



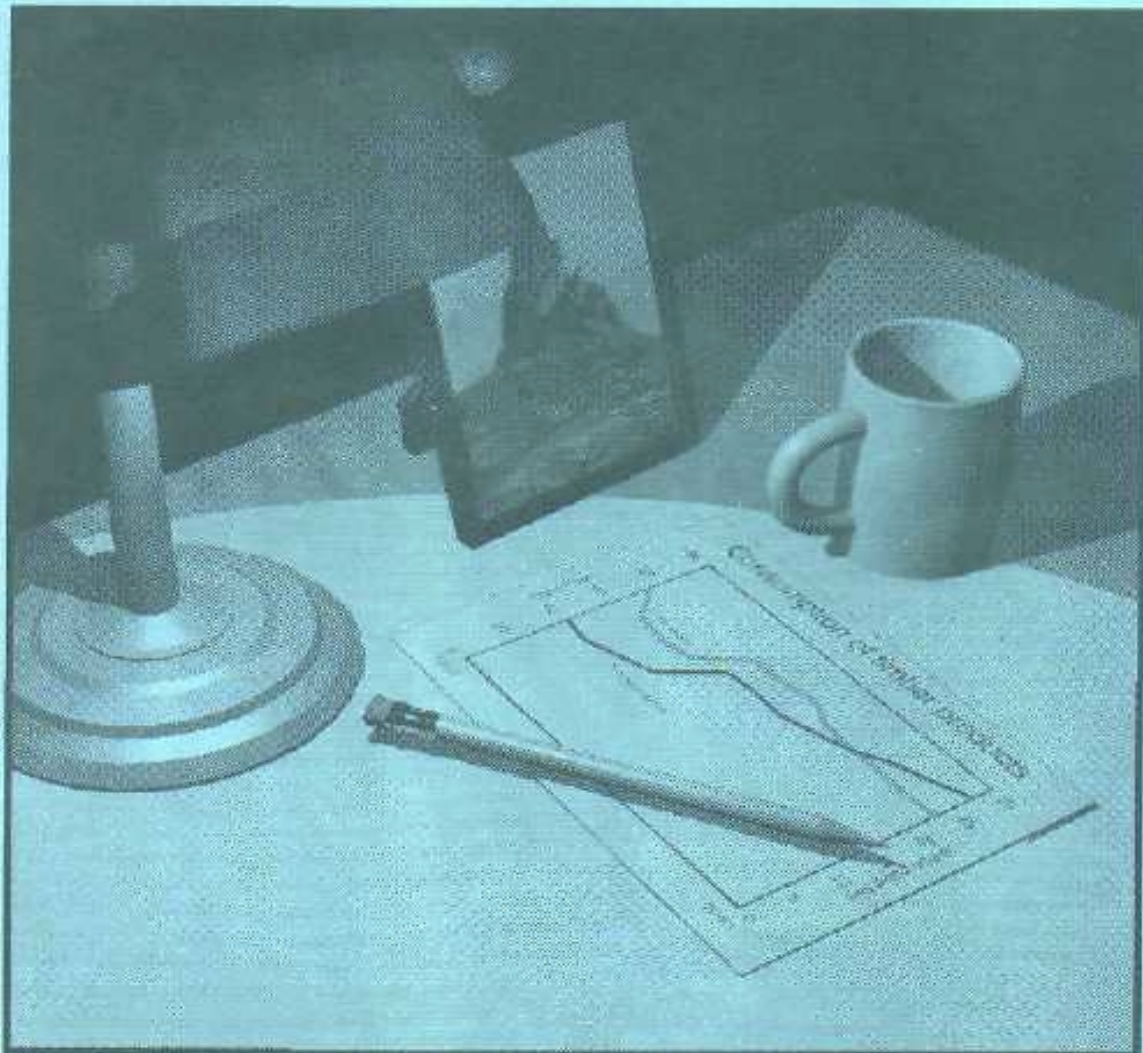
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The 1993 Timber Assessment Market Model: Structure, Projections and Policy Simulations

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Errata

This errata is to correct error made on page 16, fourth paragraph down:

Paragraph should read as follows:

Stumpage demand and product recovery and conversion—Given the constrained form of the production functions in equation (11), the derived demand for stumpage is simply (apply Hotelling's lemma to equation (15), π/pw),

$$d_p = \frac{Q_p^*}{r_{w,p}} \quad (20)$$

Abstract

Adams, Darius M.; Haynes, Richard W. 1996. The 1993 timber assessment market model: structure, projections, and policy simulations. Gen. Tech. Rep. PNW-GTR-368. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 58 p.

The 1993 timber assessment market model (TAMM) is a spatial model of the solidwood and timber inventory elements of the U.S. forest products sector. The TAMM model provides annual projections of volumes and prices in the solidwood products and sawtimber stumpage markets and estimates of total timber harvest and inventory by geographic region for periods of up to 50 years. TAMM and its companion models that project pulpwood and fuelwood use were developed to support the quinquennial Resource Planning Act (RPA) timber assessments and assessment updates conducted by the USDA Forest Service. This report summarizes the methods used to develop the various components of TAMM and the estimates of key behavioral parameters used in the TAMM structure, and also illustrates the use of TAMM with a base and several scenario projections.

Keywords: Forest sector models, supply, demand, prices, timber supply, RPA.

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Introduction

The 1993 timber assessment market model (TAMM) is a spatial model of the solidwood and timber inventory elements of the U.S. forest products sector (Adams and Haynes 1980, Haynes and Adams 1985). The TAMM model provides annual projections of volumes and prices in the solidwood products and sawtimber stumpage markets and estimates of total timber harvest and inventory by geographic region for periods up to 50 years. Projections of fiber products and fuelwood, which were part of the earliest TAMM model, are now derived from separate models linked to TAMM through demands for roundwood and residues.

TAMM and its companion models were developed to support the quinquennial Resource Planning Act (RPA) timber assessments and assessment updates conducted by the USDA Forest Service.¹ Over the past 15 years, TAMM has been used in four RPA assessments and updates and to provide projections in several special policy analysis projects conducted by the Forest Service (Haynes 1990, Haynes and Adams 1985, Haynes and others 1994, USDA Forest Service 1982). It also has been used by various public agencies, private firms, and environmental groups to examine issues ranging from log export policies to the impacts of carbon sequestration through tree planting. The acceptance of TAMM as a policy-analysis tool in the United States has served as a stimulus for similar research and applications in other countries.

The first version of TAMM reported in Adams and Haynes (1980) incorporated the basic spatial characteristics, two-tiered market structure, and product supply and stumpage sector representations of the current model but retained many aspects of the traditional analytical approach to long-term timber market projections used by the Forest Service. Revisions in subsequent years have updated the product demand, timber inventory projection, capacity, residue accounting, and hardwood lumber elements. This report documents the structure of TAMM as applied in the 1993 RPA timber assessment update. The next section, "Model Components," describes the behavioral relations used for elements of demand and supply, links to other models such as those for pulpwood and fuelwood, and model solutions, procedures, and operation of the timber inventory projection module using aggregate timberland assessment system (ATLAS) (Mills and Kincaid 1992). The third section, "Model Behavior in Simulations of a Historical Period," illustrates model behavior when used to simulate historical time periods. The fourth section provides examples of recent applications of TAMM to examine some key forest policy issues. A final section addresses changes in the TAMM structure planned for the future.

¹ 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, in the case of timber, is to analyze the timber resource situation to provide indications of the future cost and availability of timber products to meet the Nation's demand. The analysis also identifies developing resource situations that may be judged desirable to change and developing opportunities that may stimulate both private and public investments.

Model Components

TAMM IS comprised of two major parts (1) the market model portion that generates annual production, consumption, and price projections, as well as growing-stock inventory harvest requests, and (2) an inventory projection module derived from the ATLAS model that processes the harvest requests and updates inventories at periodic intervals. Flow of control in a TAMM run is shown in figure 1. Boldface names in the figure are routines or groups of routines that conduct specific computations as will be described below. After reading input and initializing key storage arrays, computations proceed sequentially through the routines listed in the "annual cycle" loop shown in figure 1. The annual cycle is repeated until the projection is complete.

Inventory Linkage

The NEWGRO routine provides the interface between the market module and the inventory module. Computational difficulties arise here because of the annual cycle of the market module and the periodic cycle (5 or 10 years depending on region) of the inventory module. NEWGRO approximately links the two time scales by means of a simple annual inventory identity

$$I_t = I_{t-1} + G_{t-1} - H_{t-1}, \quad (1)$$

where

I is growing-stock inventory at the start of year t and $t-1$,

G is estimated annual growth in year $t-1$, and

H is harvest in year $t-1$.

Starting with an initial value of inventory (I) from ATLAS, inventory in years between periodic ATLAS updates is computed by using equation (1) and an estimate of growth (G). NEWGRO cumulates annual harvests and, when a periodic ATLAS update year is reached, passes the cumulated cuts to ATLAS. ATLAS processes the harvest and passes an updated inventory back to NEWGRO, which resumes the inventory approximation process by using equation (1).

The value of G_{t-1} used in equation (1) is an estimate because periodic growth in ATLAS can be determined only when the inventory projection of a period is completed. Consequently, the annual inventory projection from equation (1) at the end of an ATLAS update cycle will differ from the updated inventory returned by ATLAS by some amount depending on the accuracy of the growth estimate. The "optional growth iteration cycle" shown in figure 1 resolves this problem. At the end of a projection, NEWGRO and ATLAS pass periodic harvests and inventories, respectively, to the routine ATLINK. ATLINK recomputes apparent growth for each period in the projection by rearranging equation (1) and feeds these revised growth estimates back to the input stream as shown in figure 1. The projection is rerun in this iterative fashion until the growth estimates, or some other convergence measure, differ by less than some user-specified tolerance between successive iterations. The cycle is optional, because for small changes in projection conditions, activating the cycle may have only modest impacts on the projection results.

Computational Tasks

To give a brief overview of the structure of TAMM, this section describes the computations performed in each routine in the annual cycle loop listed in figure 1.

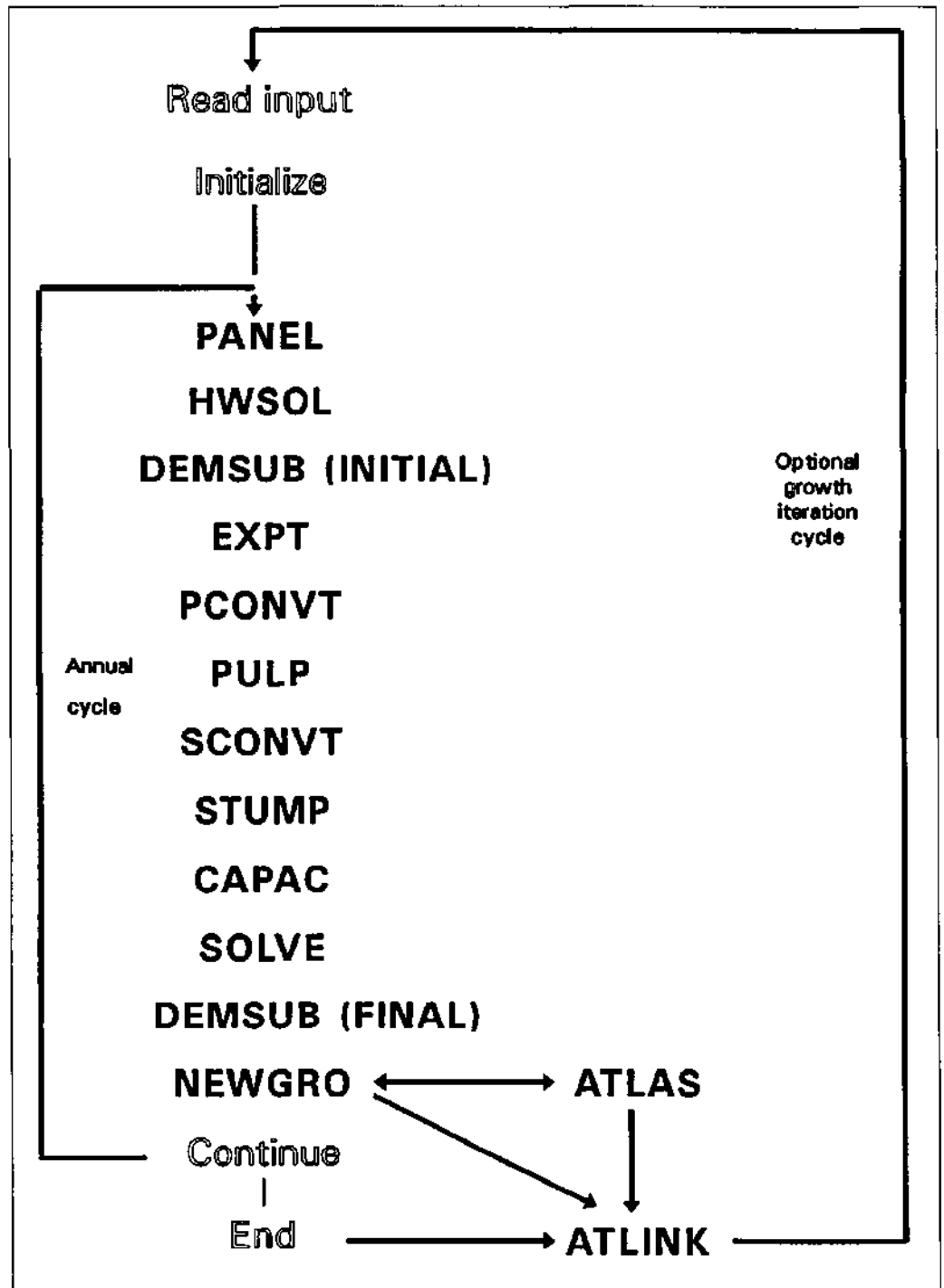


Figure 1—Flow of control in 1993 Tamm model (boldface names refer to computational routines described in text)

PANEL Establishes consumption, production, and trade of nonstructural panels (hardwood plywood, particleboard, hardboard, and insulating board). These products are not price-sensitive in TAMM, but their roundwood and residue fiber requirements are integrated with those from other endogenous products.

HWSOL Initializes and solves the hardwood lumber model

DEMSUB (INITIAL) Initializes the demand module for softwood lumber, softwood plywood, and OSB (oriented strand board). Demand relations are linearized and estimates developed for demand regions.

EXPT Establishes exogenous offshore demand quantities (exports) for softwood lumber, softwood plywood, and OSB

PCONVT Computes residue generation factors and other conversions essential for the fiber products-solidwood products interface.

PULP Receives pulpwood requests from the separate pulpwood model and monitors the production and use of residues.

SCONVT Computes conversion factors for the solidwood sector

STUMP Initializes sawtimber stumpage supply relations for both public and private ownerships, including delivered wood cost relations for the Canadian softwood lumber segment

CAPAC. Adjusts production capacity to the start of the current year in the softwood lumber, softwood plywood, and OSB markets based on the margin between gross revenue and variable production costs.

SOLVE Initializes the remainder of model equations, including product supply relations, and solves the softwood lumber, softwood plywood, and OSB markets.

DEMSUB (FINAL). Called a second time once the overall market solution is obtained to compute projections of consumption by end-use category for softwood lumber, softwood plywood, and OSB using equilibrium prices

Regions

For computations involving solidwood product supply and timber harvest, TAMM uses nine (9) regions in the United States and three (3) in Canada (fig. 2).² solidwood demand relations are developed for six (6) regions in the United States for softwood lumber, softwood plywood, and OSB (fig. 3).³ Canadian demand for these products is taken as exogenous. Only a single national demand relation is developed for hardwood lumber in the United States.

Supply regions include only the contiguous states. Consumption in Alaska and Hawaii is included in other demand regions. Inventory projections for Alaska are developed in other parts of the timber assessment process.

² Supply region names and acronyms are Pacific Northwest, West (PNWW) west side of the Cascade Range, Pacific Northwest, East (PNWE) east side of the Cascade Range, Pacific Southwest (PSW), northern Rockies (NR), Southern Rockies (SR), North-central (NC), Northeast (NE), South-central (SC), Southeast (SE), British Columbia coast (CBCC), Interior Provinces (CINT), and Eastern Provinces (CEST)

³ Demand region names and acronyms are Pacific Northwest (PNW), Pacific Southwest (PSW), Rockies (RK), North-central (NC), Northeast (NE), and South (SO)

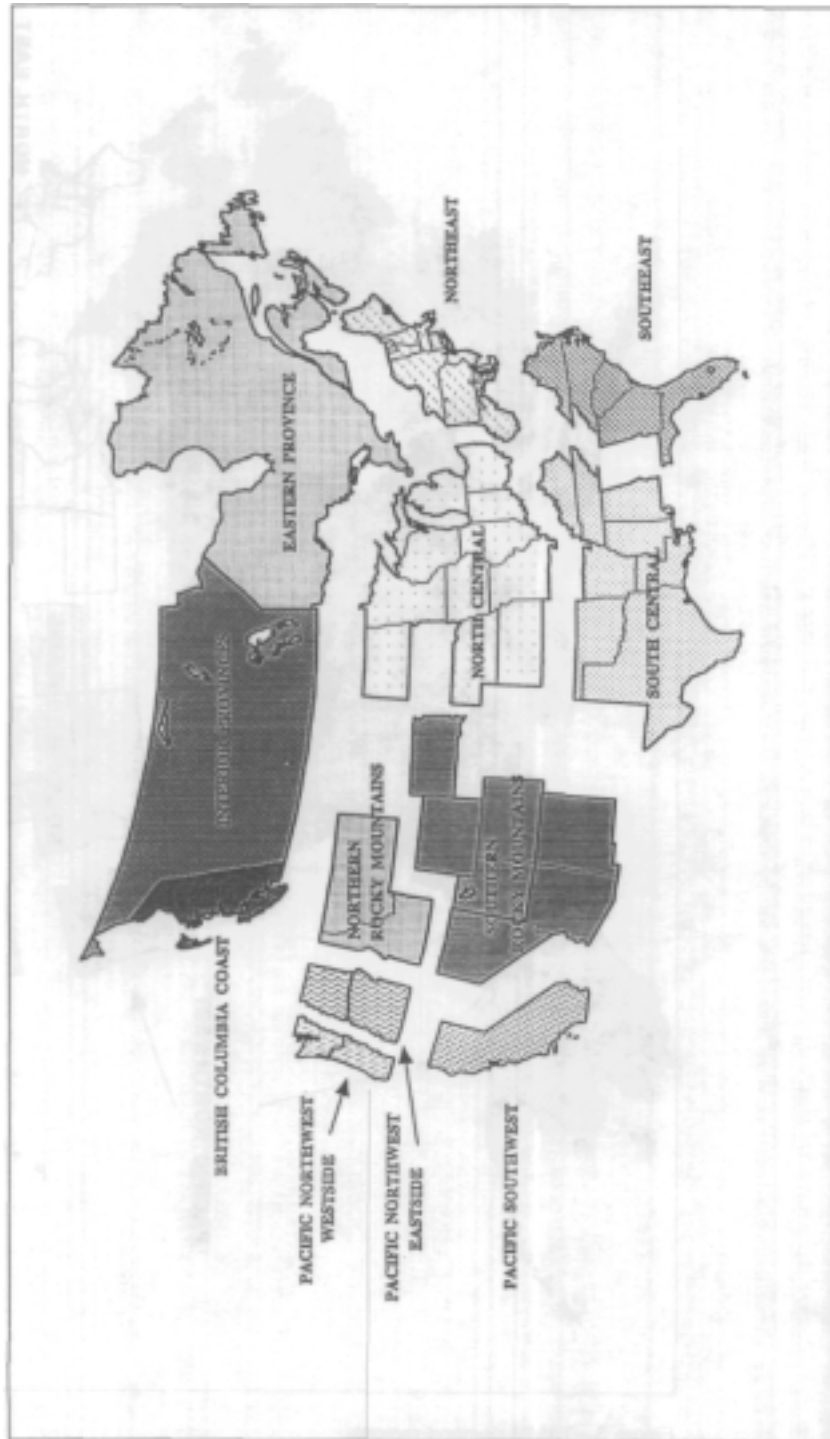


Figure 2—TAMM supply regions.

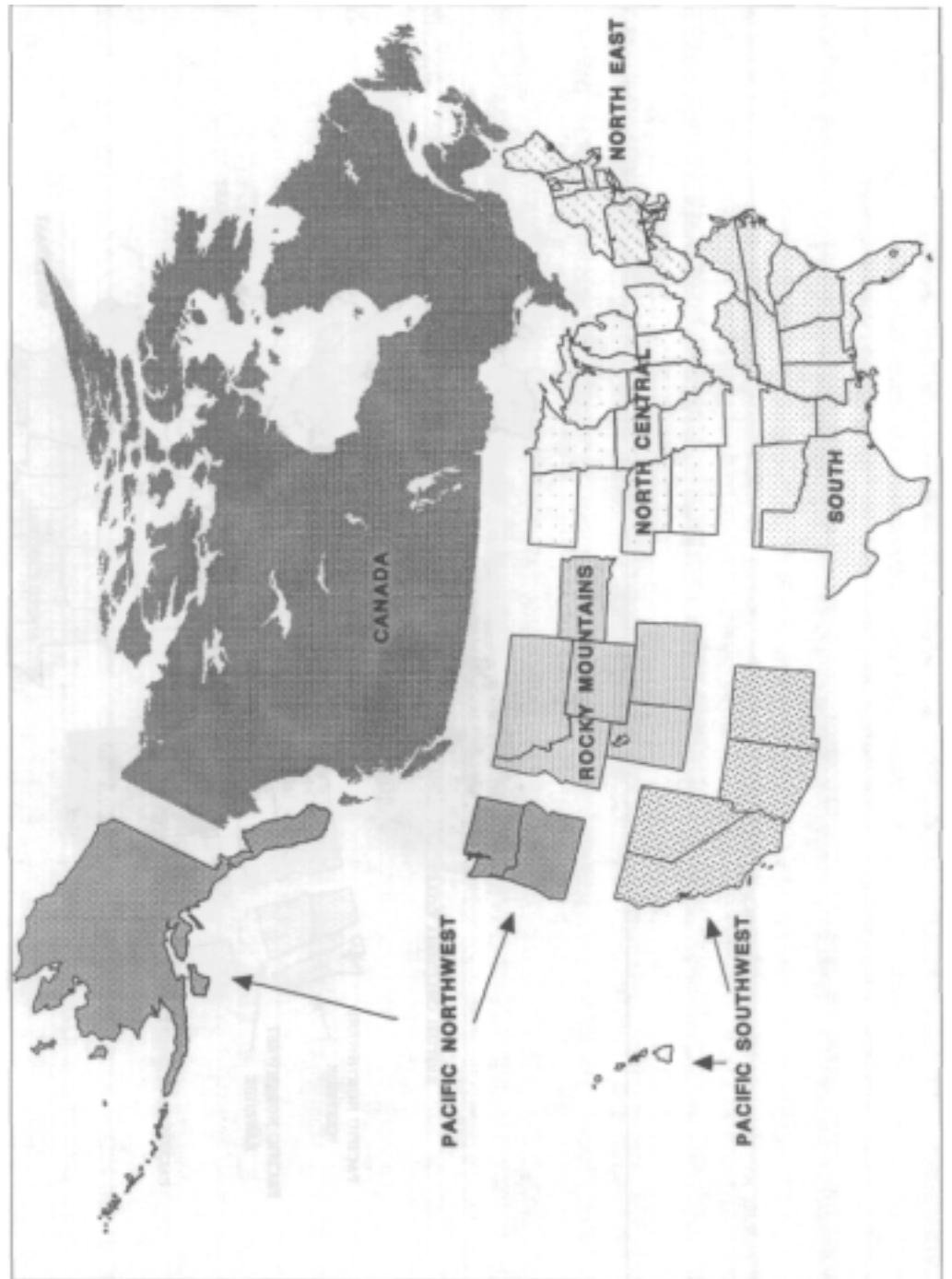


Figure 3—TAMM demand regions.

Softwood Solidwood Sector

The softwood solidwood sector includes softwood lumber, softwood plywood, and OSB. Although OSB uses both softwood and hardwood fiber in its manufacture, it is grouped with the softwood products because its principal substitute is softwood plywood.

Product demand—The demand module for softwood products is based on the technology diffusion models developed by Spelter (1984, 1985, 1992).⁴ In Spelter's approach, the market for a given product (p) is divided into m_p end-use categories (denoted by the subscript i so that $i = 1, \dots, m_p$). An end-use category is a specific industry or group of industries that uses product p as an input; for example, new residential construction. Total U.S. demand for product p (Q) is given by the following relations (time subscripts are deleted except where essential):

$$Q = \sum_{i=1}^{m_p} Q_i, \quad (2a)$$

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where

$$Q_i = \sum_{i=1}^{m_p} M_i U_i \quad (2b)$$

$$U_i = \bar{U}_i S_i, \quad (2c)$$

$$S_i = \exp\left(-\frac{b}{T_i}\right), \text{ and} \quad (2d)$$

$$T_i = T_{i-1} + \frac{P_{i,p,t} - P_{i,s,t}}{P_{i,s,t}} \quad (2e)$$

where

Q_i is the demand for end-use i,

M_i is a measure of output of the i th end-use category (for example, housing starts),

U_i is the consumption of product p per unit of output of end-use category i,

$\bar{U}_i$ is the maximum use of product p per unit of product i output,

S_i is the fraction of the maximum use of product p per unit of output of end-use category i,

b is a parameter to be estimated,

T is the cumulative price difference, and

$P_{i,p,t}$ and $P_{i,s,t}$ are prices (put-in-place) of product p and its substitute (s) in end-use category i in period t,

⁴ For an alternative derivation of demand models in "end-use factor" form based on a more traditional production theoretical approach, see Adams and others (1992).

For "mature" commodities such as lumber and plywood, $b < 0$, for new commodities such as OSB, $b > 0$. The cumulative relative price difference term, T , drives the substitution process. As the price difference between the solidwood product and its substitute rises (or persists over time), T grows. For lumber or plywood, this would reduce S and hence the consumption of the solidwood product.

The present model includes demand equations for the end-use categories shown in table 1. Most, but not all, of the relations are of the form shown in equation (2) (see Spelter 1985 for discussion of other forms used). The equations are too numerous to include a full tabulation of estimation results. In the aggregate, however, softwood lumber demand is highly inelastic⁵ with respect to its own price in the short term (annual elasticities average -0.07 during the 1980s) as is softwood plywood (annual elasticities average -0.09 during the 1980s with a rising trend after 1982 to -0.1 in 1989). The OSB demand elasticities averaged -0.59 during the 1980s, with a sharply declining trend (-0.826 in 1980 to -0.361 in 1989).

For lumber and plywood, these annual elasticities are one-quarter to one-fifth the magnitude of elasticities used in the first application of TAMM in the late 1970s (-0.35 for lumber and -0.3 to -0.4 for plywood, see Adams and Haynes 1980, p. 15-18). Demand models in the earliest versions of TAMM included no explicit intertemporal adjustment mechanism and were estimated by assuming constant demand parameters over a data sample ending in the early 1970s. The associated elasticities were interpreted as long-run or "equilibrium" levels. More recently, both Spelter (1985) and Adams and others (1992), using markedly different methods, have found evidence of steadily declining short-term (annual) demand elasticities for these products over the period since 1950. Thus, part of the difference between elasticities in the current and earlier versions of TAMM may relate to the sample period "averaging" inherent in earlier constant parameter econometric studies. In addition, earlier demand models were static and the elasticities were treated as the levels obtained after all consumption adjustments had taken place. The model of equation (2) includes an explicit adjustment process yielding, as would be expected, more elastic response for longer adjustment periods. Thus, for the aggregate of all end uses, both lumber and plywood demand elasticities rise by a factor of 2 to 3 over a 5-year period during a sustained own price change.

The prices employed in Spelter's model represent the costs of the solidwood and substitute products put-in-place.⁶ Since different types (grades and species) of lumber and plywood are used in the various end-uses categories, Spelter incorporated different price measures in some of the end-use demand relations to best represent the grade of product actually used. Softwood lumber is represented by the all softwood

⁵ If some economic variable y is determined by some other variable x as given by the functional relation $y = f(x)$, the *elasticity of y with respect to x* is defined as the percentage of change in y for a 1 percent change in x . The relation is said to be *inelastic* if the elasticity is less than 1, *unit elastic* if just equal to 1, and *elastic* if greater than 1.

⁶ Thus, for example, the price of lumber used in the 'single family dwelling walls' end use would include the cost of lumber and all other inputs needed to produce one unit of wall in a single family dwelling. This might be viewed as a composite input to the single family dwelling production process.

Table 1—End-use categories included in TAMM solidwood demand module for softwood lumber, softwood plywood, and oriented strand board (OSB)

End-use category	Softwood lumber	Softwood plywood	OSB	End-use output measure
Single-family dwellings (total)	X	X	X	
Framing	X			Floor area single starts
Sheathing (total)	X	X	X	Floor area single starts
Roof		X	X	Floor area single starts
Floor		X	X	Floor area single starts
Wall		X	X	Floor area single starts
Siding		X	X	Floor area single starts
Millwork	X	X		Floor area single starts
Basement	X			Floor area single starts
Multifamily dwellings (total)	X	X	X	Floor area multistarts
Mobile homes (total)	X	X	X	Floor area mobiles
Residential repair and alteration				Real expenditures residential repair and alteration
Nonresidential				Real value of nonresidential construction
Building	X	X	X	For buildings
Farm	X	X	X	For farms
Utilities	X	X	X	For utilities
+Miscellaneous	X	X	X	For all other
Shipping				Index of manufacturing production
Manufacturing				Index of manufacturing production
Pallets	X			Softwood pallet production
Furniture	X			Index of manufacturing production furniture
Ties				Total softwood the production
Other	X	X	X	

lumber producer price index (in most cases) and the price of ponderosa pine 1- by 12-inch boards (where board grades are important). Plywood is represented by prices of 1/2-inch CDX⁷ southern pine (delivered NE) and 1/2-inch CDX Douglas-fir. Only a single OSB price is used (7/16-inch delivered NE). Hardwood lumber uses the all hardwood lumber producer price index. In TAMM, however, all lumber and plywood species-grade prices in Spelter's original formulation are replaced by functions of their related producer price index. For example, the 1/2-inch CDX southern pine plywood price is replaced by a simple linear regression of the southern pine price on the all softwood plywood producer price index.

Linearization and regionalization—Spelter's model is too complex to incorporate directly in the TAMM spatial solution process, and it gives only national-level demand for solidwood products. To simplify the model, a linear approximation is developed in each year of the simulation at a set of projected product prices. Equations (2, a-e) can be written in general form as,

$$Q_p = Q_p(p_L, p_p, P_o, Z) \text{ for } p = L, P, O, \quad (3)$$

where

p_p are the national prices of lumber (L), plywood (P), and OSB (O), respectively, and Z is the set of all exogenous variables in the model.

Estimates of current period equilibrium prices for PL, PP, and Po are obtained by a simple linear extrapolation of prices in the previous two periods. Setting the exogenous variables to their current period values, equation (2b) is then linearized by using numerical methods to a form,

$$Q_p = a_p + a_{1,p}P_L + a_{2,p}p_p + a_{3,p}p_o \text{ for } p = L, P, O, \quad (4)$$

Regional demand equations are derived from the linearized national-demand relations in (4). Regional delivered product prices are linked to the national prices, PL, Pp, and Po by simple linear regressions of the form:

$$P_{p,r} = b_{o,p,r} + b_{1,p,r}P_p, \quad (5)$$

where

$p = L, P, O$ and $r = 1, \dots, n_r$, and

$p_{p,r}$ is the price of product p in region r, and

n_r is the number of U.S. demand regions.

⁷ CDX is common grade of exterior plywood with C-grade and D-grade veneer faces suitable for application in exterior uses.

Regional shares of national consumption for product p are derived from exogenous projections of regional per capita consumption trends and regional population as:

$$S_{p,r} = \left(\frac{Q}{N}\right)_{p,r} N_{p,r}, \text{ and} \quad (6)$$

$$Q_{p,r} = S_{p,r} Q_p, \quad (7)$$

where

$s_{p,r}$ is region r's share of national consumption of product p,

$(Q/N)_{p,r}$ is projected per capita consumption of product p in region r,

$N_{p,r}$ is projected population in region r, and

$Q_{p,r}$ is consumption of product p in region r.

Substituting equations (4)-(6) into (7), regional demand equations can be written as follows:

$$Q_{p,r} = S_{p,r} \left[a_p + \sum_{k=L}^o a_{k,p} \left(-\frac{b_{0,k,r}}{b_{1,k,r}} + \frac{1}{b_{1,k,r}} p_{k,r} \right) \right], \quad (8)$$

The elasticity of regional $\frac{\partial Q_{p,r}}{\partial p_{p,r}} \frac{p_{p,r}}{Q_{p,r}} = s_{p,r} \left(\frac{a_{p,p}}{b_{1,p,r}} \right) \frac{p_{p,r}}{Q_{p,r}}, \quad (9)$

Replacing the region $e_{p,r} = \left(\frac{p_{p,r}}{Q_{p,r}} \right) \left(\frac{\partial Q_{p,r}}{\partial p_{p,r}} \right) = \left(\frac{p_{p,r}}{Q_{p,r}} \right) e_p, \quad (10)$

$$e_{p,r} = \left(\frac{p_{p,r}}{p_p b_{1,p,r}} \right) \left(\frac{\partial Q_p}{\partial p_p} \frac{p_p}{Q_p} \right) = \left(\frac{p_{p,r}}{p_p b_{1,p,r}} \right) e_p, \quad (10)$$

where

$e_{p,r}$ is the region r own price demand elasticity for product p, and

e_p is the national own price demand elasticity for product p.

Thus the relation of the regional and national elasticities is proportional to the regional-national price ratio.

Product supply relations and capacity adjustment—In Forest Service timber assessment projections, trends in the technology of wood products processing and logging are treated by using specific scenarios or projections of future technical developments. Wood use efficiency 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 product supply

relations, we assume a constrained form of the production process. Product output is obtained in fixed proportions to log input (the product recovery factor linkage) but in variable proportions to all other factors. Assuming quasi-fixed capital inputs, the production function for a specific product would appear as,⁸

$$Q = \min [r_w W, f(X_1, X_2, \dots, X_n, K)], \quad (11)$$

where

Q is output,

r_w is the product recovery factor for logs,

W is log input,

X_i for $i = 1, \dots, n$ are nonwood variable inputs, and

K is capital.

The function f can be viewed as an aggregator function for the other inputs, and the two groups of factors, W and (X_i, K) , are weakly separable.

If $P = [p_w, (P_1, \dots, P_n)]$ is the set of prices of wood and other inputs, the cost function for the production function in equation (11) can be shown to be,

$$C(p, Q) = C_w(p_w, Q) + C_o(p_1, \dots, p_n, Q, K), \quad (12)$$

where

C_w is the cost function for the wood input and is,

$$C_w(p_w, Q) = p_w \left(\frac{Q}{r_w} \right), \quad (13)$$

⁸ A production function is a relation describing the conversion of various inputs into outputs in the production process. Inputs, also called productive factors, in broadest terms may be classed as labor, raw materials (such as logs), capital (including physical production facilities and machines as well as the technique embodied in the process itself), land, and so on. A factor is said to be variable over some time period if the level or amount of its use in production can be freely varied. A factor is said to be quasi-fixed if its level cannot be readily varied in the short term. Groups of factors are said to be separable in a production process if the production process can be thought of as occurring in separate stages that are then brought together to produce the final product. Changing the levels or mix of inputs in stage 1 would impact the output of stage 1 and perhaps the output of the overall production process as well but not the mix or levels of inputs of stage n. This is a strong form of input separability. A weaker form, and one sufficient for the purposes noted in the text, is that changes in stage 1 might influence the levels of inputs (and hence output) of stage n but not the relative mix of inputs.

and C_o is the cost function for all other inputs. Chambers (1988) shows that the profit function can be written as follows:

$$\Pi(p, P, K, Q^*) = PQ^* - C_w(P_w, Q^*) - C_o(p_1, \dots, p_n, Q^*, K) \quad (14)$$

where

P is product price,

Q^* is optimal output.

Thus the supply function can be found by Hotelling's lemma (see Chambers (1988) for definition and discussion of the lemma) from,

$$\frac{\partial \Pi}{\partial P} = P \frac{\partial Q^*}{\partial P} + Q^* - \frac{\partial C_w}{\partial Q^*} \frac{\partial Q^*}{\partial P} - \frac{\partial C_o}{\partial Q^*} \frac{\partial Q^*}{\partial P} = Q^* \text{ or} \quad (15)$$

$$P = \frac{\partial C_w}{\partial Q^*} + \frac{\partial C_o}{\partial Q^*}, \quad (16)$$

We normalize the profit and cost functions by the price of one of the inputs (see discussion below) and assume that C_o can be represented by the (normalized, restricted) quadratic form (see Chambers (1988) for definition and discussion of functional forms),

$$\begin{aligned} C_o(p_1, \dots, p_n, Q, K) = & b_o + \sum_i b_i p_i + \frac{1}{2} \sum_i b_{ii} p_i^2 + \sum_i b_{ik} p_i K \\ & + \sum_i b_{iQ} p_i Q + b_Q Q + b_K K \\ & + \frac{1}{2} b_{KK} K^2 + \frac{1}{2} b_{QQ} Q^2 + b_{KQ} KQ. \end{aligned} \quad (17)$$

Using equations (13) and (17), in equation (16) we obtain, after some simplification, an expression for the supply function,

$$Q^* = -\frac{b_Q}{b_{QQ}} + \frac{1}{b_{QQ}} \left(P - \frac{P_w}{r_w} - \sum_i \frac{b_{iQ}}{b_{QQ}} p_i - \frac{b_{KQ}}{b_{QQ}} K \right) \text{ or} \quad (18)$$

$$Q^* = a_0 + a_p \left(P - \frac{P_w}{r_w} \right) + \sum_i a_i p_i + a_K K. \quad (19)$$

In estimation we assume that residues in lumber and plywood production are generated in fixed proportion to output and hence add residue revenues per unit output to product price in the term in parentheses in equation (19). Nonwood variable factors are separated into two groups: a first, readily measurable set, comprising direct labor,

energy, and certain other materials and services, and a second set of all other variable inputs. The first group is treated as a composite input, and its aggregate price is measured as the average cost of the set of factors per unit output. The second group used as a numeraire is also a composite input. Its price is assumed to be measured by the all commodity producer price index.

Capital is the aggregate of all buildings, machinery, and production organization methods used in the milling process. Studies of production typically construct some real value measure of the stock of structures and machinery to represent capital input, assuming capital services are proportional to stock. In TAMM, capital is measured by an estimate of output capacity, which might be viewed as the maximum service level obtainable from the capital stock. Capacity data are derived from a combination of estimates by industry associations and from production, price and, cost data by using a modified form of the "trends through peaks" method.⁹

Estimation results for equations used in the 1993 timber assessment are shown in table 2, including price and cost elasticities, capacity coefficients, and adjusted coefficients of determination from regressions.¹⁰ Lumber and plywood equations were estimated by using two-stage least squares, with the exception of the NC and NE lumber relations, which were estimated with simple ordinary least squares (OLS). Given the paucity and poor quality of price and cost data available for these latter regions, we view these equations as only the roughest of estimates. The OSB equations were estimated with three-stage least squares for the United States and Canada as aggregates. Direct estimation of regional OSB supply equations was not attempted given the limited number of observations. Regional equations were derived by scaling the national relations using proportions of total (U.S. or Canadian) capacity at the start of each period. Thus regional and national OSB supply elasticities are identical.

⁹ In the usual "trends through peaks" method, capacity is identified as the name implies by simple straight line trends through peak output levels. Our approach uses output prices and operating margin (gross revenue less variable costs) to identify key points on the capacity time path. For example, periods when output approaches capacity are identified by peaks in the basic output series and also by peaks in price and operating margin. Just as critical are the points where capacity expansion is reinitiated after periods of stability or decline. Here again increases in operating margin, even with a continued decline in output, help to identify such points.

¹⁰ For comparative purposes, the direct price elasticities of softwood lumber and plywood supply from the 1980 version of TAMM were as follows:

Region	Elasticities	
	Lumber	Plywood
PNWW	0.21	0.43
PNWE	60	98
PSW	23	2.17
Rockies	35	97
SC	79	92
SE	31	85
Canada	47	

Table 2—Estimation results for softwood lumber, softwood plywood and OSB products supply equations: lumber and plywood estimates using 2SLS, OSB using 3SLS, and elasticities calculated at mean values of estimation sample

	Supply elasticities			
Region	Product price	Nonwood cost	Capacity coefficient	Adjusted R ²
Softwood lumber				
PNWW	0.335	-0.204	0.865	0.57
PNWE	.586	-.227	.712	.67
PSW	.794	-.311	1.756	.81
NR	.866	-.456	.801	.75
SR	.395	-1.077	.718	.68
NC ^a	.848	-.265	.619	.61
NE ^a	.188	-.202	1.446	.82
SC ^b	.937	-.552	.665	.87
SE ^b	.963	-.456	.610	.88
BCC ^c	.935	-.993	1.639	.77
CINT ^b	.447	-.260	.966	.97
CEST	.492	-.405	.947	.97
Softwood plywood ^c				
PNWW	.748	-1.144	.956	.90
PNWE	.444	-.118	.704	.89
PSW	1.120	-1.691	.691	.92
NR ^d	.600	-1.000	.585	.94
SC	.395	-.782	.819	.96
SE	.343	-.806	.776	.96
Oriented strand board ^e				
United States	.512	-.208	.872	.99
Canada	.433	-.192	.946	.98

^a NC and NE estimated with OLS, data samples 1951-89 and 1960-89, respectively.

^b Estimation sample for SC and SE 1951-89, all other regions 1956-89.

^c Estimation samples: PNWW, PNWE, and PSW 1951-89, NR 1957-89, and South 1968-89.

^d NR estimates constrained to elasticities shown for both price and nonwood cost coefficients.

^e Estimation sample 1976-89 for both regions.

Capacity is projected by using a two-stage process.

1. Initial estimates of capacity change, or net investment in capacity, are derived from a set of regional adjustment equations. These relations use an accelerator structure in which change in capacity is a distributed lag in past changes in output ¹¹ We experimented with both finite lag structures by using the polynomial distributed lag approach and with exponential, Koyck-type schemes. Forms of the final equations differ across regions depending on which approach provided the best explanation of historical behavior.

2. Projections from the capacity equations are then adjusted for anticipated operating margin performance. A naive estimate of expected operating margin is developed from the average margin over the past three years. This is compared to a "target" or minimum acceptable margin. If expected margin is higher than the target, projected capacity increments are increased or projected decrements are reduced by preset fractions. If the expected margin is below the target, decrements are increased or increments are reduced. An upper bound on the absolute level of capacity change also is imposed. Because our basic cost and price data differed from region to region in the breadth and specificity of costs and products covered and because the quality mix of products differs across regions, we varied margin targets by region rather than establish a single national target for a product.

This second-stage adjustment was included to mimic the effects of competition, forcing capacity migration into (or out of) regions that realize high (or deficient) margins over long periods. Ensuring this behavior at the product market level was particularly critical if we were to obtain reasonable long-term stumpage price projections at the regional level.

Stumpage demand and product recovery and conversion—Given the constrained form of the production functions in equation (11), the derived demand for stumpage is simply (apply Hotelling's lemma to equation (15), $\partial Q_p / \partial p_w$),

$$d_p = \frac{Q_p^*}{r_{wp}}, \quad (20)$$

where

d_p is the derived demand for stumpage for product p , and

r_{wp} is the recovery factor for product p .

¹¹ An accelerator structure is a model in which capacity change is driven by levels or changes in past output. A distributed lag relation between a variable y and a "causal" variable x would have the general form $y = a_0x_t + a_1x_{t-1} + a_2x_{t-2} + \dots$. The variable y is determined by a weighted summation of various time lags of x (potentially an infinite number of past values). The coefficients a_0, a_1, a_2 , and so on can be fixed values or functions of other variables. The time patterns of these coefficients (and their methods of construction or estimation) give rise to their names: a polynomial form (for example, where the a_i varies as a quadratic in the length of the lag) is called a polynomial lag, one that declines exponentially with the length of lag an exponential lag structure.

For OSB, the roundwood-residue and softwood-hardwood mixtures also are pre-specified as part of the recovery process. In all cases, stumpage volume is measured in cubic feet.

Product recovery data are not collected or reported on a systematic basis for any of the softwood products. Historical estimates used in TAMM are intended to represent *regional average* recovery experience and are derived from industry association and public agency sources, often with extensive adjustments for consistency of units of volume and types of milling processes. Historical recovery data for softwood lumber and plywood are shown in figures 4 and 5. Projections of future recoveries, as noted above, are derived in other portions of the timber-assessment process.

As sawtimber is harvested and processed for lumber and plywood, various residues are generated in woods and mills. TAMM contains an array of relations to account for these residues and their use. Estimates of residues generated in milling (see discussion in a later section for estimates of logging residues) are driven by projections of product recovery, size of logs processed, and the size mix of products produced. TAMM's development of factors for estimating residue generation and product conversion is summarized in the following relations:

$$\begin{aligned} OR &= \frac{RF}{BFCF} \\ R\% &= 1 - (RF)(PVF) \\ RGF &= R\% \left(\frac{RWF}{RF} \right), \end{aligned} \tag{21}$$

where

OR is Scribner log scale "overrun" used in converting sawtimber stumpage prices to a product output basis (product units per board foot, log scale, Scribner rule),

RF is the product recovery factor (product units per cubic foot, log scale),

BFCF is the board-foot per cubic foot scaling conversion for logs (board foot, log scale, Scribner per cubic foot, log scale),

R% is the residue fraction, the proportion of logs processed that is left as wood residue of all types (cubic foot, residue per cubic foot, log scale of logs processed),

PVF is the product volume factor, the solid wood volume per unit of product produced (cubic foot, solid wood per product unit),

RGF is the residue generation factor per unit of product output (bone dry tons or green tons per product unit), and

RWF is the residue weight factor, the weight in tons of a cubic foot of wood residue (bone dry or green tons per cubic foot, residue).

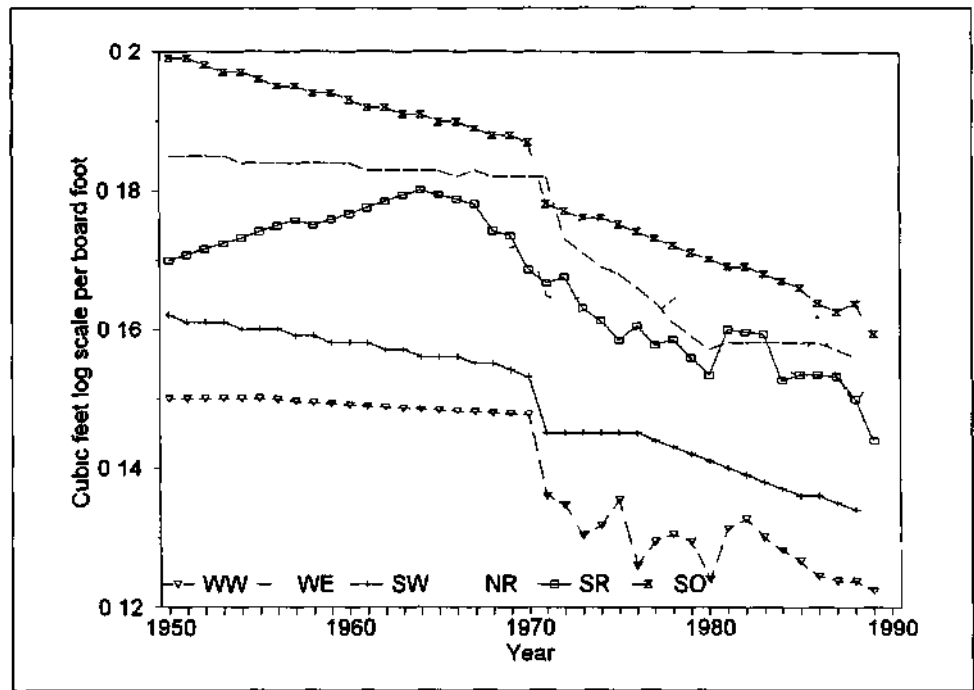


Figure 4—Softwood lumber recoveries by region 1950-89

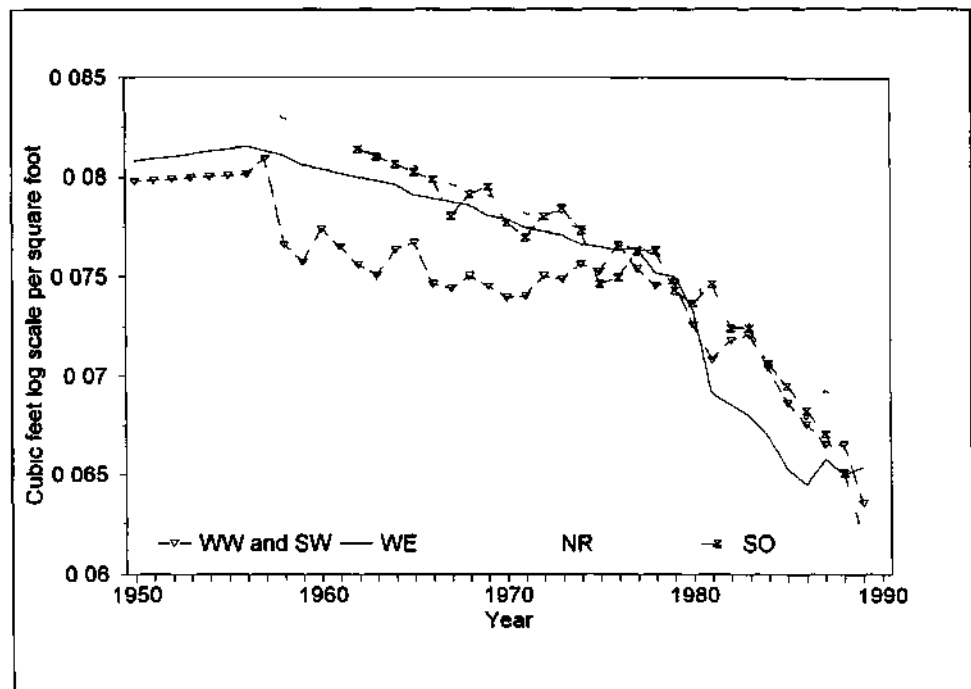


Figure 5—Softwood plywood recoveries by region 1950-89

The BFCF depends on the average size of logs processed. The PVF differs with the mix of product sizes and qualities produced (for example, dimensions of lumber, such as 2 by 4 inches or 2 by 12 inches, and amounts that are produced green and dried and thickness of plywood sheets) and with standards defining nominal versus actual product dimensions (for example, a nominal dry 2-by 4-inch board under current standards is actually $1\frac{1}{2}$ by $3\frac{1}{2}$ inches). The RWF differs with the mix of species processed. In the West, residues are customarily measured on a bone dry ton basis, whereas in the South, green tons are used. The process described above is intended to estimate total wood residue production. Additional adjustments of RWF are applied to estimate portions usable for pulping and reconstituted panels.

Public and private stumpage supply—Total timber harvest in TAMM is divided between sawtimber and nonsawtimber classes based on the product for which the harvested timber is used.¹² Sawtimber includes timber harvested for lumber, plywood, miscellaneous products and saw-veneer log trade; nonsawtimber includes fiber for reconstituted panels, pulpwood and fuelwood. TAMM includes models of public and private sawtimber stumpage supply in the United States and delivered saw-log costs in Canada. Pulpwood supply equations for the United States and Canada and behavioral relations for fuelwood supply from standing timber are included in the pulpwood and fuelwood models. These supply relations are linked to the sawtimber relations in TAMM by means of timber inventories and prices through an iterative solution process described in a later section. Supplies of timber for reconstituted panels are treated as a perfectly inelastic portion of the aggregate nonsawtimber supply.

Public supply—In the PNWW, PNWE, PSW, NR, and SR regions, the National Forest component of public timber supply (the volume harvested in the current period) is treated as price sensitive. Supplies from all other public agencies in the Western United States, and from all public lands in the Eastern United States, are treated as fixed (price inelastic). The Western National Forest supply process comprises five elements: volume sold, bid price, harvest price, volume harvested, and the uncut volume under contract.¹³ The volume sold is assumed to be equal to the volume offered. Because our focus here was exclusively on sawtimber, the sold volume is equivalent to the Forest Service's allowable sale quantity (ASQ). Nonsawtimber volumes (the difference between total product sale quantity, TPSQ, and ASQ) are treated as price inelastic.

Bid price is modeled as a simple linear function of lagged softwood lumber price.¹⁴ We experimented with various alternative forms to better capture the expectational structures that must play a key role in the bidding process. None proved as robust to errors in "input" or provided equivalent historical explanatory power within the TAMM structure as this simple naive model.

¹² The term sawtimber also is used in Forest Service inventory statistics to denote trees of certain size and quality characteristics, but these distinctions are not used in TAMM.

¹³ See Adams and Haynes (1989) for a detailed discussion and model of the National Forest timber supply process in the Western United States.

¹⁴ This approach follows Cardellicchio and others (1988).

The volume of timber harvested is determined by a "supply" relation drawn from Adams and others (1992):

$$\frac{CUT_t}{UCV_{T-1} + SOLD_t} = \alpha_0 + \alpha_1(CP_t - \sum_{i=0}^{L_{MAX}} W_i BP_{t-i}), \quad (22)$$

where

CUT_t is the harvest volume in period t ,

UCV_{t-1} is the uncut volume under contract at the end of period $t-1$,

$SOLD_t$ is the volume sold during period t ,

CP_t is the average price of timber harvested (the harvest price) during period t ,

L_{MAX} is the age of the oldest sale remaining unharvested in period t (taken as a constant),

W_i is the (assumed fixed) proportions of the uncut volume under contract remaining in sales of ages from 0 (just sold) to L_{MAX} years, and

BP is the average bid price for timber sold during period t .

We assumed a competitive regional market in timber for immediate harvest. Thus CPT is also the average regional price for timber for immediate harvest across all ownerships. As CPT rises relative to the average cost of timber in the uncut backlog, the fraction of the adjusted uncut volume that is harvested also rises.¹⁵

Finally, the uncut volume under contract is updated by a modified inventory relation:

$$UCV_t = \beta_u UCV_{t-1} + \beta_s SOLD_t - \beta_c CUT_t, \quad (23)$$

where the β 's differ from 1 in several regions owing to errors and adjustments in the timber sale and execution process.

Private supply— Private timberland owners are divided into forest industry and non-industrial groups based on integration of the owner with wood or fiber products processing facilities. When TAMM was first developed in the late 1970s, this split was thought to provide a rough distinction between the broad objectives for holding timberland as well: industry owners being primarily concerned with present value maximization, whereas the objectives of nonindustrial owners might include various nontimber or amenity concerns in addition to wealth maximization. Developments over the past 15 years suggest that a further division within the nonindustrial group would now be appropriate, with an "industrylike" group to represent the growing number of non-integrated owners that hold timberland purely as an investment, and a "miscellaneous" group to represent the traditional farm and diverse other private owners with a more heterogeneous set of ownership objectives. Unfortunately, sufficient data on timber harvest and timber inventory using this more detailed categorization are not available. Including the 1980s in the estimation sample with the old owner classification scheme,

¹⁵ Adams and Haynes (1989) and Adams and others (1991) present two complementary rationales for this behavior.

however, leads to several problems. For example, in some regions there seems to be a shift in behavior of the nonindustrial group after 1980, with a marked increase in price responsiveness. Although we believe that changing ownership composition was the cause of this shift, we have few ways to test this supposition.

As noted above, we assumed that forest industry owners act as present value maximizers. Following Ovaskainen (1992), a simple two-period representation of the industrial owner's intertemporal harvest optimization problem would be,

$$\max_{\{C_t\}} P_1 C_1 + (1+r)^{-1} P_2 C_2$$

subject to

(24)

$$C_2 = I_0 + g(I_0 - C_1) - C_1$$

where

C_t is harvest in period t ,

P_t is stumpage price in period t ,

r is the discount rate,

I_0 is initial inventory, and

g is the growth function of residual inventory, $g' > 0$, $g'' < 0$.

Assuming constant future price expectations ($P_2 = P_1$), the formulation in equation (24) yields a current (first) period timber harvest function that depends on price, inventory, and the discount rate:

$$H = H(P, I, r) . \quad (25)$$

Assuming all else constant $H_p > 0$, $H_I > 0$, and $H_r > 0$.

Nonindustrial owners were assumed to be intertemporal utility maximizers who derive benefits from (1) the consumption of goods purchased with income earned either selling timber or from other "nonforest" sources, and (2) the standing stock of timber itself. Again, following Ovaskainen (1992), a simple, two-period version of the typical owner's intertemporal maximization problem can be written as,

$$\max_{\{G_1, G_2, C_1, C_2\}} U(G_1) + V(I_1) + (1+\delta)^{-1} (U(G_2) + V(I_2))$$

subject to:

where

$$\begin{aligned} I_1 &= I_0 - C_1 \\ I_2 &= I_1 + g(I_1) - C_2 \\ G_1 &= P_1 C_1 + M - S \\ G_2 &= P_2 C_2 + (1+r)S, \end{aligned} \quad (26)$$

δ is the owner's rate of time preference,

I_0 , I_1 , and I_2 are inventories at times 0 (given), 1, and 2,

C_1 and C_2 are harvests in periods 1 and 2,

M is exogenous nonforest income,

P_1 and P_2 are exogenous prices of stumpage in periods 1 and 2,

S is period 1 savings, and

r is the exogenous earnings rate on savings.

We assumed an additively separable utility function both over time and between commodities and noncommodities.¹⁶ The utility functions for commodities, U , and non-commodities, V , are assumed to display positive but diminishing marginal utilities so that V and $U' > 0$, and V'' and $U'' < 0$. Noncommodity benefits are assumed to derive from the stock of timber, I_1 and I_2 , in each period after harvest. Only G_1 , C_1 , and C_2 need be considered in the optimization, because S can be replaced by a function of C_1 and G_1 . G_2 is then a function of G_1 , C_1 , and C_2 and the inventory terms depend only on the C_1 and C_2 . Finally, the growth function, g , has the same properties as assumed in the industrial case.

Solution of the problem in equations (26) yields a first period harvest function dependent on the P , r , M , initial inventory (I), and the unobservable δ . Dropping the latter and assuming constant future price expectations ($P_2 = P_1$), we have,¹⁷

$$H = H(P, I, M, r), \quad (27)$$

We implemented these theoretical developments by using a partial adjustment form of the supply relation in which the elasticity of harvest with respect to inventory is constrained to unity for both owners:

$$\begin{aligned} \frac{H}{I} &= H\left[P, r, \left(\frac{H}{I}\right)_{t-1}\right] \text{ for industrial owners and} \\ \frac{H}{I} &= H\left[P, r, M, \left(\frac{H}{I}\right)_{t-1}\right] \text{ for nonindustrial owners,} \end{aligned} \quad (28)$$

and the functions H are linear in arguments. The inventory elasticity restriction limited the generality of our results but resolved significant collinearity problems between the inventory, price, interest rate, and income terms. The forms in (28) also have proven to be quite powerful in explaining historical harvest behavior across all regions. Stumpage price elasticity results are shown in table 3.

¹⁶ See our previous definition of separability in the case of the production function. In this case the function is strongly separable in consumption and investments in the two time periods. Aggregate utility over the full two-period time horizon is obtained by summing contributions from the two periods.

¹⁷ Comparative statistics using the first order conditions from optimization of (26) reveal that $HM < 0$ and $H_I > 0$, but the expected signs of H_P and H_r cannot be unambiguously determined.

Table 3—Stumpage price elasticities of private timber supply by U.S. region computed at sample period averages

Region	Industrial	Nonindustrial ^a
PNWW	0.440	0.416
PNWE	.169	.402
PSW	.436	.145
NR	.247	.180
SR	.784	.513
NC	.283	.672
NE	.340	.310
SC	.321	.290
SE	.193	.288

^a Sample periods for PNWW, PNWE OP, PSW OP, NR, SC, and SE 1951-89; PNWE FI, SR, and NE FI 1975-89; NC and NE FI 1960-89; SW FI 1970-89

Significant strides have been made in recent years in assaying the Canadian timber resource and modeling the costs of timber extraction (see for example, Messmer and Booth 1993, Williams 1991). Although these new tools hold much promise for future use in an expanded model, TAMM at present employs a highly simplified scheme for modeling the cost of wood delivered to Canadian lumber mills. A log-linear regression is used to link historical delivered wood cost and the volume of wood consumed at lumber mills in each of the three Canadian regions (volumes are in cubic feet, log scale, costs in real \$C per MCF). In projections, these relations are shifted according to externally generated scenarios of future Canadian allowable cut policies and cost developments. The Canadian relations enter TAMM in the same way as do the private U.S. timber supply equations, and delivered wood cost is determined simultaneously with other endogenous prices and quantities. The elasticities for delivered logs in the three Canadian regions (at lumber mills for the period 1980-90) are 1.217, 0.668, and 1.330 for CBCC, CINT, and CEST, respectively.

Hardwood Solidwood Sector

Hardwood lumber is the only hardwood solidwood market treated as price-endogenous in TAMM. Hardwood plywood is projected in the nonstructural panels segment discussed below, and miscellaneous products are projected outside the model. Timber requirements for these latter products are incorporated as fixed demands in the hardwood sawtimber demand relations.

General hardwood lumber model—The general structure of the hardwood lumber model is described in the following simplified relations:

$$\begin{aligned}
D &= \sum_e D_e(P) \\
S &= \sum_r S_r(P, p_r) \\
D &= S \\
d_r &= c_r S_r + O_r \\
s_r &= s_r^P(p_r) + s_r^G \\
s_p &= d_r,
\end{aligned} \tag{29}$$

where

D and D_e are total U.S. hardwood lumber demand and demand in end-use e in board feet (export demand is also included here);

P and p_r are national average lumber price (real dollars per thousand board feet lumber tally) and regional sawtimber stumpage price (real dollars per thousand board feet) in region r ;

S and S_r are total U.S. supply and supply from region r in board feet (import supply is also included here);

d_r is sawtimber stumpage demand (in cubic feet) in region r ;

c_r is region r lumber recovery factor;

s_r , s_r^P and s_r^G are total, private and government sawtimber supply in region r , and

O_r is output of other sawtimber products (plywood and miscellaneous products) in region r ;

The model is nonspatial with a single U.S. demand relation (the aggregate of all end uses and exports) and price-sensitive supply relations for each of the Eastern regions (supply from Western regions and external trade flows are fixed and projected outside the model). We retain the fixed coefficients stumpage conversion assumption of the softwood segment, so regional lumber supply is converted directly to sawtimber stumpage demand. Total regional sawtimber supply is the sum of a price-sensitive private component and a fixed public component.

Although hardwood lumber was estimated to comprise some 20 to 25 percent of total U.S. lumber production and is the principal lumber species in some portions of the Eastern states, econometric modeling of the market has been limited.¹⁸ Data limitations are a primary reason for this lack of research. Binkley and Cardellichio (1986) and, more recently, Luppold and Dempsey (1989) have demonstrated the problems in basic hardwood lumber-production data as reported by the Department of Commerce. In addition, there is little information on production and logging costs, and stumpage price data of acceptable quality are available only for recent years in the South. Given this paucity of data, most past studies have employed markedly simplified structures of the market and a similar tack is taken in TAMM.

¹⁸ Binkley and Cardellichio (1986) describe the most recent publicly reported effort and summarize previous research.

Hardwood lumber demand—Eight end-use categories (or industries) are recognized for hardwood lumber consumption: furniture, flooring, millwork, ties, pallets, mining, containers and dunnage, and miscellaneous (all other categories). We treat use in mining and containers and dunnage as exogenous. Demand relations for the remaining six categories use an "end-use factor" form as described by Adams and others (1992):

$$\frac{D_e}{A_e} = f\left(\frac{P_{L,e}^C}{P_{S,e}^C}, t\right), \quad (30)$$

where

D_e is hardwood lumber consumption in end-use category e ;

A_e is the level of output (or activity) in end-use category (industry) e ;

$P_{L,e}^C$ and $P_{S,e}^C$ are the prices of hardwood lumber and substitute composite products used in industry e , and

t is a time trend representing technological change in the end-use industry.

Prices of the composite products, also termed "cost put-in-place," include wherever possible, both materials (such as lumber or substitutes) and labor.

Estimated lumber price elasticities are shown in table 4. For ties and pallets, hardwood lumber consumption is derived in a two-step process. In the demand equations (for which price elasticities are shown in table 4), consumption is expressed as number of hardwood pallets or ties produced, and end-use industry output is measured as total ties or pallets produced. Thus the end-use factor in the equation is the fraction of total ties or pallets that is made from hardwood lumber.¹⁹ The volume of lumber consumption is then computed as the fraction of total units that are hardwood multiplied by the total number of units produced and then multiplied by a factor giving lumber use per unit.

In two cases (furniture and millwork), the estimation sample was split between 1979 and 1980, recognizing the somewhat more price elastic consumption response in the period since 1979. This shift coincides with the sharp, sustained drop in the relative price of the lumber-using composite for these end uses and a reversal of historical trends toward declining consumption per unit of end-use output. The elasticity differences are not great, but the coefficient shifts do improve the statistical properties of the equations. Although variations in relative price trends do not constitute structural changes in the usual sense, these coefficient shifts are effective because our demand models are too simple to capture the consumer behavior associated with the large trend reversals observed in the early 1980s.

Hardwood lumber supply—Hardwood lumber supply relations employ a form used in earlier versions of TAMM:

$$Q = a_0 + a_1 \left(P - \frac{P_w}{r_w} - \frac{P_o}{r_o} \right) + a_2 K_{-1}, \quad (31)$$

¹⁹ We ignore the recovery and other differences associated with mills that produce pallets directly from logs rather than purchasing hardwood lumber.

Table 4—Characteristics of hardwood lumber demand relations and lumber price demand elasticities by end-use

Enduse	Demand elasticity for period:			End-use activity measure	Proportion of total hardwood lumber consumption 1958-88
	<1980	1980+	All years		
					<i>Percent</i>
Furniture	-0.62	-0.69		IIP-furniture ^a	24.2
Flooring			-1.865	Floor area of single-family homes;	4.7
Millwork	-.942	-.978		IIP-millwork	5.7
Ties			-.12	Total U.S. tie production	8.9
Pallets			-.287	Total U.S. pallet production	25.2
Miscellaneous			-1.235	IIP	16.4

^a IIP the index of industrial production, 1982 = 1.0, IIP-FURNITURE is the index of industrial production for furniture, 1982 = 1.0. Lumber consumption shares for end-use categories treated as exogenous: mines 3.9 percent and containers and dunnage 11.0 percent.

where

P , P_w , and P_o are normalized product, wood, and other input prices;

r_w and r_o are output-input coefficients for w and o ;

and K_{-1} is the level of fixed capital at the start of the period.

Other than the fixed conversions between inputs and output, this form does not correspond to any specific underlying technology assumption (form of the production function). As discussed by Cardellicchio and Kirjasniemi (1987), changes in either p_w or p_o in this form (like the Leontief production function) shift the aggregate marginal cost by the inverse of the output-input coefficients.²⁰ Unlike the Leontief model, however, marginal cost per unit of output rises with output and declines with the level of fixed capital (a_1 and a_2 are both positive). This form assumes that marginal cost at some fixed base level of output is consistent with the Leontief model but then rises more rapidly than the sum of the converted input prices as output expands beyond this level.

²⁰ The Leontief production function is characterized by the use of productive factors in fixed proportions: one unit of output requires x units of factor a , y units of factor b , etc., n units of output require nx units of a , ny units of b , and so on. With this production process, the marginal costs of production are constant as long as factor prices are constant, because each additional unit of output requires an identical increment in all the factors and hence variable costs.

Supply relations of the form in equation (31) were estimated for the four Eastern production regions (NC, NE, SC, and SE). Estimated supply elasticities with respect to product and stumpage prices are shown in table 5. Elasticities for the Southern regions are nearly four times those in the North, reflecting the stability of Northern output over the past two decades despite widely fluctuating prices and costs.

Capacity is projected over time by using a partial adjustment procedure similar to that described by Cardellichio and others (1989). Target capacity utilization rates (U^T) are established for each region based on historical data. Desired capacity is then defined as

$$K^T = \frac{S_{t-1}}{U^T}, \quad (32)$$

where

S_{t-1} is last period's output.

If actual capacity at the end of the previous period is K_{t-1} , then for

$$\begin{aligned} K^T &> K_{t-1}, \\ \Delta K &= \mu(K^T - K_{t-1}) \text{ and} \\ K^T &< K_{t-1}, \\ \Delta K &= \delta(K^T - K_{t-1}), \end{aligned} \quad (33)$$

where

K is the projected change in capacity and

μ and δ are preset fractions of the difference between target and actual capacity by which capacity is allowed to change in a period.

Hardwood stumpage demand and supply—Treatment of hardwood stumpage demand and supply is generally the same as in the softwood sector. Stumpage demand is derived from product output by using conversion coefficients that differ over time according to external projections and scenarios. Estimates of residue production are derived as previously described for softwoods. Public supply in all regions is treated as fixed and insensitive to price (supply is equal to harvest, which is assumed to equal the volume sold). Private stumpage supply relations for industrial and non-industrial owners have the same forms as in the softwood sector but are estimated only for the Eastern regions. Private supplies in the West are assumed to equal the quantities demanded. A summary of estimated private stumpage supply elasticities for the eastern regions is given in table 6. As was the case for product supply, elasticities in the North are consistently lower than those for the South.

Nonstructural panels—Nonstructural panels include four broad groups: hardwood plywood, particleboard, hardboard, and insulating board. Domestic consumption and production of these products are determined in TAMM by using a mechanical accounting procedure that is not sensitive to product price or the prices of substitutes. Roundwood and residues used in the production of these products are estimated by using prespecified (externally projected) conversion factors and enter TAMM's materials balance accounting together with the volumes for all other wood and fiber products.

Table 5—Hardwood lumber supply elasticities for Eastern production regions

Hardwood	Price per region			
	North-central	Northeast	South-central	Southeast
Lumber	0.189	0.244	0.813	1.011
Stumpage	-.042	-.057	-.121	-.127

Table 6—Estimates of the elasticity of private hardwood stumpage supply with respect to stumpage price in the Eastern regions

Region	Ownership	
	Forest industry	Nonindustrial
North-central	0.346	0.214
Northeast	.076	.264
South-central	.407	.480
Southeast	.454	.509

Ten end-use categories are identified for each panel group: single-family residential construction, multifamily residential construction, mobile home production, residential upkeep and improvement, nonresidential construction, manufacturing, pallets, containers, dunnage, and other (comprising all other unspecified uses). End-use factors, the ratio of consumption to a measure of output in the end-use category, are computed for each category and projected outside of TAMM.²¹ Projections of consumption by end-use category and panel group are then computed as in equations (2a) and (2b) by using externally generated projections of output in the end-use categories. Domestic production is found as the sum of projected consumption and net trade (the latter also projected externally).

²¹ End-use activity measures are total floor area of new dwelling units for the three residential construction categories, total real expenditures for residential upkeep and improvement, total value of nonresidential construction, value of manufacturing shipments, total U.S. pallet production for pallets, and value of wooden container shipments for containers. Dunnage consumption is projected directly, and consumption in other uses is computed as a percentage of use in the sum of the explicitly identified uses.

Fiber Products Sector

Projections of volumes, prices, and trade flows in the markets for pulp, paper, and paperboard are provided by the NAPAP model (see Ince 1994). NAPAP is a spatial market model of the North American fiber products sector that uses three regions in the United States and two in Canada and accounts as well for offshore trade.²² NAPAP provides TAMM with projections of pulpwood consumption by roundwood and mill residue categories and of roundwood and residue prices by region and species. Roundwood and residue volumes enter TAMM's materials balance accounting, and roundwood demands are cumulated with other harvest requirements as input to timber inventory projections. Residue prices are used in the supply processes for lumber and plywood as described in an earlier section.

Roundwood pulpwood supply in NAPAP is the sum of a price-sensitive private component (aggregated across all private owner classes) and a fixed public harvest. Private supply is represented by stumpage supply relations that depend in part on growing-stock inventory and prices of sawtimber. To implement these supply relations, projections of sawtimber prices and growing-stock inventory are provided by TAMM. Residue supply is treated as a fixed-coefficients production process (consistent with the assumptions regarding its generation used in TAMM) with marginal costs constant for volumes up to the amount generated (a "right angle" supply curve). Marginal residue production cost estimates are derived in part from timber harvest and log transportation cost projections provided by TAMM. Projections of total available residues generated at mills also are derived from TAMM.

Given the contemporaneous interdependence between the two models, an iterative (Gauss-Seidel) solution scheme is used to seek an overall equilibrium in the two (solidwood and fiber) sectors. An initial TAMM solution is found with input from NAPAP. Inventory, sawtimber price, and residue data are then transferred to NAPAP, which is re-solved with the resulting pulpwood consumption and residue prices being returned to TAMM. The process continues until solutions in both models stabilize. In the 1993 assessment update, acceptable convergence generally was achieved in three to five iterations, with more iterations needed for scenarios depicting extreme departures from baseline conditions.

Timber Inventory Projection

Timber inventories **on private ownerships only** are projected in TAMM by using a modified version of the ATLAS model (Mills and Kincaid 1992). Basic inventory data are derived from the Forest Service's periodic forest surveys.²³ Because the dates of these inventories differ with region (for example, some are circa 1985 and others 1990), the simulation structure allows staggered "starting" times in the projection process. Lands include only those classed as "timberland," meeting a minimum standard of productivity and not reserved from timber harvesting. Timberland is stratified by

²² The NAPAP regions are North (TAMM's NE and NC regions), South (TAMM's SE and SC regions), West (the remainder of TAMM's U.S. regions), West Canada (TAMM's Coastal British Columbia and Interior Canada regions), and East Canada (corresponding to TAMM's Eastern Canada region).

²³ Summary inventory data for the United States are contained in Powell and others (1993).

region, owner, (representative) age class, site productivity group, management intensity (MI) class, and forest type. No quality descriptors are available. Average diameter at breast height is projected and reported together with stand yields, but the inventory cannot be disaggregated by diameter class.

General management regimes—ATLAS uses both even-age and partial cutting modes to describe the broad type of management regime applied to forest lands. For lands classed under even-age management, ATLAS uses a "model II" format (following Johnson and Scheurman's [1977] terminology). Acres shift through time by age class, and once harvested and regenerated, cannot be readily linked back to the acres in the original (starting) inventory. Lands classed under partial cutting are harvested according to preset removals regimes by using a process that adjusts average stand age to reflect the impact of removals and ingrowth on stand-age composition, volumes per acre, and growth. Assignment of areas to even-age and partial cutting classes is based on data derived from field measurements and judgments of Forest Service inventory analysts. Lands grouped in either even-age or partial cutting categories remain in these classes throughout a projection.

Elements of inventory projection—

MI classes and MI class shifting—A (MI) class is defined by a combination of silvicultural activities including, but not limited to, regeneration, precommercial and commercial thinning, and fertilization. These actions are depicted in ATLAS through the use of a specific age-dependent yield function for even-age-strata (or yield process for partial cutting) that reflects the growth and yield impacts of the regime. Yield relations used in the 1993 timber assessment update are summarized by Mills.²⁴ Lands classified under even-age management can shift among MI classes over time to reflect changes in timber management investment. At present, the extent and timing of these shifts are determined outside of the TAMM-ATLAS model and occur only after an acre is harvested.

Area change—Over time, the timberland base is adjusted for the movement of land between forest (timber production) and nonforest (including, agricultural, urban, and reserved) uses. Projections of these shifts are developed outside of the model. When land shifts to a nonforest use, a portion of its volume at the time of shifting is assumed to be harvested and is counted in the current aggregate cut from its stratum. This reflects the process of land clearing or volume reduction associated with most land use changes in the private sector.

Harvest allocation and harvest order—All strata have externally set minimum harvest ages below which timber cannot be cut. This age is intended to represent a lower bound of merchantability under current and foreseeable processing standards. The sum of all volume in age classes above minimum harvest age in a given stratum is termed the "available volume," or the volume that can be cut.

²⁴ Mills, John R. Data files 1993. Timberland inputs to the 1993 RPA assessment. Portland, OR: Pacific Northwest Research Station. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR 97208-3890.

Once the market clearing harvest volumes are determined for a given period in the market portion of TAMM-ATLAS, they must be allocated in some way to the several strata in the timber inventory. At the market level, products are divided into two broad species classes: softwoods and hardwoods. In ATLAS, forest types also are grouped into hardwood and softwood fiber types depending on the preponderant source of volume in the type (hardwood types generally have some softwood volume and softwood types some hardwood volume). The allocation process is begun at the fiber type level (combinations of forest types) by using the following simple simultaneous solution scheme, where we seek S and H:

$$\begin{aligned} P_S^S S + P_S^H H &= SR \text{ and} \\ P_H^S S + P_H^H H &= HR, \end{aligned} \quad (34)$$

where

P_j^i are the proportions of available volume of species type i (S = softwood, H = hardwood) in the total volume in fiber type j (either S or H);

S and H total harvest volumes (all species combined) in the softwood and hardwood fiber types; and

SR and HR total softwood and hardwood cut requests from the market portion of the TAMM-ATLAS model.

The resulting split of harvests between the softwood and hardwood fiber types from solving equations (34) is,

$$\begin{aligned} S &= \frac{(SR + HR) P_S^H - SR}{P_S^H - P_S^S} \text{ and} \\ H &= (SR + HR) - S, \end{aligned} \quad (35)$$

Within a given fiber type, harvest is then allocated across forest types, sites, and MI classes in proportion to available volumes in these classes. Harvest is allocated to age classes in proportion to an externally established "preferred harvest order." If the cut request cannot be fully satisfied under this order, the remainder of the request is filled by using the "oldest first" rule.²⁵ This approach has proven to be reasonably effective in practice, but final harvest volumes can differ slightly from requests. This results from the allocation of cut to age classes in a manner that is not proportional to available volume. Hence the P_j^i fractions for the fiber type are not identical to the fractions observed in the strata that are actually cut.

²⁵ This approach does not guarantee nonnegative S and H . In cases where one of S or H is negative, the smaller of the two harvest requests (SR or HR) is first allocated to strata in both fiber types in proportion to available volumes in the strata. The larger request, adjusted for volumes already generated from the first allocation, is then allocated to strata in proportion to their available volumes.

Other Model Elements

External trade—Canadian softwood lumber and OSB are the only endogenous non-11.S. markets in TAMM. All remaining external trade links are exogenous. Export demands and all other import supplies of both logs and products are assumed to be perfectly inelastic at externally established levels over time. In general, trade volumes (for both imports and exports) are set at the national (U.S. total) level and allocated to U.S. producing or consuming regions by using exogenous proportions. Options exist in the TAMM-ATLAS model to employ export demand and import supply relations with some price elasticity if estimates of these relations are available. Given the endogenous link to Canadian solidwood markets, TAMM also requires projections of future Canadian-U.S. currency exchange rates and levels of any tariffs on softwood lumber and OSB.

Transport costs—As part of the analysis of spatial equilibrium, TAMM requires estimates of transportation costs associated with the shipment of products from producing to consuming (demand) regions. Initial data for these costs were derived from available public and industry association reports on rail and truck shipments. In strictest terms, however, competitive spatial equilibrium requires that goods classed in any given product category (such as softwood lumber) be relatively homogeneous in quality. If this were the case, the difference in mill (FOB) prices between any two supply regions shipping to the same demand region would equal the difference in transport costs to this market. Similarly, differences among prices in demand regions served by a given supply region would be no larger than the transport cost differential to the two markets.

For most of the products treated in TAMM, the quality mix of production differs markedly across regions. At the same time, TAMM uses a high level of product aggregation, and regional prices are volume-weighted averages across all quality classes. Thus, differences among the average regional supply prices for any two regions serving a given market may be substantially different from the average transport cost difference. This is but one of many examples of the quality aggregation problem discussed by Brooks (1987). In TAMM projections, we have adjusted average inter-regional transport costs so as to preserve the correspondence between observed and projected prices at the supply region level.

Model Solution

Contemporaneous price linkages between the hardwood and softwood solidwood sectors in TAMM are limited. The current period hardwood lumber price appears only in the railroad tie end-use demand relation for softwood lumber, whereas softwood lumber price appears in the hardwood lumber end-use demand for ties and pallets (pallet end-use factor projections are exogenous for softwoods). Technically, this would require the simultaneous solution of both sectors to find market equilibrium. To simplify the solution process, we solve the hardwood sector first by using the one-period lagged price of softwood lumber and then solve the softwood sector by using the resulting hardwood lumber price.

Hardwood sector—As illustrated in equation (29), the hardwood sector is a nonspatial system of simultaneous equations, though some of the end-use demand relations are nonlinear in variables. We solve the system by using a simple Newton-Raphson gradient method²⁶ structured to find the price solution that minimizes the difference between aggregate demand and supply quantities at the product and stumpage levels.

Softwood sector—Considering only the product and stumpage quantities and prices, the softwood sector model can be represented with the following set of matrix equations where matrices are denoted by capital letters and lower case names denote vectors:

$$\begin{aligned}
 sq - E_1 sp &= rhd \text{ product demand} \\
 sq - A_2 sp - B_2 hp &= rhs \text{ product supply} \\
 -C_{11} sq &+ hq = rhb \text{ stumpage demand} \\
 -D_2 hp + hq &= rhh \text{ stumpage supply}
 \end{aligned} \tag{36}$$

where

sp and sq are vectors of prices and volumes in the product markets;

hp and hq are vectors of prices and volumes in the stumpage markets;

rhd, rhs, rhb, and rhh are vectors computed from exogenous and predetermined variables and their associated coefficients in the four blocks of equations.

Trade in logs among domestic U.S. regions is extremely small and is ignored in TAMM. Consequently, the product supply, stumpage demand and stumpage supply relations in each region can be solved simultaneously to yield expressions for stumpage price that depend solely on the regional product supply quantities (sq) and the exogenous and predetermined variables in the several equations. These expressions appear as,

$$hp = D_2^{-1}(rhb - rhh + C_{11} sq). \tag{37}$$

Equation (37) is then used to replace stumpage prices in the product supply relations. The resulting product supply equations are partially reduced form expressions that depend only on the prices of other *products*, recognizing price and output adjustments in the stumpage market.

²⁶ The Newton-Raphson approach involves the use of derivatives or gradients of sets of equations characterizing the solution of the model system to locate that solution. In this case, the equations are simply the difference between demand and supply equations in the product and stumpage markets. We want these equations or differences to equal zero at the solution point; that is, supply should equal demand. We find the prices that bring about this equality by using an iterative process, beginning with "guesses" of the solution. We repeatedly examine the price slopes of the demand and supply functions to determine the best directions in which to change our guesses to find the equality points.

Model Behavior in Simulations of a Historical Period

The product demand functions and the partial reduced form product supply relations comprise a spatially disaggregated system, where the product demand relations in each demand region are (in general) interdependent in product prices and the product supply curves are interdependent in regional supply prices. This system is solved for equilibrium values of the product prices and volumes by using the reactive programming algorithm (Brooks and Kincaid 1987). Stumpage prices and volumes are then retrieved from equation (37) and the stumpage supply relations.

To illustrate the performance of the model, and to provide some qualitative basis for judging its adequacy in tracking market behavior, figures 6-11 show model simulation results and actual data for 34 selected concepts for 1977 through 1992. Reliable historical hardwood data were available only through 1988. Table 7 provides a summary of average absolute percentage error (AAPE) measures for these same series. In this simulation, historical rather than model-simulated data are used for timber inventories in the SE and SC regions through 1985 and in all other regions through 1990. In most cases, behavioral equations were estimated with data through 1989 (exceptions used a shorter sample).

Of the 34 series in table 7, 10 have AAPEs less than 5 percent, 26 are less than 10 percent, and 29 are less than 15 percent. TAMM errors tend to be largest in those regions with limited solidwood output and sawtimber harvest, such as the NC, NE, and SR. This results in some cases from low-quality and limited data for costs, recoveries, product, and stumpage prices. Large errors for OSB volumes result from the inability of TAMM to track the rapid increases in output over the 1977-92 period in some regions. In all cases, the model reproduces the general pattern of growth but underestimates actual levels in several years. Larger errors also arise in TAMM projections of sawtimber stumpage prices in the PNWW and Southern regions. Southern projections seem to exaggerate all the peaks and troughs relative to actual levels. PNWW projections have the more common mixture of underestimated peaks and troughs, excepting that the model overestimates the sharp rise in prices beginning in 1987-88. In considering TAMM's performance in these and other price projections, it should be remembered that, unlike most other widely used models of forest products markets, there are no explicit behavioral relations to explain price. Rather, prices are determined by the interaction of supply and demand relations at the stumpage and product levels.

Projections, Policy Simulations, and Model Evaluation

To illustrate the application of TAMM, this section presents a set of alternative scenarios of the future development of the U.S. forest sector under different assumptions on forest resource policies. We examine a "base" case and four variants derived from the 1993 timber assessment update (Haynes and others 1994): (1) reduced harvest from public lands in the United States, (2) increased rates of paper and paper-board recycling, (3) the adoption of more stringent public regulations on private forest practices, and (4) limited harvests from provincial forest lands in Canada. A concluding section presents some general criticisms of the policy simulation behavior of TAMM .

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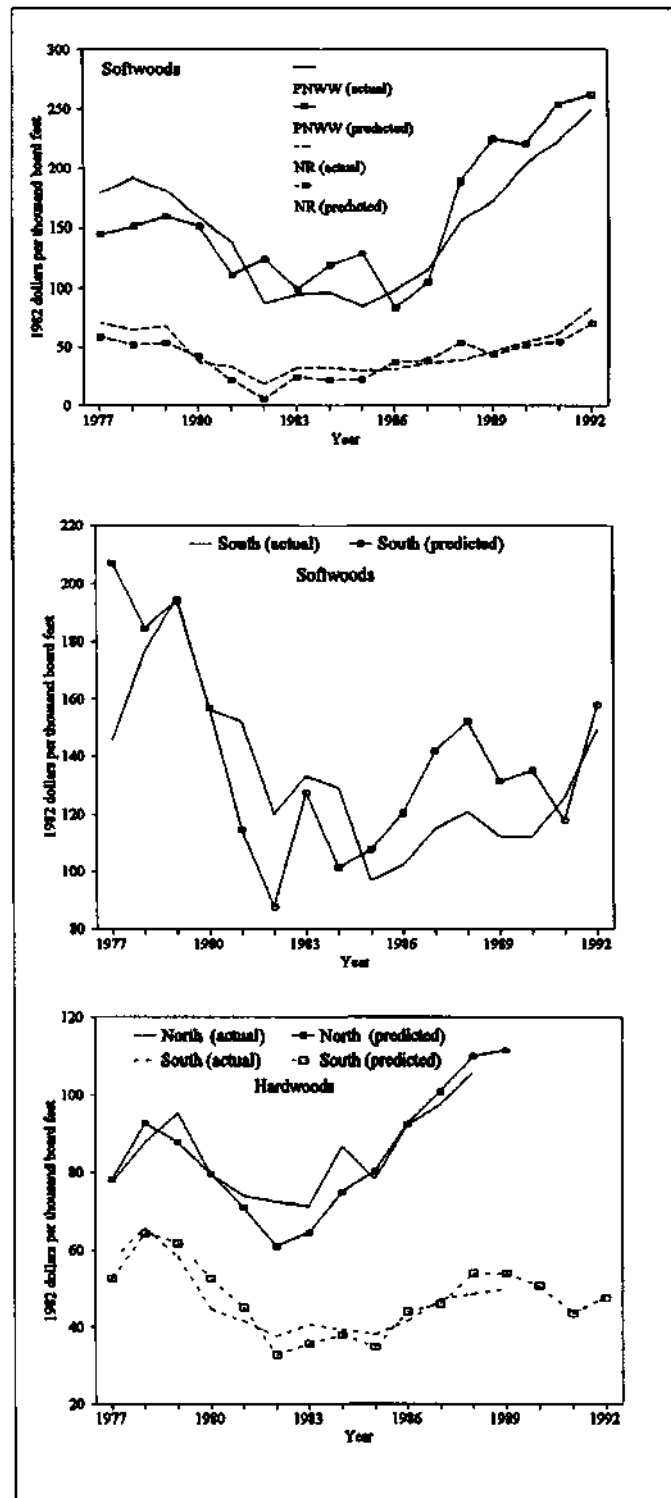


Figure 6—Softwood and hardwood sawtimber stumpage prices, actual and projected values for selected regions

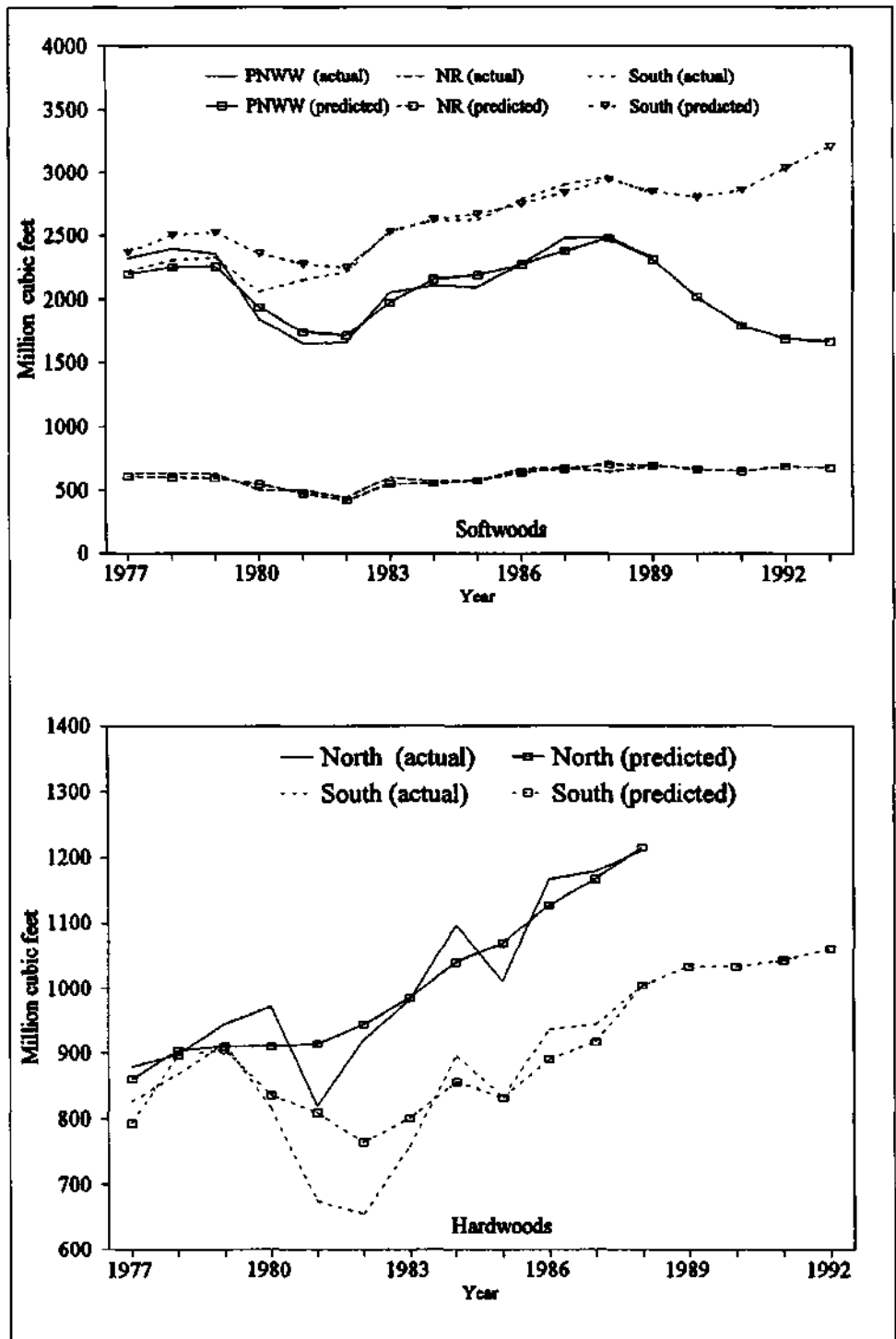


Figure 7—Softwood and hardwood sawtimber harvest volumes, actual and projected values for selected regions

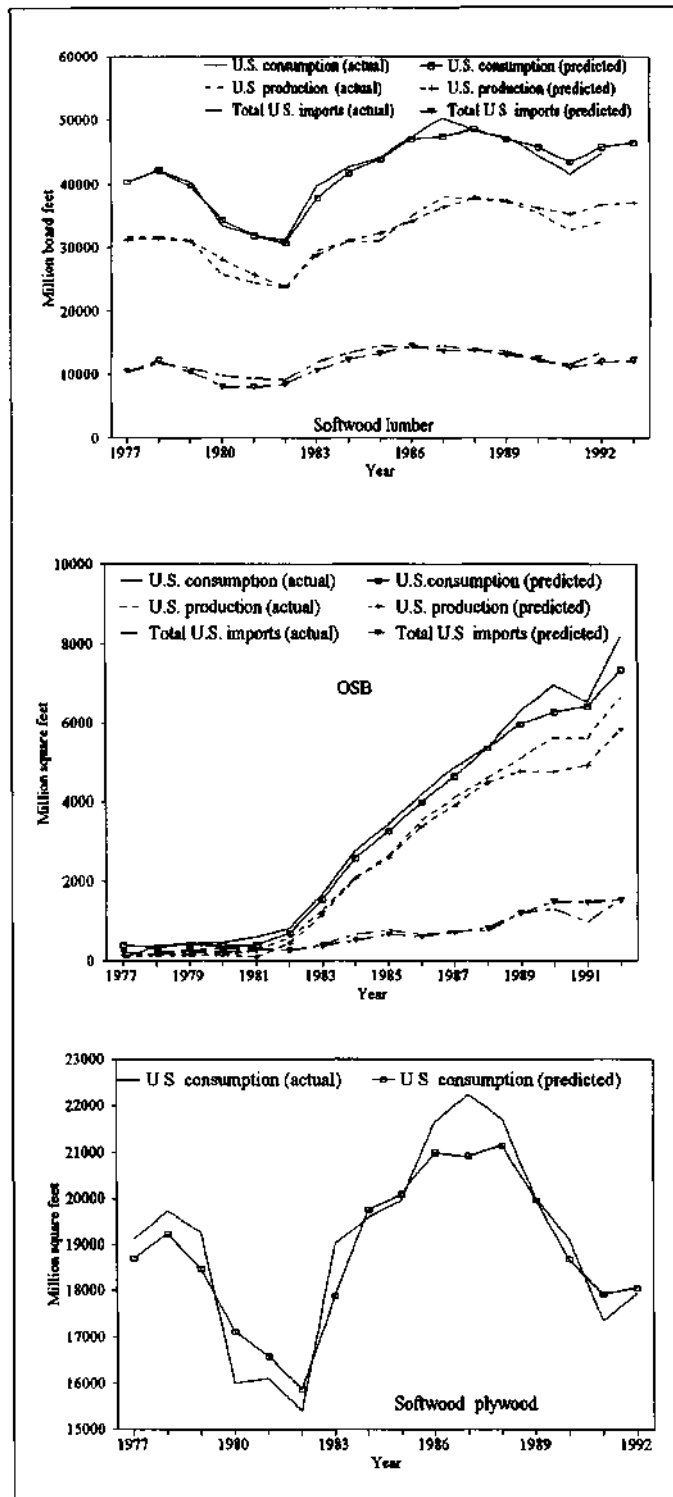


Figure 8—Softwood lumber, OSB, and softwood plywood production, consumption and imports, actual and projected values.

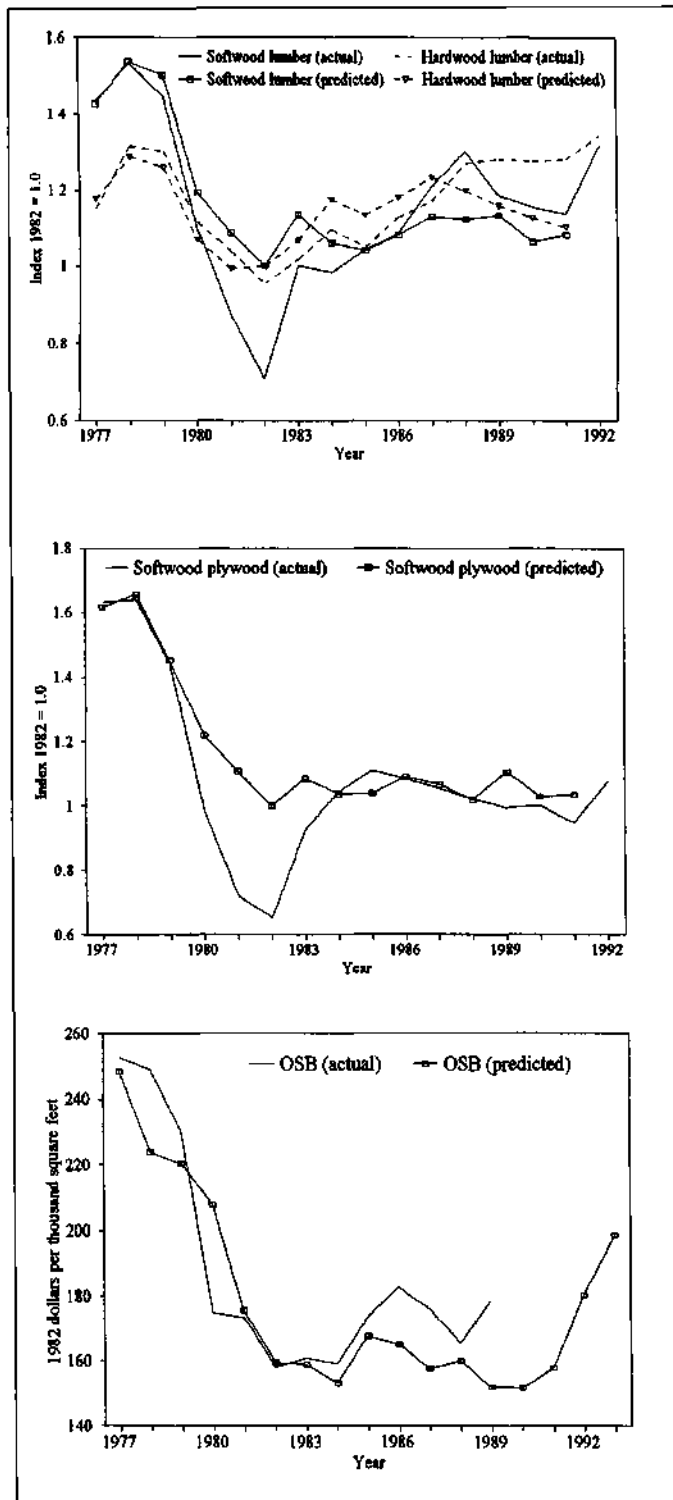


Figure 9—Indexes of real prices for softwood lumber, hardwood lumber, softwood plywood, and price of OSB, actual and projected values.

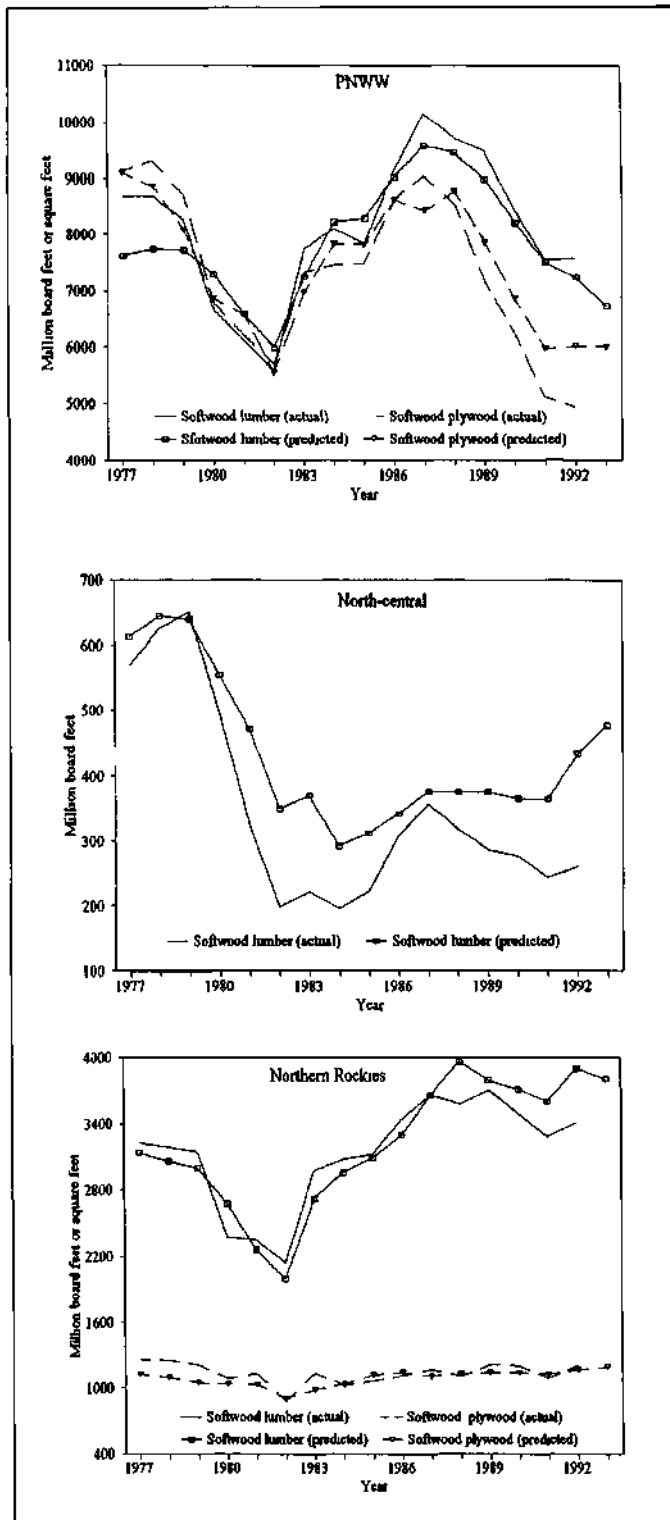


Figure 10—Production of softwood lumber and plywood, actual and projected values for selected regions

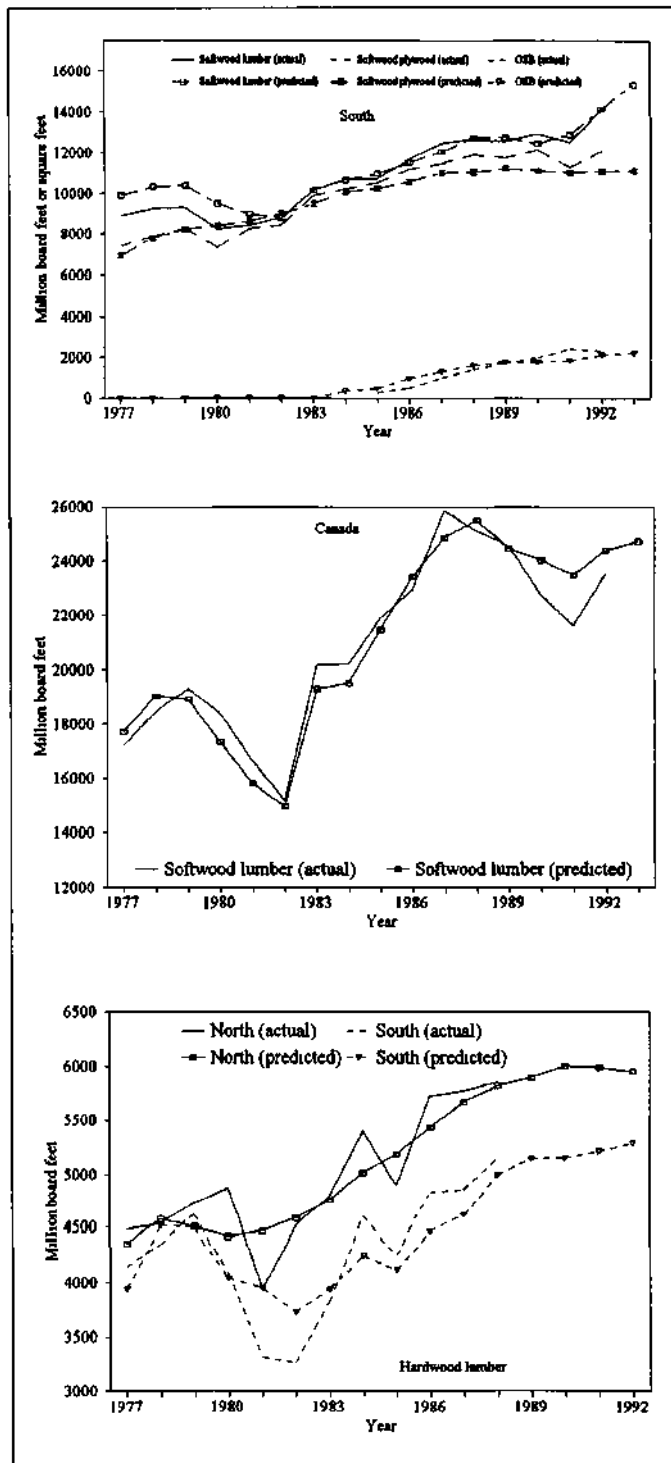


Figure 11—Production of softwood lumber, softwood plywood, OSB, and hardwood lumber, actual and projected values for selected regions

Table 7—Average absolute percentage errors, TAMM projections for historical period 1977-92

Concept per region	U.S. total	PNWW	NR	NC	North	South	Canada
<i>Percent</i>							
Softwood lumber:							
Consumption	1.88						
Production	3.06	5.59	6.00	32.02		4.58	3.49
Imports	6.68						
Price per index	7.89						
Softwood plywood:							
Consumption	2.95						
Production		6.53	6.30			5.03	
Price per index	9.47						
OSB:							
Consumption	28.96						
Production	14.93			26.36		14.41	
Imports	14.64						
Price per index	6.44						
Hardwood lumber:							
Consumption	5.19						
Production					4.45	6.22	
Price per index	6.70						
Stumpage sector:							
Softwood cut		2.94	4.69			3.85	
Hardwood cut					3.57	5.45	
Softwood price		18.89	8.73			21.61	
Hardwood price					5.70	8.29	

Base Scenario

As a datum for comparison in policy simulations, the timber assessment process develops a base projection. This scenario is to be interpreted as the results of a specific macroeconomic projection and continuation of past trends in all of the key land base, timber management investment and policy elements of the forestry sector. For the 1993 timber assessment update, the several assumptions underlying the base projection are described in Haynes and others (1994). The associated TAMM base projections for selected market elements are shown in figures 12-17.

Product and stumpage price trends (fig. 12) provide a useful summary illustration of general developments in the base scenario. Softwood lumber prices rise in two major steps over the projection. The 1990s increase derives from reduced public harvest in the West. The step-up beginning just before 2010 reflects the limitation on private harvests in the South, which becomes most pronounced in that period. After 2015, softwood lumber prices remain roughly stable as growth in demand and supplies are more nearly in balance. Hardwood lumber prices rise steadily over the projection, thereby reflecting the steady growth in demand and stable to declining hardwood inventories and private supply. Prices of OSB remain essentially stable after the mid-1990s, despite rapid growth in consumption, as capacity expands and wood and other costs are stable in real terms. Softwood plywood prices are at first held in check by the substitution prospects of OSB. Once these use changes have played out, and as prices of timber force up costs, plywood prices rise slowly through 2040.

In the softwood stumpage sector, prices in Western regions show cyclical peaks early in the projection as public cut drops and "excess" processing capacity is eventually forced out of operation. Stumpage prices then resume growth following trends in product prices and demand. Southern prices catch up with those in the PNWW some time after 2000 and remain roughly aligned thereafter. The greatest rates of stumpage price growth occur in the Rockies and the North as a result of declining public cut, in the former, and rising lumber output, in the latter.

Figure 13 provides an aggregate view of softwood timber harvest for broad classes of products (sawtimber includes lumber and plywood, nonsawtimber includes pulpwood, fuelwood and reconstituted panels) by region. The effects of declining public harvest and limited private inventories in the West are clear from the drop in the Western sawtimber curve. Virtually all the substitution observed for Western public harvest reductions, and nearly all the future growth in harvest for both sawtimber and non-sawtimber products, comes from the East.

The macroeconomic forecast underlying the base projection includes limited growth in aggregate U.S. economic activity (only 2- to 3-percent growth in GNP) and little change in new housing construction relative to levels in the mid-1980s. This results in only limited growth in lumber demand in manufacturing uses and a steady decline in its use in new residential construction (despite increased house size). Rather than these traditional sources of demand, the rising trends in softwood lumber consumption shown in figure 14 derive from residential upkeep and alteration, as the housing stock ages, and to a lesser extent from nonresidential construction and miscellaneous uses. Imports from Canada provide about half the growth through 2020, then fall, supplanted by increased domestic production as young-growth timber stocks in the West and South reach merchantable ages.

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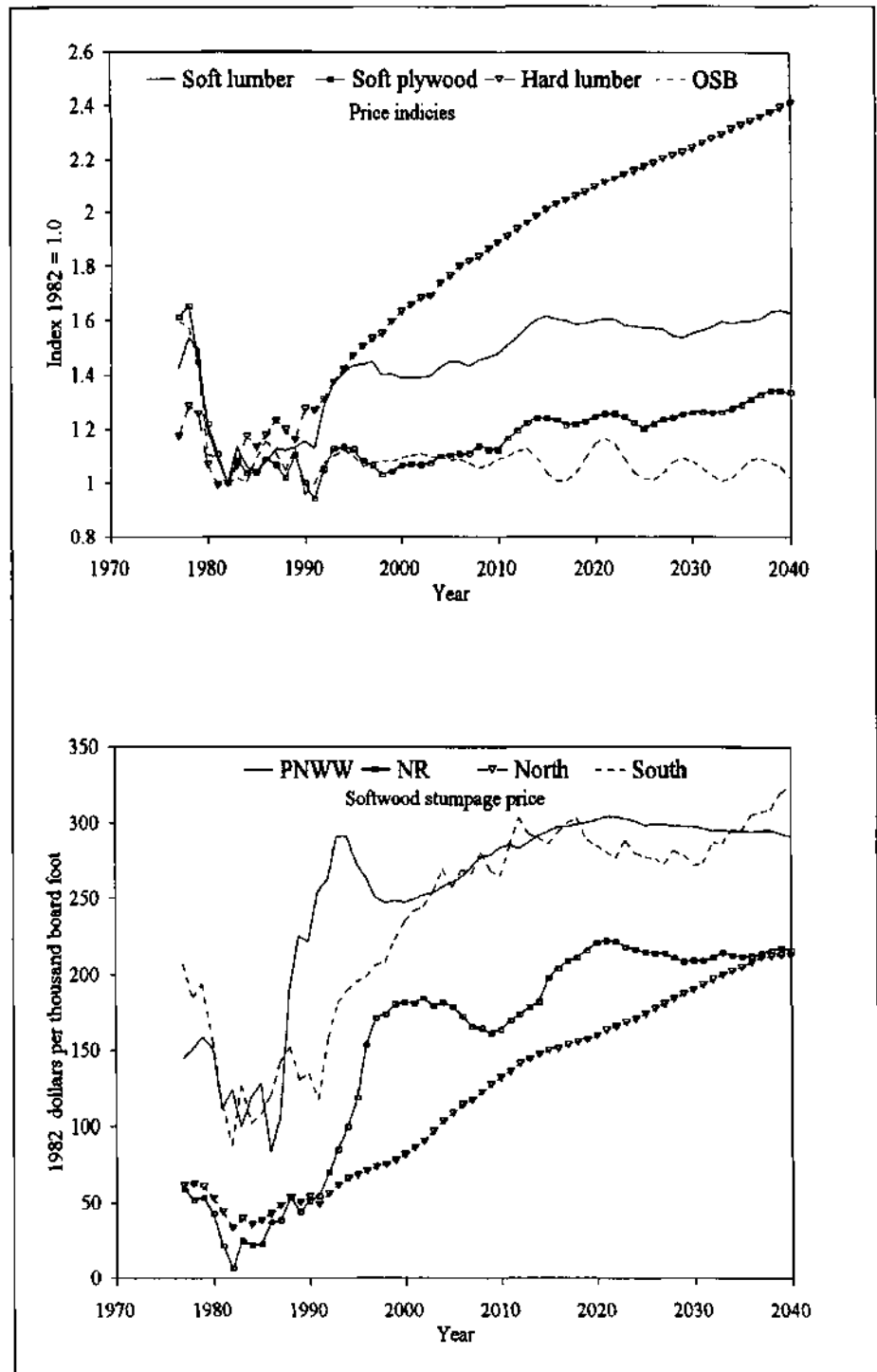


Figure 12—Projected real producer price indices and softwood stumpage prices for selected products and regions: base case.

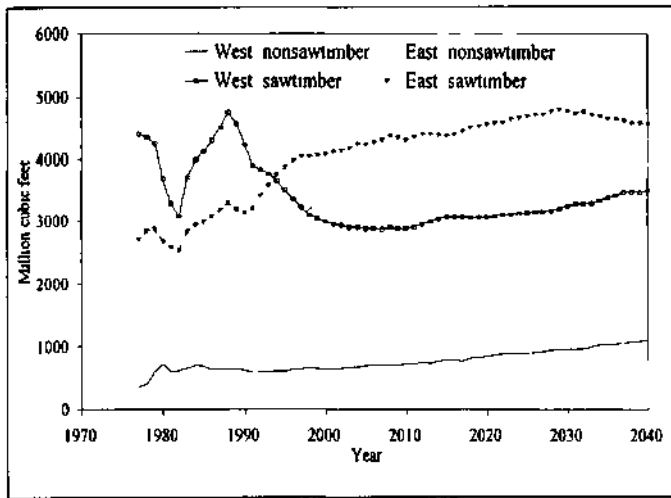


Figure 13—Projected softwood sawtimber and nonsawtimber harvests for selected regions base case

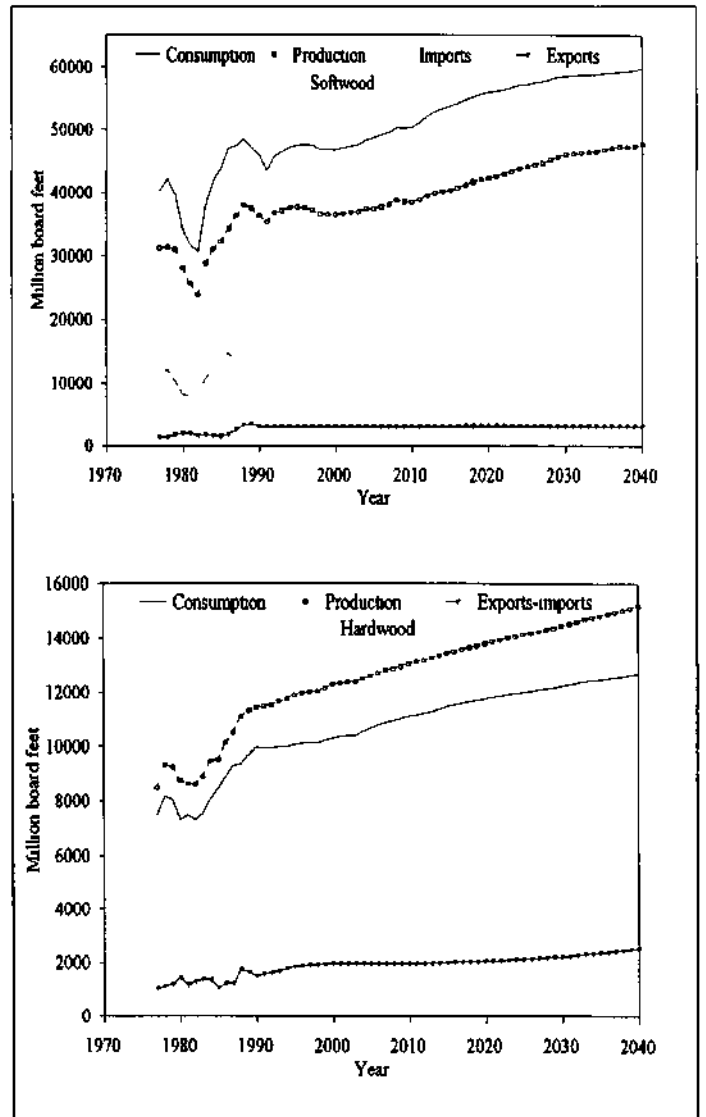


Figure 14—Projected softwood and hardwood lumber production, consumption, and imports base case

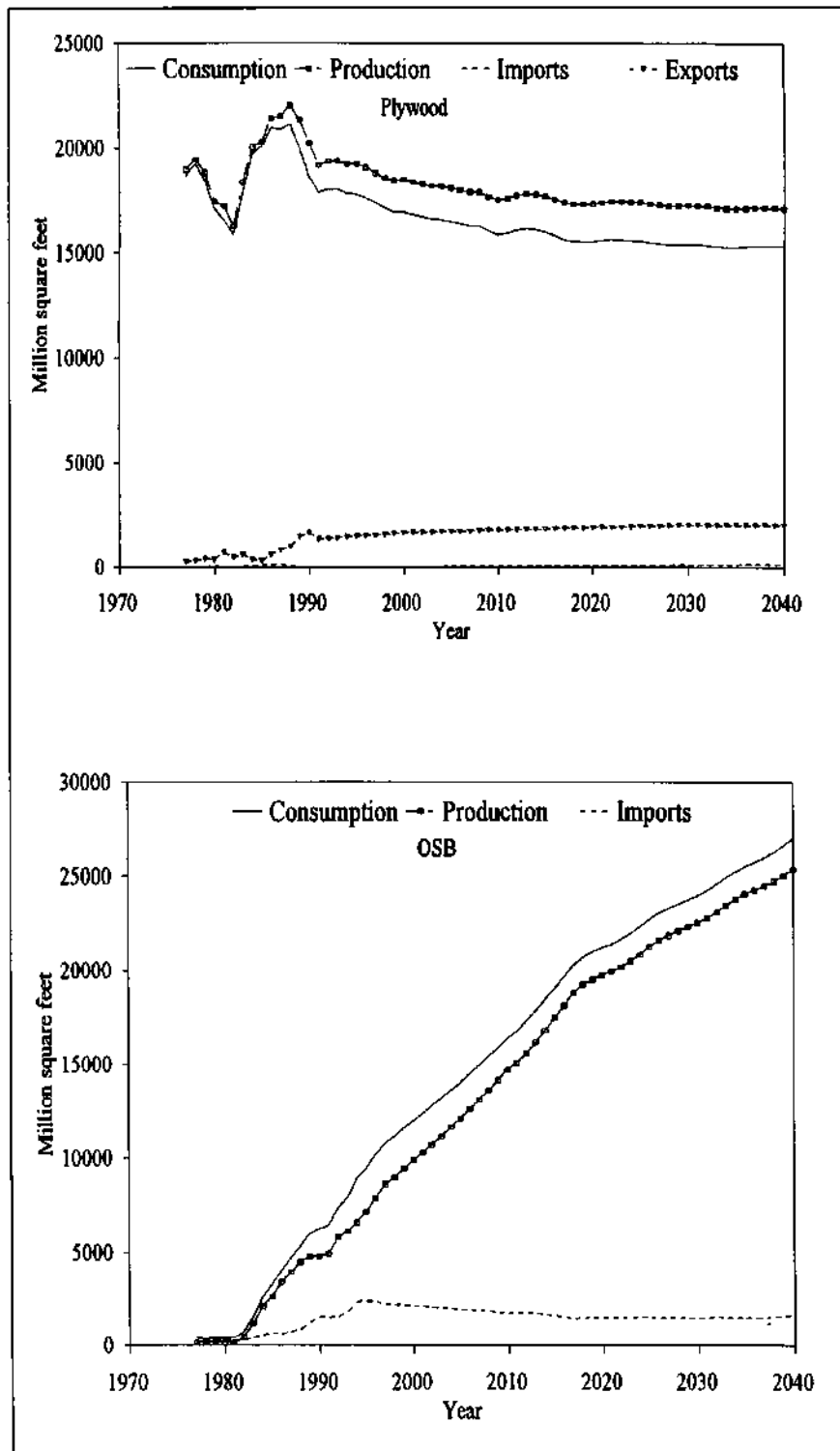


Figure 15—Projected softwood plywood and OSB production, consumption, and imports: base case.

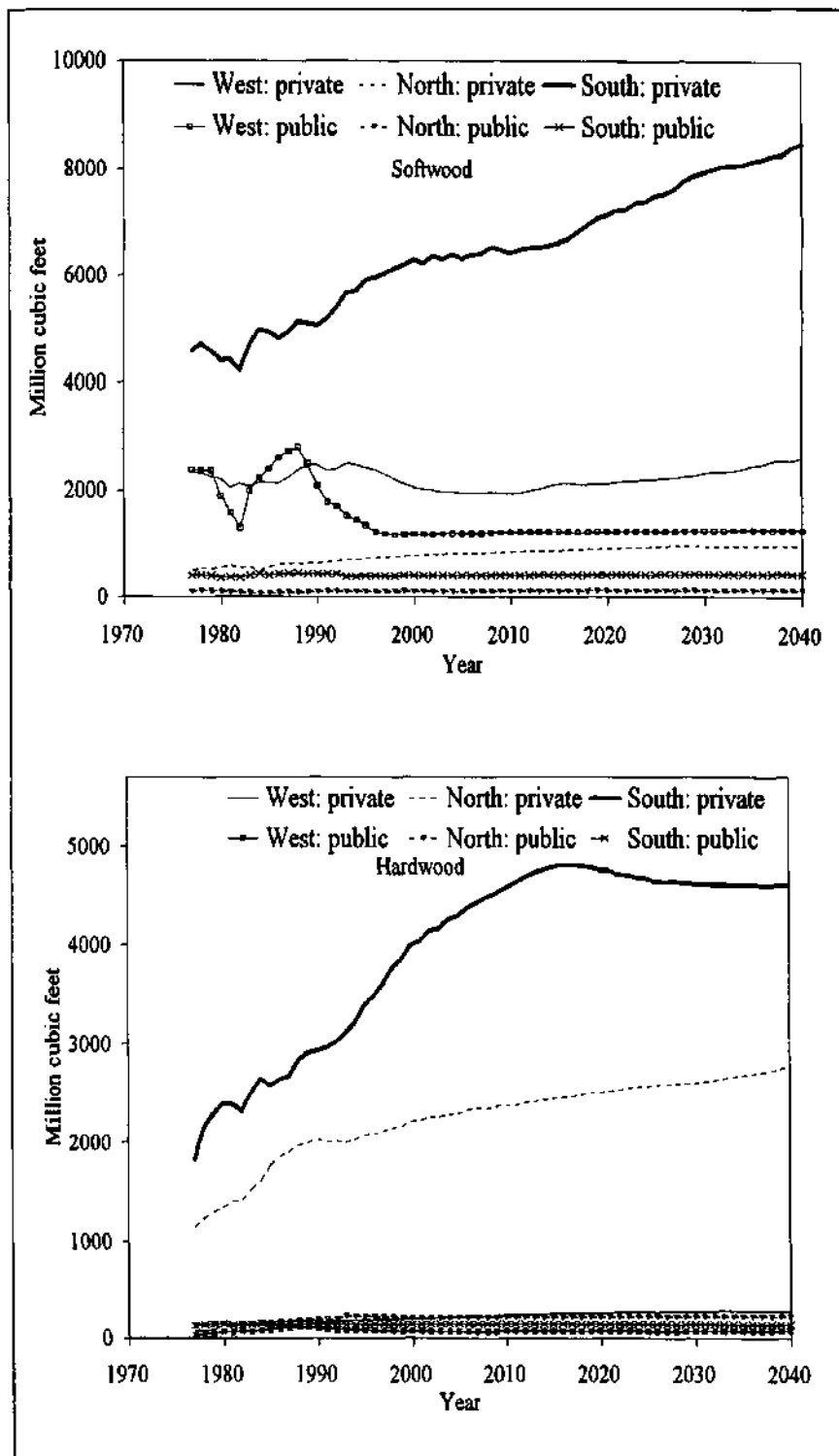


Figure 16—Projected softwood and hardwood growing-stock removals from timberland for selected regions and owners: base case.

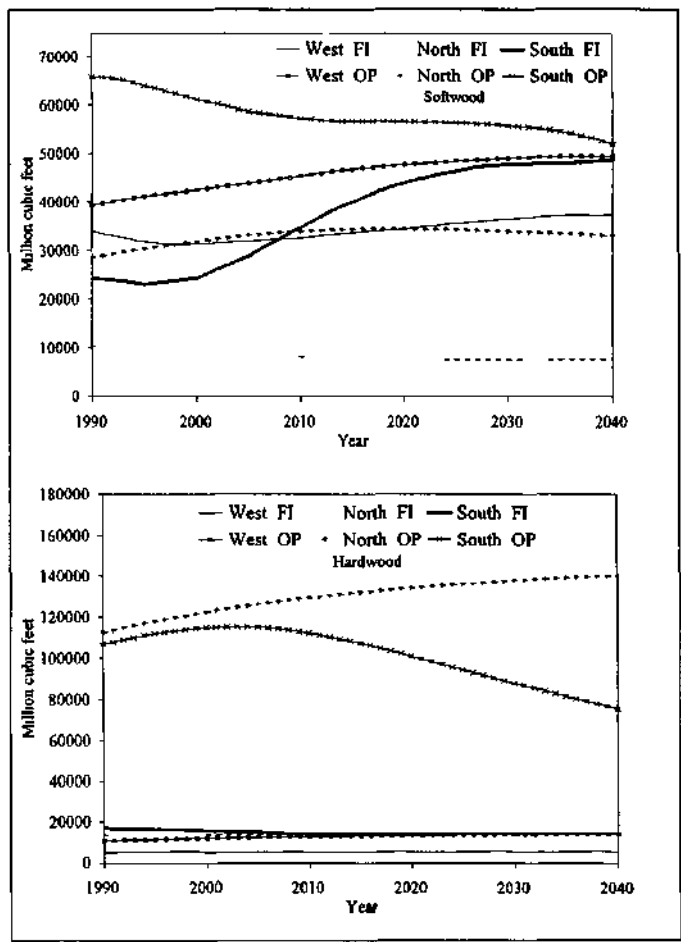


Figure 17—Projected softwood and hardwood growing-stock inventory for selected regions and owners base case

Hardwood lumber demand, in contrast, rises almost entirely because of growth in pallet consumption and use of hardwoods in millwork (though the increment in total consumption, less than 4 billion board feet over 50 years, is not large relative to softwoods). Growth in output is projected to come entirely from the Southern regions.

Consumption and production of softwood plywood falls slowly over the projection (fig. 15) due to substitution by OSB and other materials. OSB consumption, in contrast, rises nearly fivefold. Some of this increase, roughly 6 billion square feet, comes from substitution for softwood plywood. The remainder derives from the capture of virtually all of the growth in the residential upkeep and repair market and to a lesser extent from the growth in nonresidential construction as well.

Figure 16 shows TAMM projections of future regional and ownership sources of softwood and hardwood timber removals. As suggested by previous results, Southern private lands will provide the bulk of any growth in softwood removals. Removals on Western private lands are projected to return just to the levels of the late 1980s by 2040. For hardwoods (removals here include both sawtimber and nonsawtimber products), largest growth is again projected to occur in the Southern private sector, whereas Northern private lands show a less rapid but steady increase.

Reversing the trend of the past 30 years, TAMM projects a steady decline in Southern nonindustrial softwood and hardwood inventories after 2000 (fig. 17). This results in part from the shifting of Western harvest to Eastern sources (as Western public cut and private inventories decline), continued low levels of timber management activity on Southern nonindustrial lands, and loss of these lands to other uses and other classes of private owners. Southern forest industry inventories expand sharply, thereby reflecting continued intensification of management and growth in their land base. This growth supports much of the increased Southern cut seen in other charts. Western and Northern nonindustrial private inventories rise, as growth outpaces harvest even in the face of rising prices.

Increased Public Harvest Scenario

The Increased Public Harvest scenario envisions a return to National Forest harvest levels as proposed in the final land management plans developed by each forest in 1990 and to levels of cut on other government lands as planned in the late 1980s. Over the period from 1995 to 2040, this combination of changes would lead to an increase in total public cut of some 0.8 billion cubic feet per year relative to the base scenario. This increase in public cut leads to a rapid drop in Western stumpage prices (fig. 18) and a gradual decline in other regions such as the South. These declines in stumpage prices reduce timber harvests in the South (fig. 19), but the increased public cut raises harvest in the West. In product markets, stumpage price reductions yield a decline in softwood lumber prices, a reduction in U.S. softwood lumber imports, and a net expansion in softwood lumber consumption.

Increased Recycling Scenario

This scenario examines the impacts of further increases in the use of wastepaper as raw material for paper and board production. In Forest Service assessment projections before 1988, it generally was assumed that wastepaper usage rates would remain relatively constant at around 20 percent. Little change was expected because chip-pulpwood prices were projected to experience only modest growth (no growth was expected for hardwood pulpwood and chip prices in some regions). Projections for the 1989 assessment abandoned this view in recognition of growing national concerns about waste management. The usage projections in this scenario rise still more

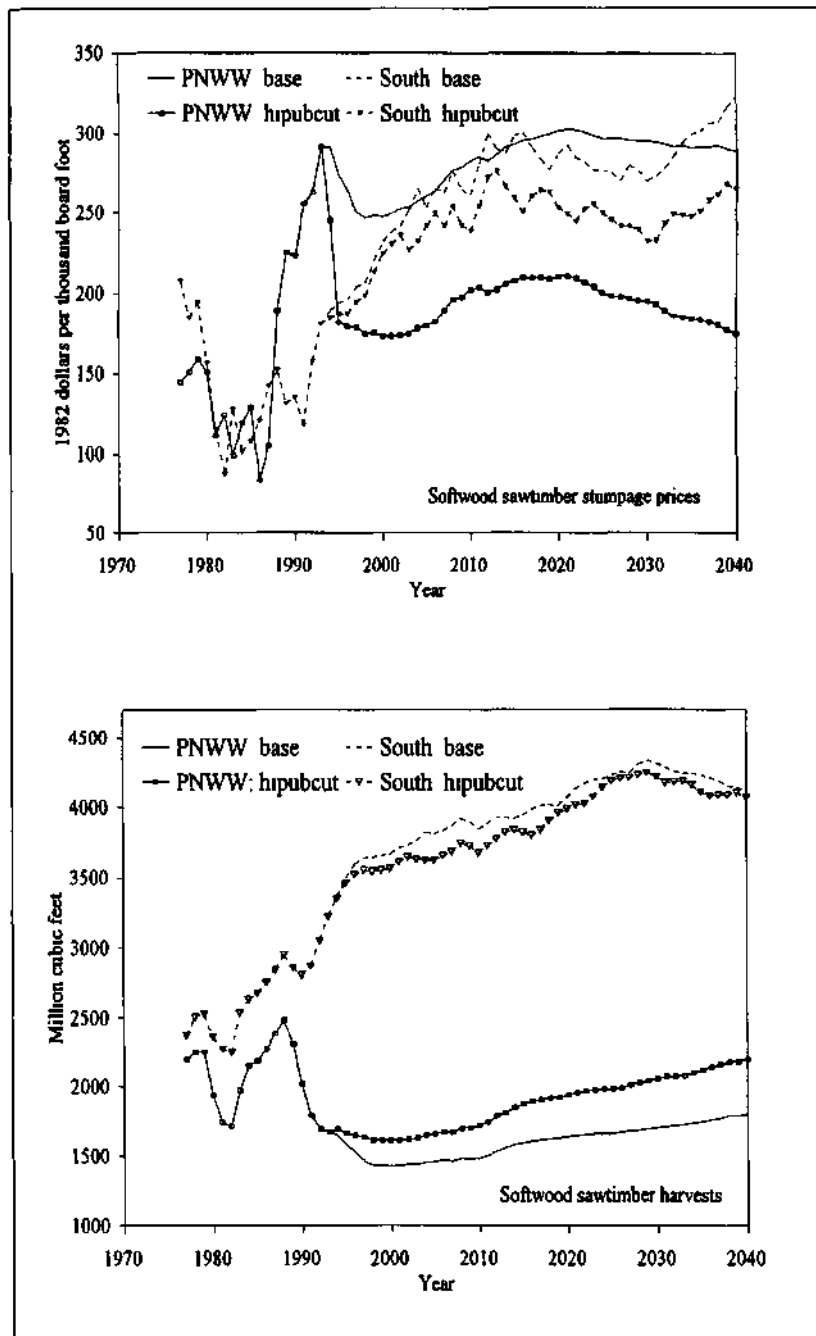


Figure 18—Projected sawtimber stumpage prices and sawtimber harvests for selected regions: BASE case and increased public harvest scenarios.

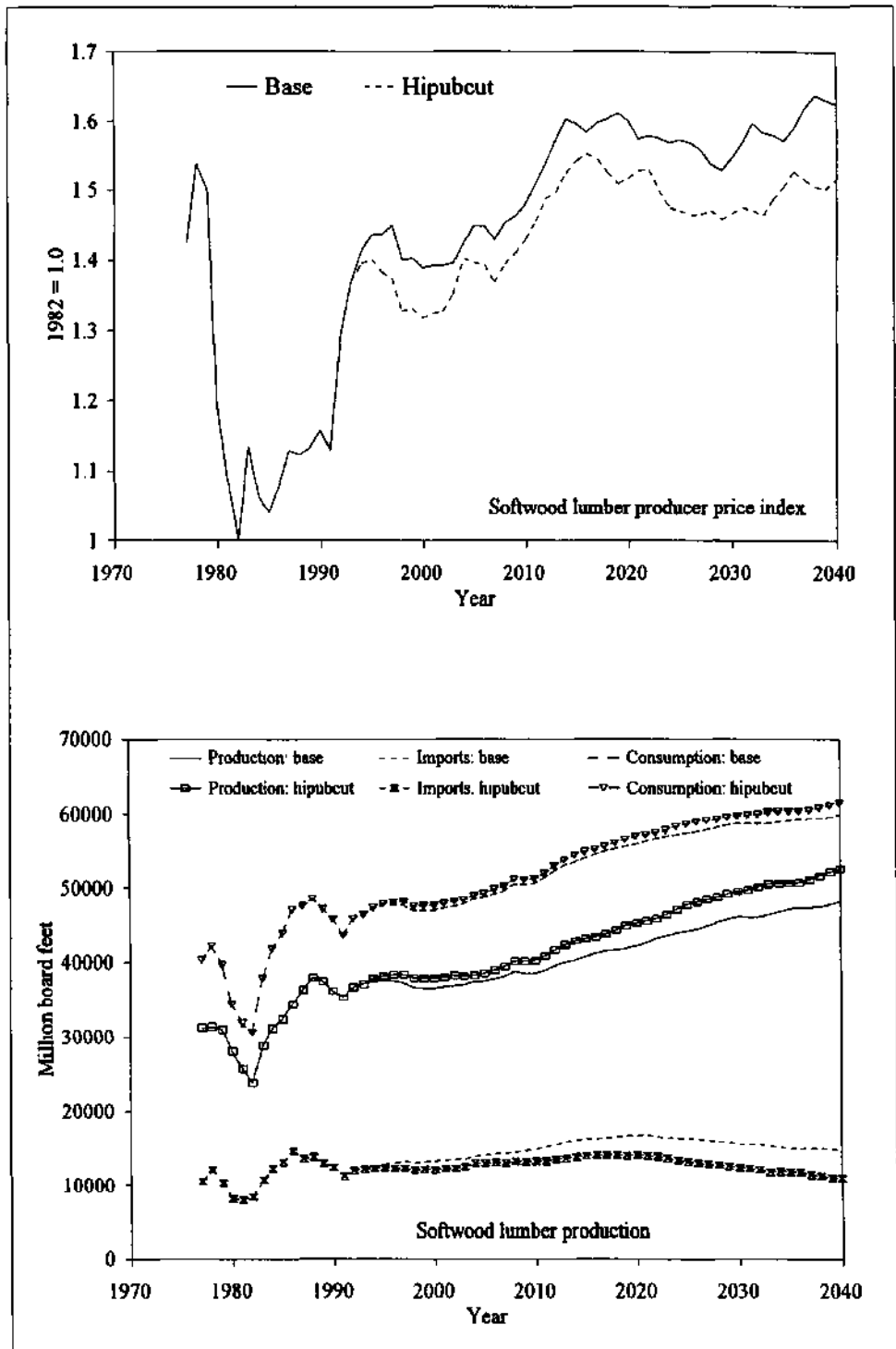


Figure 19—Projected softwood lumber producer price index and U.S. production, consumption, and imports: BASE case and increased public harvest scenarios.

rapidly, reflecting major recent gains in actual levels of usage and marked revisions in projections of future relative fiber costs. Ince (1994) discusses the technical basis for continued expansion in the use of recycled fibers and provides the motivation for this scenario.

The following tabulation gives recent historical rates of wastepaper use,²⁷ projections from the 1993 assessment update and past assessments. The increased recycling scenario calls for usage rates of about 60 percent beginning in 2020.

Wastepaper usage				
Year	Actual	Base		Increased recycling
		1989	1993	
Percent				
1986	24.7			
1991	29.2			
1993	33.0 _{est}			
2000		21	37.5	45.3
2010		22	41.2	56.5
2020		25	42.5	60.6
2030		27	43.7	60.8
2040		28	45.4	59.5

As shown in fig. 20, the effect of greater use of recycled fiber is to lower non-sawtimber demand and aggregate growing-stock removals for both softwood and hardwood in all regions. Particularly large reductions occur in Eastern softwoods, because the largest share of U.S. pulpwood harvest occurs in the East. Over time, this yields some expansion in timber inventories, reduces softwood sawtimber stumpage prices, raises sawtimber demand for lumber and plywood, and allows an expansion in softwood sawtimber harvest. Given this chain of interactions, and recognizing that all elements of private timber management intensity are fixed in the scenario at their base levels or trends, high recycling could be seen as having some potential to compensate for other policies that act to reduce timber supply.

Increased Public Regulation of Private Practices

In a recent study, Greene and Siegel (1994) obtained judgmental estimates of the potential timber supply impacts of current and potential future changes in State and Federal regulation of private forest practices from panels of forestry experts in various U.S. regions. The results of this process were a set of average percentage reductions in private timber "supply" by region associated with the two levels of regulation (current and potential future). We examine the more stringent "potential future change" category here by multiplying the stumpage supply functions in both TAMM and NAPAP by (one minus) the appropriate fixed regional percentage.

²⁷ Wastepaper usage rate is the ratio of recovered wastepaper used in domestic paper and board mills to domestic production of paper and board.

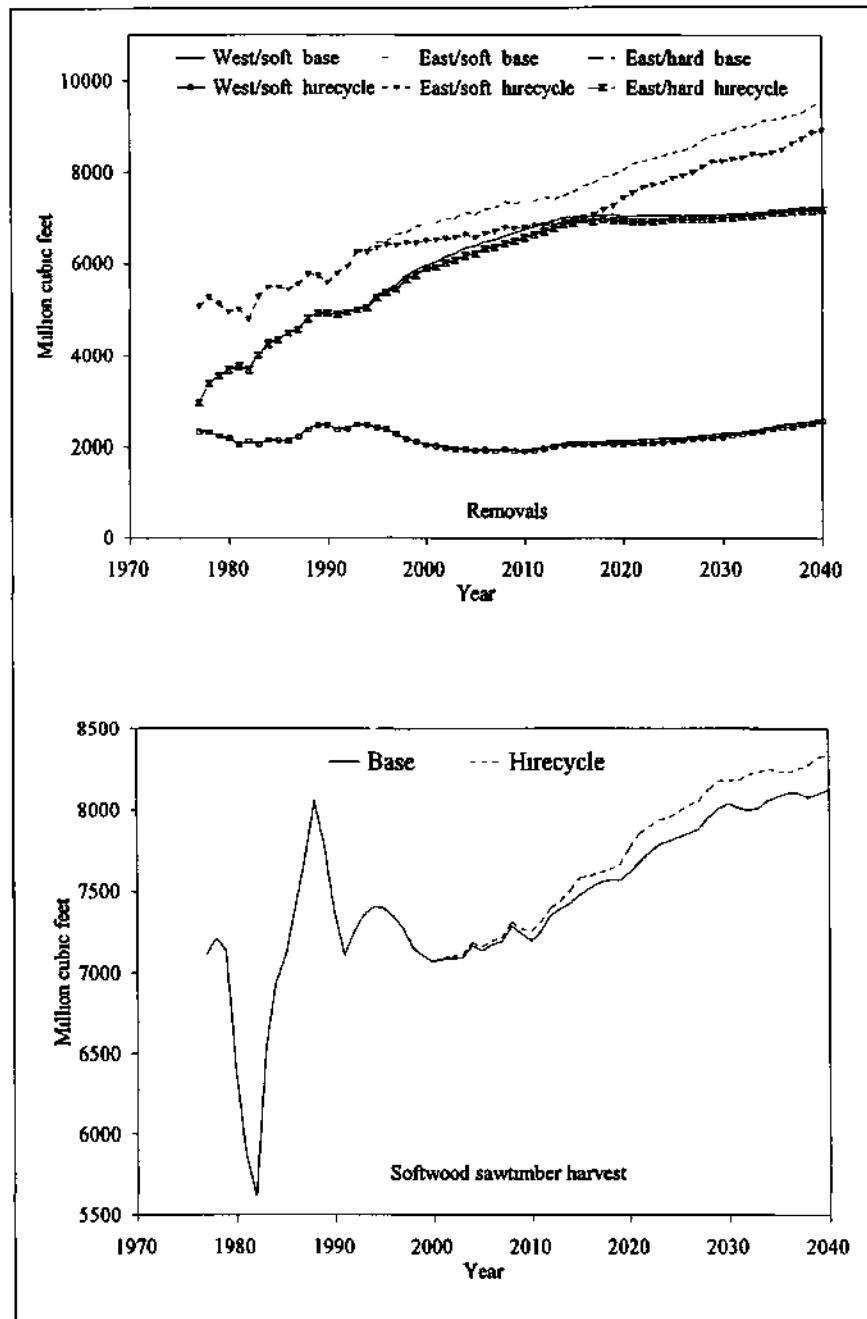


Figure 20—Projected softwood and hardwood growing-stock removals and softwood sawtimber harvest: BASE case and high recycle scenarios.

The results, as illustrated in figure 21, run somewhat counter to intuition because of substitution of fiber sources in the pulp sector. Reduced private supply lowers U.S. average annual softwood growing-stock removals by some 4.7 percent relative to the base scenario. The largest impact is on pulpwood harvest, however, with a substantial shifting of pulp fiber demand to nonroundwood and nonwood (recycled fiber) sources. This shift occurs rapidly and frees enough additional inventory to allow sawtimber harvest to rise relative to the base. Expanded inventories and private supply lead to reduced sawtimber stumpage prices in all regions.

Canadian Lumber Output Restriction

There has been some discussion in recent years of possible reductions in allowable cut levels on Crown lands in virtually all Canadian provinces (examples from British Columbia include, Government of British Columbia 1994 and Reed 1993). Restrictions would result from a combination of land withdrawals for natural preserves and from lagging regeneration on lands harvested in the past. The extent of such restrictions is, at present, highly uncertain as is the distribution of any reductions across the solidwood and fiber products sectors. To obtain some preliminary idea of the potential impacts of such changes on U.S. markets, we examined a case in which harvest restrictions are limited to the solidwood sector and act to constrain output in the future to levels no higher than those observed in the peak periods of the late 1980s.

In Canada, the hypothetical restriction reduces total softwood lumber output by an average of 3.6 billion board feet per year between 2000 and 2040 relative to the base (see fig. 22). Because Canadian domestic and non-U.S. export demands are insensitive to price in TAMM, exports to the United States fall by a similar amount. Net U.S. consumption falls by an average of 0.8 billion board feet per year (relative to a total of roughly 52 billion board feet) as U.S. domestic output rises by 2.8 billion board feet per year. Softwood lumber prices are on average 4.8 percent higher than the base.

Future Modifications in TAMM Structure and Solution

Until recently, TAMM has been run exclusively on a mainframe computer. With the advent of high-speed, high-capacity microcomputers, TAMM now has been adapted to the PC environment. Experimental systems have been developed to run TAMM-NAPAP iterations with the bulk of the file transfer procedures between models automated through spreadsheets and to link the models in their annual solution cycles with only a one-period lag. Future efforts will continue to refine this critical model interface.

The reactive programming algorithm used in TAMM since its inception has many advantages as a solution procedure, including speed and compactness. It has proven increasingly difficult, however, to adequately represent many types of policy scenarios in this structure, particularly those that involve constraints on endogenous variables such as interregional flows, levels of output in the stumpage sector, or limits on multi-regional changes in capacity. Experimental versions of TAMM have been developed in which the spatial market solution procedure uses a nonlinear programming framework following the "net revenue" maximization approach described by Takayama and Judge (1971) and Martin (1981). This has also enabled simultaneous solution of the softwood and hardwood sectors.

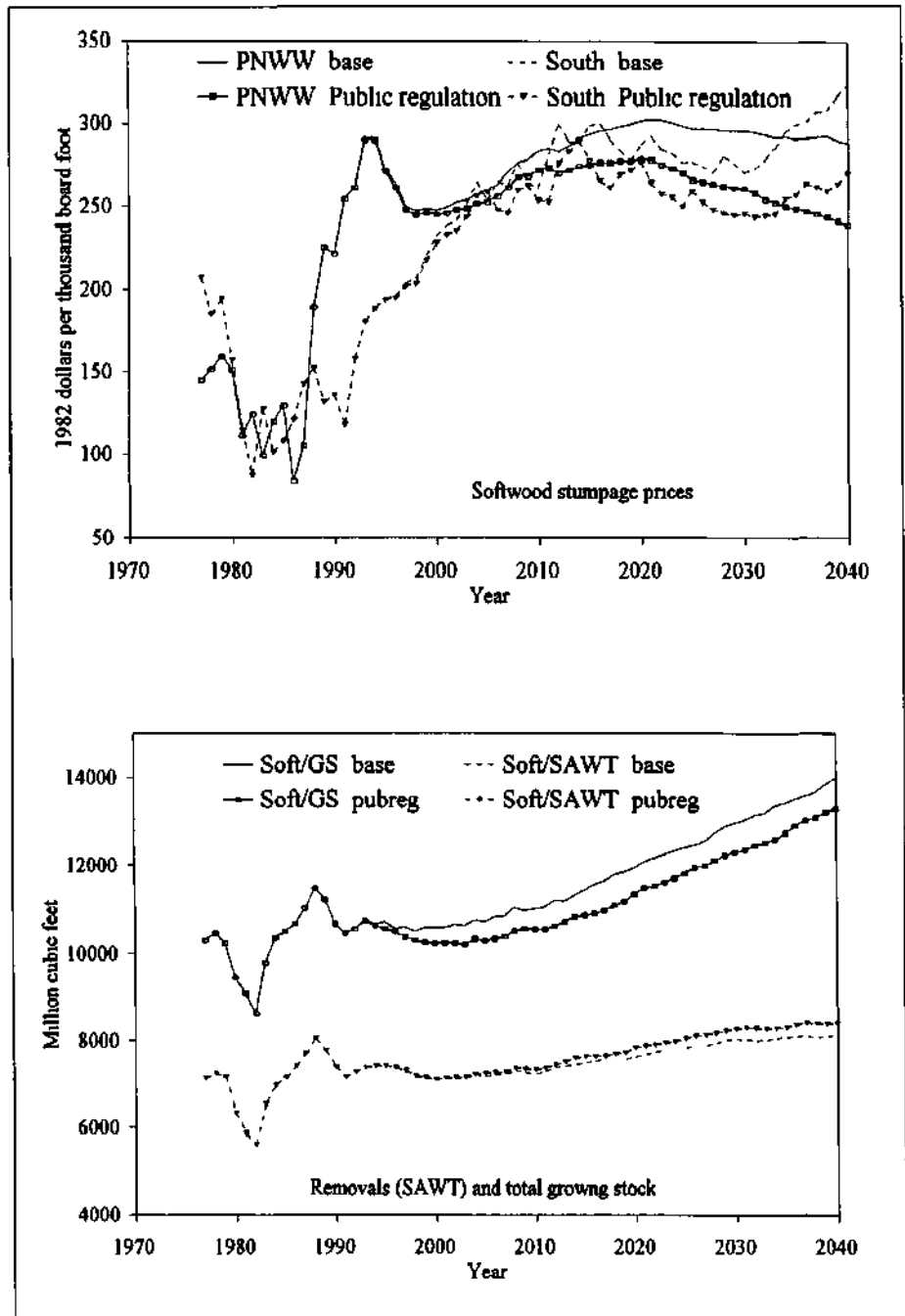


Figure 21—Projected softwood stumpage prices and growing-stock removals BASE case and increased public harvest scenarios

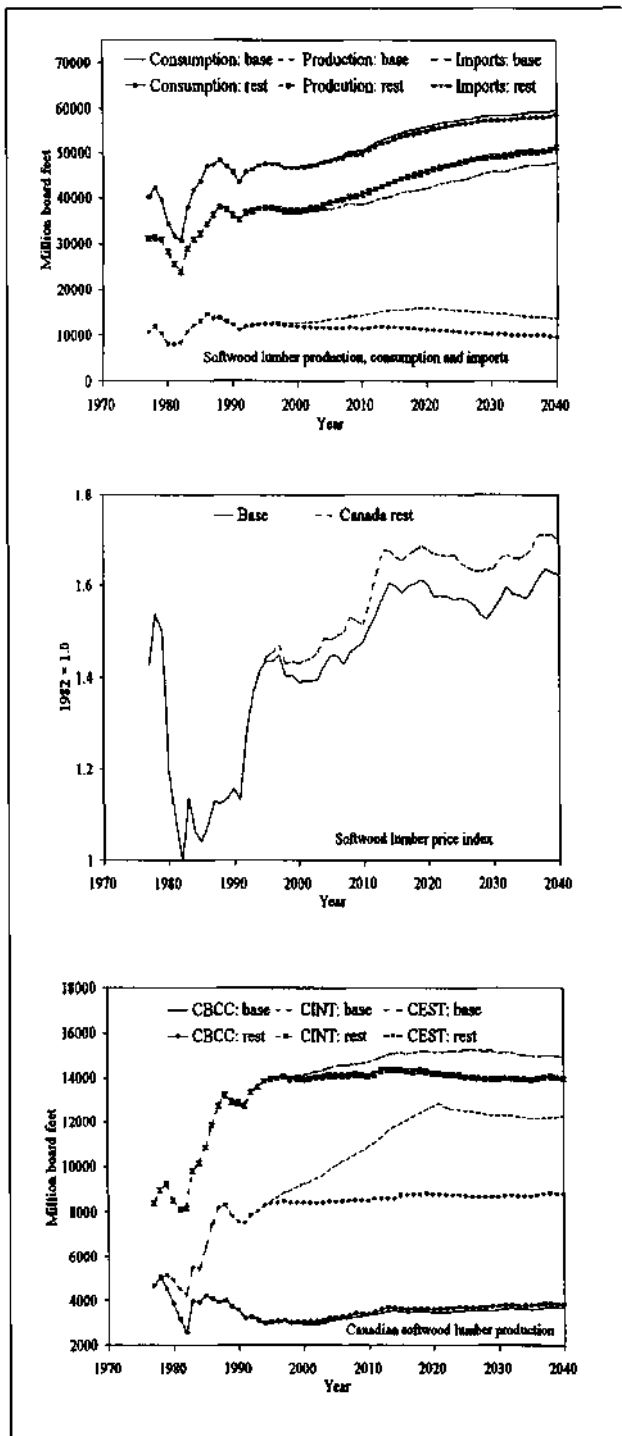


Figure 22—Projected U.S. softwood lumber production, consumption and imports, softwood lumber price index, and Canadian softwood lumber production: BASE case and restricted Canadian harvest (REST) scenarios.

Product supplies in TAMM have always been represented by continuous functions whose parameters have been estimated by econometric methods. Although useful in many respects, this approach limits the types of future product supply scenarios that can be simulated, particularly ones involving new or speculative production technologies not now widely used. Efforts are underway to develop an activity analysis representation of U.S. and Canadian lumber and plywood supply to supplant the continuous, aggregate form. This will involve specification of various existing technologies by region with associated costs and conversion coefficients (as in the present version of TAMM, there will be no product quality differentiation). Implementation of this approach also will entail an evaluation of the ability of the activity analysis form to track historical market behavior.

The current structure of ATLAS involves periodic (5- to 10-year) inventory updates, whereas TAMM operates on an annual cycle. As noted in figure 1, this disparity in projection cycles requires an additional iterative process to ensure that the annual inventory approximations generated in TAMM are "close enough" to the periodic projections developed by ATLAS. Work is now underway to allow ATLAS to employ an annual cycle. This modification may increase the size of the ATLAS module and its operating time. At the same time, it will dramatically simplify the overall projection process (by eliminating the TAMM-ATLAS iteration) and improve the ability to control simulations.

With the above modifications in place, it will be possible to directly merge much of the solidwood market solution directly with the pulpwood sector in the same solver and period-to-period update process, eliminating the need for the TAMM-NAPAP iteration. As presently envisioned, implementation of this merger will use the programming solution package presently used with NAPAP operating under an expanded simulation controller program that integrates other wood-using sectors and the timber inventory.

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The 1993 timber assessment market model (TAMM) is a spatial model of the solidwood and timber inventory elements of the U S forest products sector The TAMM model provides annual projections of volumes and prices in the solidwood products and sawtimber stumpage markets and estimates of total timber harvest and inventory by geographic region for periods of up to 50 years TAMM and its companion models that project pulpwood and fuelwood use were developed to support the quinquennial Resource Planning Act (RPA) timber assessments and assessment updates conducted by the USDA Forest Service This report summarizes the methods used to develop the various components of TAMM and the estimates of key behavioral parameters used in the TAMM structure, and also illustrates the use of TAMM with a base and several scenario projections

Keywords Forest sector models, supply, demand, prices, timber supply, RPA

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