there is a reasonable convergence of linked model outcomes.

4. USING TAMM, ATLAS, NAPAP, AND AREACHANGE

These forest-sector models are used to provide conditional forecasts, examine the impacts of various hypothetical and actual forest policies, and explore scenarios to develop a sense of the uncertainties of various outcomes.

4.1 Forecasting

One of the motivating reasons for developing forest-sector models is to assist in forecasting (see Kallio et al. 1987 for more details). This role takes advantage of the structural models that comprise forest-sector models and the way in which they capture the interplay among various components including how spatial or dynamic processes function. In the forecasting role, these models provide a quantitative set of estimates about future events, based on relations that embodied past and current events, and estimates of future values for exogenous variables. Such forecasts are said to be conditional in the sense that they are the consequences of both the model and various assumptions about exogenous variables.

The integrated system, comprising TAMM, ATLAS, and NAPAP, was developed to provide forecasts of the prices and trends in timber markets and resource conditions. For example, the RPA 2005 Update base projection envisions continued strong growth in total U.S. requirements for forest products (domestic consumption plus exports) to 2050. Imports will supply a smaller portion of the growth in total wood requirements, and domestic sources a correspondingly larger share, over the next 45 years than was the case during the previous 5 decades. Future harvests from domestic forests alone are expected to grow each year by 0.1 1 billion cubic feet (bcf), close to the trend over the past 50 years of 0.12 bcf/year (Figure 9-5). At the same time, real growth in product prices will fall below long-term historical rates for nearly all products.

Over the 50 years from 1952 to 2002, U.S. consumption plus exports of all forest products rose by some 9.5 billion cubic feet. U.S. harvest increased by 6.0 billion cubic feet, and imports rose by 3.5 billion cubic feet over this same period (Figure 9-1). Real prices of softwood lumber, hardwood lumber and paper rose (compound rates of 0.8%, 0.4% and 0.3%, respectively), while prices of softwood plywood, OSB (since 1976), and paperboard fell. In the Update base projection, U.S. consumption plus exports increases over the 2002-2050 period by 8.6 billion cubic feet. Imports grow by 1.4 billion cubic feet, while harvest from both forests and short rotation woody crops (SRWC) plantations rises by 7.1 billion cubic feet.[14] Prices of softwood lumber, hardwood lumber and OSB rise slowly (0.2%, 0.3% and 0.1%, respectively), prices of softwood plywood, paper and, paperboard remain stable or fall.

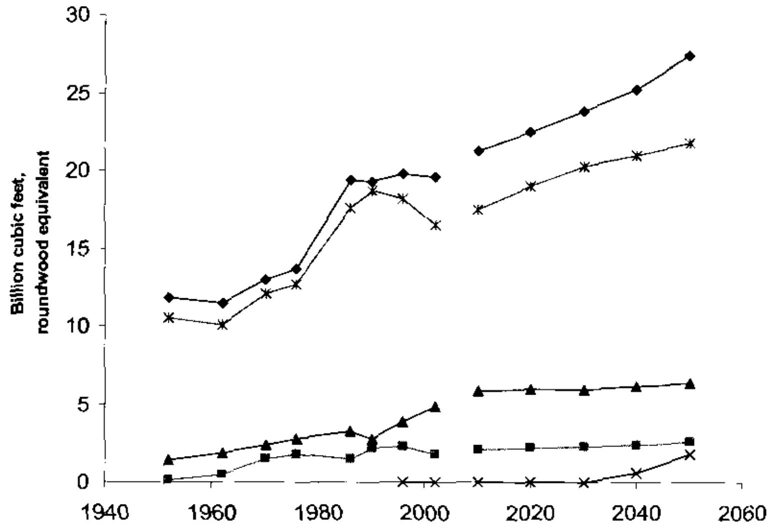

Figure 9-5. Total U.S. roundwood consumption (black diamond), harvest (gray star), imports (blank triangle), exports (gray box), and SRWC (black cross).

4.2 Policy analysis

In the context of assessment, the original policy interest was to identify policy needs in terms of impacts to prices rather than shortfalls in quantity. This price-based approach appealed to policy makers interested in price changes and estimates of consumer or producer impacts. Use of empirical policy tools also increased the ability to differentiate regional and national market impacts of changes in supply from one ownership in one region. Early applications (see Adam et al. 1976) involved potential responses of softwood markets to reductions in federal timber flows that would especially impact western producers. In this case, lumber and stumpage prices would rise, increasing harvests from private timberlands and lumber imports from Canada. Stumpage prices would increase the most on the west coast,

[14]Domestic forest harvest rises by 5.3 bcf and SRWC by 1.8 bcf.

accentuating the concentration of lumber and plywood production in the South.

These latter results demonstrated the broad market impacts of what had been characterized as relatively local or regional policy issues. Similar results (see Haynes and Adams 1979) for impacts of expanded wilderness withdrawals demonstrated that changes in availability of public timber in the west did not lead to drastic changes in timber prices. Rather, increased production from private lands, mostly in the South, and increased softwood lumber imports from Canada greatly reduced potential price impacts associated with policy changes. These results were quickly adopted in ensuing policy discussions, and were reaffirmed in the early 1990s, following reductions in federal harvests in the west for habitat conservation. Prices in the 1900s and after clearly demonstrate a step up, and do not return to levels observed in the 1980s and earlier periods. The loss of public timber did lead to a substitution—so no famine—but it did not happen without cost. If private and Canadian timber had been cheaper before the drop in public cut, they would have been used instead of the public timber. But they were not cheaper, and the price of attracting them into the market after the drop in public cut was a step up in prices. Figure 9-6 shows the interesting price behavior associated with these changes.

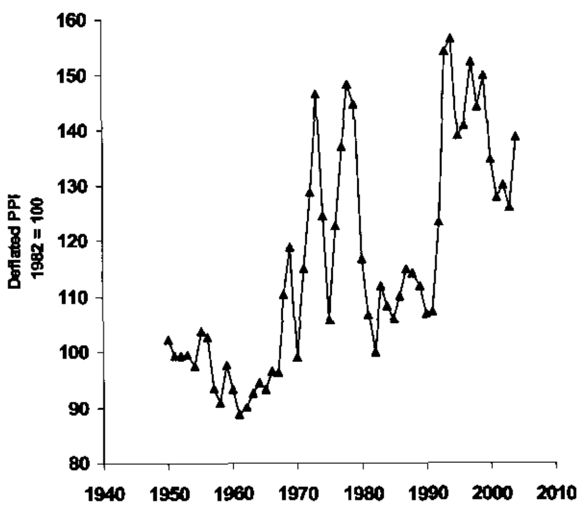

Figure 9-6. Changes in lumber producer price index

Response of market-based supply in these policy debates stimulated interest in understanding the nature of market incentives for private landowners to increase forest stewardship. A survey in the late 1970s had identified a number of treatment opportunities on private timberlands, which, in spite of forecasts of rising prices, were not implemented. This led to a policy discussion about the need for tree-planting incentives. Results of economic models showed that incentives, which increased the extent of tree plantations in the near term, would lead to increased inventories in two decades, reducing stumpage prices in the South, and elsewhere reducing financial returns of practices already implemented and lowering incentives for further forest stewardship. This dynamic link between actions now and impacts in the future was also an issue in the estimation of economic effects associated with growth slowdowns expected to result from increased forest declines caused by acid rain or other air pollutants (see Haynes and Kaiser 1990). The proponents for taking action thought economic effects should occur at the same pace as reductions in growth. The use of the models demonstrated, however, that economic impacts evolved over several decades as a function of slower growth in inventory levels and consequently harvests.

Table 9-2. Indices of changes for selected indicators for the United States, developed from data summarized in Table 23 in Haynes (2003)

	Criterion 1			Criterion 2			Criterion 6
Year	Extent of softwood area	Extent of older stands	Fragmen-tation	Area of timber land	Total growing stock inventory	Ratio of growth to harvest	Total harvest
	Percent of total	1976= 100	1952= 100	1952= 100	1952= 100	Percent	
1952	70		100	100	100	128	100
1962	68		89	99	108	161	95
1970	66		97	97	114	164	111
1976	64	100	96	95	119	171	118
1986	59	76	124	96	124	125	162
1991	57	74	124	99	128	121	164
2000	58	61	110	99	136	144	151
2010	58	66	108	98	153	140	I67
2020	60	65	107	97	166	130	181
2030	61	65	106	97	177	123	193
2040	62	65	105	96	186	117	202
2050	62	65	105	96	193	110	212

Recently, strategic discussions of broad-scale forest policies are being set in the context of whether we can sustain[15] forest resources despite increasing consumption of forest products. Both historic and projected trends are

[15] The United States adopted the Montreal Process to facilitate a discussion of indicators for sustainable forest management (for a list see http:www.fs.fed.us/land/sustain_dev/sd/welcome.htm).

illustrated in Table 9-2 for direct and indirect or proxy measures of selected national data (converted to indices to make them comparable and grouped by criterion). The historic trends illustrate that there was a general decline in some indicators characterizing conservation of biological diversity (criterion 1) and maintenance of productive capacity (criterion 2), but that this decline slowed in the 1990s, and is expected to stabilize in the future. At the same time, timber harvest (one indicator of socioeconomic benefits [criterion 6]) increased, peaking in the late 1980s. These trends suggest that, while in the period 1950-1980s there were tradeoffs between ecological conditions and economic growth, changes in public attitudes, improving forest management, and increased productivity of forestlands resulted in greater balance by the 1990s. While trade is not an indicator in the Montreal framework, net trade increased threefold (see Figure 9-1) during the 1990s enabling Americans to maintain their consumption, reduce federal harvests in the west, and improve forest conditions. The various indicators also suggest that we are seeing an aging of forests as production effectively shifts to fewer timberland acres. Overall, timber types remain relatively stable after some initial declines in the 1950s and 1960s. The results also show that, while fragmentation has emerged as a critical natural resource issue, the contribution that harvest area makes to fragmentation is expected to decline. Finally, these results have positive implications for the contribution of U.S. forests to global carbon cycles (criterion 5). In general, U.S. forest management has resulted in increasing total levels of carbon storage, given that inventory levels are expected to increase by 42% over the next 50 years.

4.3 Scenario planning: the use of TAMM, ATLAS, NAPAP, and AREACHANGE as an integrated system for strategic planning

There has been an evolution in the use of computer-based models in strategic planning by both government and non-government organizations. This is particularly evident in the use of simulation techniques to analyze alternative futures and management strategies to better inform land managers and the public. This approach, called scenario planning (Wack 1985), has been a part of RPA efforts since 1983 (USDA FS 1982, Haynes 1990, Haynes et al. 1995). These applications take a classical approach to sensitivity analysis, in which a limited number of key exogenous and endogenous elements were varied and key projection results were examined for differences. These differences allow the identification of emerging problems, and provide a way to measure the effectiveness of possible solutions to various problems.

The use of scenario analysis has added depth to the use of the bioeconomic models for policy analysis. In the latter application, the models have been used to examine the effectiveness of specific policy actions such as tariff increase or regional federal timber harvest decease. But the experience gained from examining the differences and similarities across scenarios has helped shape qualitative notions of the key uncertainties in the outlook and how the forest sector adjusts and adapts limiting the economic effects of changes in external conditions.

Examining alternative futures has shaped the perceptions of land managers and policy makers, eventually leading to better decisions. They have been useful in communicating the links between various assumptions and possible outcomes. Using scenario planning has not resulted in less acrimonious debate or less controversy, but these debates have been better informed. There are also instances in which the planning process itself led to more intense controversy by exposing the importance of underlying processes that were themselves controversial.

5. CLOSING

The U.S. experience with using bioeconomic models for broad-scale assessments and policy analysis offers a number of lessons. Key is that the use of integrated assessments increases the effectiveness of generalized approaches to planning or risk assessments. The demonstration of this was the application of bioeconomic models to the full spectrum of policy issues in the last quarter century.

Use of computer-based forest-sector models has lead to several unique economic insights. These include the extent and consequence of how private timberland owners respond (based on their objectives), both in terms of harvest and land-management intensity, to changes in prices and land values; increased environmental regulations often increase timber costs, shifting production to cheaper producers both in that region or country and elsewhere; and the models have been helpful in synthesizing information for policy development.

These models have influenced contemporary thinking about the need and way to consider the uncertainties associated with various policies. The ability to use scenario-planning approaches has facilitated strategic planning by providing policy makers with information necessary for decision making without knowledge about their welfare preferences or particular targets. These approaches also shifted the focus from forecasting the future to looking at a set of plausible futures, each dependent on the assumptions that underlie that future. By doing so, the technique focuses on what might happen, or go wrong, and how to deal with it.

Finally, using a computer-based bioeconomic model bas lead to more enduring decisions and policies by allowing decision makers to explore management options in much greater detail, as required by the increasing complexity of debates surrounding forest policies. These models, with their deliberate approach to policy analysis, can provide powerful tools and inform the debate. Models, however, do not operate in a vacuum, and by themselves will not lead to better policies. Successful application of management sciences to policy depends on the effectiveness of individuals to be advocates for their use in exploring specific policy questions.

REFERENCES

Adams, D.M., and Haynes, R.W., 1980, The 1980 softwood timber assessment market model structure, projections and policy simulations, *Forest Science Monographs* 22: 4.

Adams, D.M., and Haynes, R.W., 1996, *The 1993 timber assessment market model:* structure, *projections and policy simulations,* Gen. Tech. Rep. PNW-GTR-368, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Adams, D.M., Darr, D.R., and Haynes, R.W., 1976, Potential responses of softwood markets to the Monongahela decision, *Journal of Forestry* 74: 668-670.

Ahn, S., Plantinga, A., and Alig, R., 2002, Determinants and projections of land uses in the South Central U.S., *Southern Journal of Applied Forestry* 26: 78-84.

Alig, K., 1985, *Modeling area changes in forest ownerships and cover types in the Southeast,* Res. Pap. RM-260, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Alig, K., Butler, B.J., 2004, Projecting large-scale area changes in land use and land cover for terrestrial carbon analyses, *Environmental Management* 33: 443-456.

Alig, R., and Wyant, I., 1985, Projecting regional area changes in forestland cover in the USA., *Ecological Modeling* 29: 27-34.

Alig, R., Brink, G.E., Goforth, M.H., LaBau, V.J., and Mills, T.J., 1982, *TRAS 1980 user's manual for an expanded version of the TRAS projection system,* U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Alig, R., Plantinga, A., Ahn, S., and Kline, J., 2003, *Land use changes involving forestry for the United States: 1952 to 1997, with projections to 2050,* Gen. Tech. Rep. PNW-GTR-587, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Beuter, J.N., Johnson, K.N., and Scheurman, H.L., 1976, *Timber for Oregon's tomorrow, an analysis of reasonable possible occurrences,* Resource Bulletin 19, Oregon State University, Corvallis, OR.

Calmels, P., Buongiorno, J., and Zhang, D., 1990, *PELPS II: a microcomputer price-endogenous linear programming system for economic modeling,* R3477, Department of Forestry, University of Wisconsin, Madison, WI.

Forest Rangeland Renewable Resource Planning Act of 1974, (RPA), Public Law 93-378, Act of August 17, 1974, 16 U.S.C. 1601 (note).

Gilless, J.K., and Buongiorno, J., 1985, *PELPS: price-endogenous linear programming system for economic modeling,* R3329, Department of Forestry, University of Wisconsin, Madison, WI.

Haynes, R.W., 1990. *An analysis of the timber situation in the United States: 1989-2040.* Gen. Tech. Rep. RM-199. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Haynes, R.W., 2003, *An analysis of the timber situation in the United States: 1952 to 2050,* Gen. Tech. Rep. GTR-PNW-560, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Haynes, R.W., and Adams, D.M., 1979, Impacts of RAREII withdrawals on softwood prices, consumption, and production. *Journal of Forestry* April 1979: 230-233.

Haynes, R.W., and Adams, D.M., 1985. *Simulations of the effects of alternative assumptions on demand-supply determinants on the timber situation in the United States,* U.S. Department of Agriculture, Forest Service, Forest Resources Economics Research, Washington, DC.

Haynes, R.W., and Kaiser, H.F., 1990, Forests methods for valuing acidic deposition/air pollution effects, in: *Acidic deposition: State of Science and Technology,* G. M. Brown, Jr., and J. M. Callaway, eds., Report 27, NAPAP State of Science and Technology, National Acid Precipitation Assessment Program, Washington, DC, pp. 27-121, Section B2, Vol 4.

Haynes, R.W., Adams, D.M., and Mills, J.R., 1995, *The 1993 RPA timber assessment update,* Gen. Tech. Rep. RM-259, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Ince, P.J., 1994, *Recycling and long-range timber outlook,* Gen. Tech. Rep. RM-242. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Ince, P.J., 1999, Long-range outlook for U.S. paper and paperboard demand, technology, and fiber supply-demand equilibria, in: *Proceedings of the Society of American Foresters 1998 national convention,* Society of American Foresters, Bethesda, MD, pp. 330-343.

Johnson, K.N., and Scheurman, H.L., 1977, Techniques for prescribing optimal timber harvest and investment under different objectives, *Forest Science Monographs* 18.

Kallio, M.. Dykstra, D.P., and Binkley, C.S., 1987, *The global forest sector: an analytical perspective,* John Wiley 82 Sons, New York.

Larson, R.W, and Goforth, M.H., 1974, *TRAS: A timber volume projection model,* Technical Bulletin 1508, U.S. Department of Agriculture, Forest Service, Washington Office, Washington, DC.

Mauldin, T., Plantinga, A., and Alig, R., 1999, *Land use in the Lake States region: an analysis of past trends and projections of future changes,* Res. Pap. PNW-RP-519, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

McKillop, W.L.M., 1967, Supply and demand far forest products, an econometric study. University of California, Agricultural Experiment Station, Los Angeles, CA, 38(1) Hilgardia.

Mills, J.R., 1989, *Inventory, growth, and management assumptions for the 1989 RPA timber assessment. Part I: The South and Part II: The North and West,* unpublished document on file with John Mills, Pacific Northwest Research Station, Forestry Sciences Laboratory, PO BOX 3890, Portland, OR 97208-3890.

Mills, J.R., 1990, Developing ATLAS growth parameters from forest inventory plots, in: *Proceedings, State of the art methodology of forest inventory .symposium,* Gen. Tech. Rep.

PNW-GTR-263, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 112-118.

Mills, J.R., 1993, *Inventory, growth, and management assumptions for the 1993 RPA timber assessment update,* unpublished document on file with John Mills, Pacific Northwest Research Station, Forestry Sciences Laboratory, PO Box 3890, Portland, OR 97208-3890.

Mills, J., and Kincaid, J., 1992, *The aggregate timberLand analysis system--ATLAS: a comprehensive timber projection model,* Gen. Tech. Rep. PNW-GTR-281, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

National Forest Management Act of 1976, (NFMA), Public Law 94-588, Act of Oct. 22, 1976, 16 U.S.C. 1600 (1976).

Naylor, T.H., 1972, Policy simulation experiments with macro-econometric models: the state of the art, *American Journal of Agricultural Economics* 52: 263-271.

Plantinga, A., Mauldin, T., and Alig, R., 1999, *Land use in Maine: determinants of past trends and projections of future changes,* Res. Pap. PNW-RP-511. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Powell, D.S., Faulkner, J.L., Darr, D.R., Zhu, Z., and MacCleery, D.W., 1993, *Forest resources of United States, 1992,* Gen. Tech. Rep. RM-234, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Samuelson, P.A., 1952, Spatial price equilibrium and linear programming, *American Economics Review* 42: 283-303.

Smith. W.B., Vissage, J.S., Sheffield, R., and Darr, D.R., 2001, *Forest Resources of the United States, 1997,* Gen. Tech. Rep. NC-219, U.S. Department of Agriculture, Forest Service, North Central Research Station, St Paul, MN.

Spelter, H.N., 1984, Price elasticities for softwood plywood and structural particleboard in the United States, *Canadian Journal of Forest Research* 14: 528-535.

Spelter, H.N., 1985, A product diffusion approach to modeling softwood lumber demand, *Forest Science* 31: 685-700.

Spelter, H.N., 1992, Technology-driven substitution in the forest sector: the variable price elasticity model revisited, in: *Forest sector analysis. Proceedings P06.02 FORESEA, IUFRO Centennial 1992,* L. Lönnsted, ed. Swedish University of Agricultural Sciences, Forest-Industry-Market Studies, Uppsala, Sweden, pp. 24-29.

Tedder, P.L., LaMont, R.N., and Kincaid, J.C., 1987, *The timber resource inventory model (TRIM): a projection model for timber supply and policy analysis,* Gen. Tech. Rep. PNW-GTR-202, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

U.S. Department of Agriculture, Forest Service, 1958, *Timber resources for America's future,* Forest Resource Report 14, Washington, DC.

U.S. Department of Agriculture, Forest Service, 1965, *Timber trends in the United States,* Forest Resource Report 17, Washington, DC.

U.S. Department of Agriculture, Forest Service, 1974, *The outlook for timber in the United States,* Forest Resource Report 20, Washington, DC.

U.S. Department of Agriculture, Forest Service, 1982, *An analysis ofthe timber situation in the United States 1952-2030,* Forest Resource Report 23, Washington, DC.

U.S. Department of Agriculture, Forest Service, 1988, *The South's fourth forest: alternatives for the future,* Forest Resource Report 24, Washington, DC.

Wack, P., 1985, Scenarios: uncharted waters ahead, *Harvard Business Review* 63: 73-89.

Zhang, D., Buongiorno, J., and Ince, P., 1993, *PELPS III: a microcomputer price endogenous linear programming system for economic modeling: version 1.0,* Res. Pap. FPL-526. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.

Zhang, D., Buongiorno, J., and Ince, P.J., 1996, A recursive linear programming analysis of the future of the pulp and paper industry in the United States: changes in supplies and demands, and the effects of recycling, *Annals of Operations Research* 68: 109-139.

Zhang, Y., 1995, *Demand for paper and paperboard products in the United States:* econometric models and forecasts, Ph.D. dissertation. University of Wisconsin-Madison, Madison. WI.

Computer Applications in Sustainable Forest Management

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