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Models Needed to Assist in the Development of a National Fiber Supply Strategy for the 21st Century: Report of a Workshop

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Roger A. Sedjo and Alberto Goetzl

Abstract

This discussion paper reports on a Workshop on Wood Fiber Supply Modeling held October 3-4, 1996 in Washington, DC. The purpose of this discussion paper is to provide an overview of some of the modeling work being done related to timber supply modeling and some of the issues related to the more useful application of wood fiber supply and projections models. This paper includes brief presentations of three commonly used long-term timber projections and forecasting models: the Timber Assessment Market Model (TAMM) of the Forest Service; the Cintrafor Global Trade Model (CGTM) of the University of Washington; and the Timber Supply Model (TSM) of Resources for the Future. Also, issues related to the useful of the models are addressed as well as a discussion of some applications of other timber or fiber projection models. The usefulness of the models are addressed from both a technical perspective and also from the perspective of their usefulness to various model users.

Key words: timber models, market forecasting models, wood fiber supply, projections

JEL Classification Nos.: C62, Q21, Q23

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1. Introduction

Roger A. Sedjo and Alberto Goetzl

On October 3-4, 1996, Resources for the Future (RFF), together with the American Forest and Paper Association (AF&PA) and the US Department of Agriculture Forest Service (USDA-FS) jointly sponsored the "Workshop to Examine Models Needed to Assist in the Development of a National Fiber Supply Strategy for the 21st Century. The Workshop, held at the Kimball Conference Center at RFF in Washington, DC, was attended by about 35 participants.

The driving force of the Workshop was W. Henson Moore, president of AF&PA. whose earlier experiences in the energy sector demonstrated to him the usefulness of long-term models to assist in the development of long-term sector strategies. The Workshop was viewed as the first step in a process that will ultimately assist the US, and indeed North America, in better anticipating future wood fiber needs both domestically and globally.

To this end the Workshop assembled the foremost economic forest modelers in North America, and indeed probably the world. They met together for two days with representatives of the forest products industry and government to discuss the cutting edge models that exist and to ponder how these could be used to form a more effective approach to addressing the Development of a National Fiber Supply Strategy for the 21st Century. The purpose of this collection of papers is to capture some of what transpired at the Workshop.

The Workshop was focused around presentations of the four commonly used long-term timber projections and forecasting models. This are the Timber Assessment Market Model (TAMM) of the Forest Service; the Cintrafor Global Trade Model (CGTM) of the University of Washington; the Timber Supply Model (TSM) of Resources for the Future; and the North American Pulp and Paper Model (NAPAP) of the Forest Service's Forest Products Laboratory. Short papers describing the first three models are presented in this volume as well as other papers that discuss aspects of all four models. A copy of the agenda of the meeting is found in Appendix A and a list of participants in Appendix B.

The objective of this volume is to capture some aspects of the very productive Workshop and to allow for its dissemination. To facilitate an understanding of the issues, this volume is made useful to the non-technician by minimizing the use of complex mathematics. Nevertheless, some technical background is necessary for an understanding of some parts of the presentations.

The structure of this volume is as follows: First, Joshua Bishop's paper presents some recent examples of how forest sector models have been used with special reference to the recent IIED study of the global pulp and paper industry. This is followed by a paper by Brent Sohngen in which he presents a "Historical Perspective of Modeling Timber Markets" in which he compares and contrasts the models within a somewhat broader discussion of earlier models and the strengths and weaknesses of various approaches. This is followed by papers focused on the specific models. These are: Haynes and Adams on the TAMM; Perez-Garcia and Lippke on the CGTM; and Sedjo and Lyon on the TSM.

The next section consists of a number of papers addressing a range of issues related to the usefulness of forest projection models, from general issues to specifics of individual models. Paul C. Van Deusen gives his perspective in "One User's View of Fiber Supply Market Models," while Fred Cubbage's paper examines the promises and problems of timber supply modeling. A paper by Steve Winnett discusses recent EPA timber modeling activities. Next, Michael Carliner gives a home builder's perspective in his "Comments at the Workshop on Fiber Market Models." Finally, Alberto Goetzl presents his review and observations of the Workshop in his paper "Fiber Supply Modeling -- Advancing the Art (and Science).

Additionally, the Workshop also benefited from the modeling experience of another natural resource sector - energy. An important perspective was provided by John Weyant in his discussion of some recent work on energy modeling undertaken by the Energy Modeling Forum at Stanford, although that work is not represented in this volume.

Overall, these papers represent work in progress. We believe that the Workshop provided an important first step, but only a first step, in a process that we expect will eventually assist the US and North America in developing a National Fiber Supply Strategy for the 21st Century. Such a strategy will allow the forest industry to better anticipate and plan for the future wood fiber needs of the globe.

2. Beyond Price and Volume: Forest Sector Models and the Environment

Joshua Bishop[1,2]

INTRODUCTION

Traditionally, economic forecasting models of the forest sector have focused on a few key variables of interest to policy-makers and industrialists, in particular the price of wood, the volume of production and consumption, and in some cases, employment. Today, however, public concern about the environmental impacts of industrial forestry leads model users to seek additional information. This presents a challenge to model builders, who must find ways to incorporate a broader set of input variables and output indicators in their creations.

This paper offers some suggestions with respect to the types of environmental questions that forest sector models must begin to address, from the perspective of a model user. It is based on recent experience at the International Institute for Environment and Development (IIED), which has commissioned forecasts of the global forest sector on two occasions during the past four years:

- once for a global study of timber trade policy, for the International Tropical Timber Organization (ITTO); and more recently,
- for a global study of the pulp and paper industry, sponsored by the World Business Council for Sustainable Development (WBCSD).

These studies, and the role of forest sector modeling within them, are described below. We then make a few suggestions on how forest sector models could be enhanced to address questions related to land use, environmental indicators, substitution effects and the dynamics of the supply response.

FOREST SECTOR MODELING, INTERNATIONAL TRADE POLICY AND THE ENVIRONMENT: THE ITTO STUDY

In 1992-1993, IIED carried out a major study for the ITTO of the role of forest sector and trade policy in tropical forest management (Barbier *et al.* 1994). The particular focus of the study was on the potential for using trade instruments to encourage more sustainable forest management in the tropics. At the time, there was much discussion in policy-making circles

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[2] The author gratefully acknowledges and thanks Bruce Lippke and John Perez-Garcia, of CINTRAFOR, Kenneth Lyon of Utah State University and Roger Sedjo of Resources for the Future, for their many and patient explanations of the mysteries of forest sector modelling.

(especially in Europe) in favor of trade bans or increased barriers on tropical timber imports. This in turn was stimulated by public concern about deforestation. Such concerns are still widespread, but the enthusiasm for trade restrictions has waned.

As part of the study, IIED commissioned the Center for International Trade in Forest Products (CINTRAFOR), in Seattle, to develop a set of forecasts and policy simulations, based on their Global Trade Model (CGTM). A particular attraction of the CGTM was the relatively detailed treatment of bilateral trade flows in the model, which enabled us to assess the potential trade effects of alternative policies at a regional or country level.

One of the main conclusions of the study was that unilateral imposition of barriers to trade in tropical timber by importing countries would not help to encourage better forest management in the tropics, and might even hurt, by depressing producer prices and thus reducing the economic incentives to invest in forestry. Thanks to the work of CINTRAFOR, we were also able to show the potential cost of trade barriers to developing countries, in terms of reduced market share and export revenues, as well as the likely impact on consumers through higher product prices.

While CINTRAFOR's Global Trade Model provides rich detail on bilateral trade flows between regions, thanks to separate estimation of demand and supply for each responsive region, the dynamics of trade are not easily captured by such a mathematical model. In particular, one can argue with the way that historical trade relations are captured in the CGTM, through the use of "inertial" limits on period-to-period shifts in trade flows. A modeler's response might be that trade flows reflect many non-price factors, such as cultural and political links between countries or multi-year delivery contracts, which are not amenable to formal specification. Such factors can often only be approximated in the model by rules and limits which, to a casual observer, may seem arbitrary.

This kind of approximation is not always easy to explain to the sponsors and ultimate users of economic policy analysis. Unfortunately, some people seem to believe that anything less than a perfect mathematical representation of the world, with all its blemishes and foibles, is a waste of time and money. Others simply dismiss all models as artifices which can be used to prove anything and thus prove nothing. At IIED, however, we believe that forest sector models can make an important contribution to informed policy analysis, by providing a consistent framework for comparing alternative scenarios or policy options.

FOREST SECTOR MODELING AND INDUSTRIAL SUSTAINABILITY: THE PAPER CYCLE STUDY

In 1995 IIED again sought the services of a forest sector modeler, for a major study of the global pulp and paper industry, sponsored by the World Business Council for Sustainable Development (IIED 1996). Our brief was to examine the entire paper cycle, world-wide, from fiber production through manufacturing, consumption, recycling and disposal. IIED was asked to evaluate the industry's current performance and future prospects in social, economic and environmental terms - in short, to assess the extent to which the industry was "on track" with respect to the vexatious term "Sustainable Development".

This was an impossibly ambitious objective, of course, not least because of the many different (and sometimes incompatible) views of what constitutes sustainable development. Such differences often led to heated arguments during the course of the study, both among ourselves and with our partners from industry, government and the environmental movement. Much of the debate ultimately boiled down to differences of opinion rather than fact, especially regarding the moral legitimacy of modern consumer lifestyles in the developed world, and the age-old conflict between relativism and absolutism in public policy-making.

One issue on which matters of fact did usefully intrude, however, was the perennial question of whether the world is running out of raw material, in this case, wood resources. This is a myth that just won't die! This author holds to the view that human economies have always adapted to relative scarcity and that, as long as they are allowed to do so, market economies will meet the twin challenges of rising demand and increasing raw material costs.

However, not everyone shares this optimistic view, including many people in positions of authority in industry and government, not to mention the environmental movement. IIED therefore decided, once again, to commission some modeling in order to address the question of whether, and to what extent, the world faces a serious wood "fiber gap." On this occasion we approached Roger Sedjo of Resources for the Future and Kenneth Lyon of Utah State University, attracted by the sophisticated supply response in their Timber Supply Model.

At IIED's request, Sedjo and Lyon made a number of improvements and modifications of their model. In addition to partially updating the underlying database, they were able to distinguish pulpwood from solid wood, and to allow for substitution between wood harvested for pulp and wood destined for solid products. The result was a new, improved "Pulpwood Supply Model" (PSM) also referred to as TSM96 (Sedjo and Lyon 1996).

IIED's main objective in using the TSM96 was to forecast the likely response of industrial wood producers to increased demand for fiber over the long-term. We wanted to know how much wood fiber would be required, where it would come from and at what price. As a result of the modeling, we were told that world fiber supply will keep up with rising demand, although higher real prices suggest some tightening.

In addition, Sedjo and Lyon were asked to simulate a number of alternative scenarios. These were designed to represent various people's fears and proposals with regard to future demand and supply conditions.

Thus one scenario examined the impact of vastly increased demand for fiber, which might result from higher than expected economic growth in the developing world. Another scenario considered the potential impact of depressed demand for virgin wood fiber, due to increased recycling of waste paper or widespread adoption of an "ascetic" lifestyle by Northern consumers - not a very likely scenario, perhaps, but one strongly supported by many environmentalists and thus worthy of consideration in its own right.

We also developed a number of scenarios focusing on the supply-side, on the grounds that many environmentalists demand (and many industrialists fear) further set-aside of forest lands and the adoption of more costly forest management and harvesting systems. Finally, we considered various combinations of demand and supply scenarios, to account for the possible interactions between complementary or competing proposals and trends.

In general terms, of course, the results were entirely predictable. Higher growth in demand for pulp leads to more rapid increase in output and a rise in prices, relative to solid wood. Forest set-asides and cost increases lead to slower growth in output and similarly high prices. It's fair to ask whether we really needed a fancy computer model to tell us this.

The advantage of the model, in this case, is not in telling us the direction of change - which we could have predicted - but rather the relative magnitude of change in different regions and under different assumptions.

SOME LESSONS AND CONCLUSIONS: A MODEL USER'S PERSPECTIVE

Based on IIED's experience with the CINTRAFOR GTM and with Sedjo and Lyon's TSM96, a number of observations can be made regarding the qualities or features of a "useful" forest sector model. To begin with the obvious:

- price matters - a model which cannot simulate the way that prices adjust to match demand and supply is not worth having;
- a good model must attempt to capture the way that wood producers alter their investment, management effort and harvest decisions in response to changes in relative prices; and,
- trade matters - the international organizations and development agencies that IIED typically works for care tremendously about imports and exports. Hence from my point of view a good model should permit explicit estimation of trade flows. This in turn requires regional detail, both on the demand side and the supply side.

Of course, these are only the bare minimum features of a useful forest sector model -- most existing models already achieve this. However, some other desirable features of a forest sector model are not so widespread. Based on IIED's experience, several potential areas for improvement may be suggested. Inevitably, these will reflect the peculiar vantage point of an international policy research institute engaged in global studies of the linkages between environment and development. They are as follows:

Land Use

Forest sector modelers need to account more fully for competition for land and forests, both from within the industry and from agriculture and other land users. Exogenous adjustments of the resource base are not a convincing way of accounting for change in the opportunity cost of land and timber. Recent dramatic increases in plantation establishment in some regions, for example, are both stimulated by and ultimately limited by the availability of good, cheap land. Additions to the resource base thus need to be endogenized as much as possible.

Other factors likely to influence the future availability and cost of forest land and products, especially in the developing countries, include:

- increased demand for forest conservation and forest recreation;
- increased demand for agricultural land and; in some countries,
- reduced demand for fuel wood, as incomes rise and people switch to fossil fuels.

Of course, forest sector models are different from agriculture sector models. Nevertheless, one cannot but wonder if it might be possible to improve the linkages between forest sector models and other land using sectors. Or should we, perhaps, be thinking in terms of integrated land use models, combining agriculture, industrial forestry and other uses?

Environmental Indicators

A second and related point is that forest sector models need to include and report a broader range of results indicators. Many policy-makers and observers of the industry are concerned about environmental attributes, such as changes in forest cover, age distribution and species mix. Others worry about employment and tax revenue. Most models, on the other hand, focus exclusively on timber price, production volume and capacity. Perhaps it would not be too difficult to extract some additional information of interest to non-industrialists, which could also be used as decision variables.

Substitution Effects

Substitution is another problem: hardwood versus softwood, pulpwood versus solid wood, tropical versus temperate, and of course wood versus non-wood. Some models are better than others in this regard, but all could be improved in their treatment of quality differences among wood producers, as well as substitution between wood and non-wood products. This has implications for whether models allow real price differentials to persist across regions or, if a "law of one price" approach is used, how to account for quality differences.

The Dynamics of Supply Response

Based on the limited experience of IIED, it would appear that the dynamics of supply response are either not very well understood or are poorly captured by existing forest sector models. Both of the models we used seem to rely heavily on "ad hoc" adjustments, e.g. the use of long-run moving averages, limits on substitution and other "inertial" factors. While such compromises may be required, and justified, as a means of addressing non-price influences on supply, they leave a bad taste in the user's mouth.

In other cases, supply response can seem overly-idealistic, as in the PSM's assumption of rational expectations to account for the impact of anticipated future prices on current investment and harvest decisions. Irrespective of the validity or otherwise of a rational expectations approach in forest sector modeling, it is clearly a difficult concept to convey to our non-economist colleagues and clients, particularly when it leads to such strange results as different (current) starting points in supply forecasts!

In conclusion, there are a number of areas where forest sector models could be improved to provide more useful information for economic and environmental policy analysis. Particular areas for improvement include impacts on land use and competition for land, the need for a broader range of environmental and social indicators, product substitution issues and the dynamics of supply response.

REFERENCES

Barbier, E.B., J. C. Burgess, J. T. Bishop, and B.A. Aylward. 1994. *The Economics of the Tropical Timber Trade*. Earthscan. London.

IIED. 1996. *Towards a Sustainable Paper Cycle*. London: International Institute for Environment and Development.

Sedjo, R. A. and K. S. Lyon. 1996. *Timber Supply Model 96*. RFF Discussion Paper 96-15. Washington, DC: Resources for the Future.

3. An Historical Perspective of Modeling Timber Markets

Brent Sohngen[1]

Abstract

The theoretical background for four widely used timber market models is described and their structure is compared. Model projections over the past 20 years are then presented alongside revealed market activity. Such a comparison allows us to analyze important factors that contribute to differences in market predictions among the models. Several conclusions are drawn. First, theoretical differences suggest that alternative models may best be used to answer different questions, depending on several factors. Second, model outlooks depend on model theory, model scope and exogenous growth and management assumptions. It is not always clear which differences are most important. Finally, the models are not intended for short term model predictions, and the model comparison suggests that users should not rely on them for that purpose.

INTRODUCTION

Over the last 15 to 20 years, numerous timber market models have been developed to analyze policy changes, to project market behavior, or to consider other, more specific questions related to timber markets. While similar in some respects, most models are quite distinct in the economic theory upon which they rely, and all of them are different in the scope of their analysis. Scope includes issues such as how many regions or how many market levels to consider. In addition to structural differences, the models have often been at odds in their actual predictions of future market activity.

These differences raise several interesting questions: (1) what are the predominate theoretical and structural differences; (2) how do theoretical differences affect predictions; and (3) what is the track record for these models? Although economic theory and modeling is unlikely ever to find the perfect predictive tool, it is nonetheless interesting for researchers and modelers to analyze critically their past endeavors. This is of particular interest for timber market modeling, where model results may be used as the basis for harvesting decisions, capital investment decisions, and policy-making.

This paper attempts to answer the three questions raised above. Looking first at theoretical differences, the model structures are compared. Then the discussion centers on assessing how these differences may affect market behavior. Turning to actual predictions over the past 20 years, the historical record of these models is analyzed relative to actual

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market indicators. Such a comparison provides insight into both model performance, as well as the specific factors that may have lead to differences in predictions.

A word of caution about this paper: it is not about trying to find the best timber market model. Instead, it compares and contrasts the theoretical underpinnings and the empirical results of four such models in light of historical revelation. It follows, to some extent, Binkley and Vincent (1988), but they did not have the benefit of an historical perspective.

The four models considered in this paper are the Timber Assessment Market Model (TAMM; Adams and Haynes, 1980), the CINTRAFOR Global Trade Model (CGTM; Cardellichio et al., 1989), the Timber Supply Model (TSM; Sedjo and Lyon, 1990), and the North American Pulp and Paper Model (NAPAP; Ince et al., 1994a). All models except for the NAPAP model have been in the literature since the mid or early 1980s, with the TAMM model having the longest historical record of activity. The NAPAP model in its current form is a relative newcomer to timber market modeling, although it is a substantially revised version of and earlier model (the PAPYRUS model; Gilles and Buongiorno, 1987). Including the NAPAP model is important and interesting because it models a market segment that historically has been under-modeled by the other groups. The TSM model has recently been revised to include pulp markets (Sedjo and Lyon, 1996), but the revised edition is not considered here because there is no historical record associated with it.

THE MODELS

While the theoretical and empirical literature of timber market models has a long history, this paper considers only the literature relevant directly to the four models compared. The reader is referred to Adams and Haynes (1980) for an excellent summary of the evolution of timber market models. This section considers the theoretical and empirical differences between the models.

The four models are the Timber Assessment Market Model (TAMM; Adams and Haynes, 1980), North American Pulp and Paper Model (NAPAP; Ince, 1994a), CINTRAFOR Global Trade Model (CGTM; Kallio, et al., 1987 and Cardellichio et al., 1989) and the Timber Supply Model (TSM; Sedjo and Lyon, 1990). The theory behind each of the models represents a wide cross-section of modeling approaches and modeling scope. Three of the models-- TAMM, NAPAP, and CGTM-- are based on similar theory, although they differ significantly in geographic scope, detail, and market levels considered. TSM rests on a distinctly different line of economic theory from these three models, although it is similar to the CGTM model in that it is global.

The Timber Assessment Market Model

The TAMM model was developed in the late 1970s as a tool for the US Forest Service's Resource Planning Act (RPA) timber assessment. The RPA timber assessment is decadal evaluation of the supply and demand situation for timber in the United States mandated by Congress. In recent years, TAMM has been used extensively for policy analysis of forestry sector issues within the US (Adams and Haynes 1990, 1991a, 1991b; Winnett et al., 1993; and Sohngen and Haynes, 1996).

TAMM may be broadly classified as a static simulation timber market model. A static simulation model utilizes econometrically estimated functions of demand and supply behavior to determine the single period equilibrium price and harvest level. By linking together solutions in many periods, static simulation models are used to project market behavior over time.

Such a model differs significantly from dynamic econometric and dynamic optimization models, although it is "dynamic" in the sense that it projects behavior over time. Dynamic econometric models are those that make use of the autoregressive structure of time series data in forecasting future behavior (see Box and Jenkins, 1970). Alternatively, dynamic optimization models make use of rational expectations, and the maximization of discounted market welfare. Future market activity is assumed to be rationally predicted by producers and consumers today, so that decisions made in any one period are consistent with future market activity.

The TAMM model made (at least) two very important innovations over previous attempts to model timber market behavior. First, TAMM recognized the spatial nature of both supply and demand in timber markets by making use of the theoretical structure pioneered by Samuelson (1952). Such models recognize the importance of the transportation costs necessary to move products from manufacturing facilities to demand centers. Because the most productive forests are located remotely from the urban centers where most wood is demanded, transportation costs are an important component in the overall value of wood.

A spatial market model attempts to maximize consumer's plus producer's surplus minus the costs of transporting products to other markets. In any period, then, the objective is to maximize

$$\sum_i \int_0^{Q_i^D} D(Q_1 \ldots Q_I)\,dq_i - \sum_j \int_0^{Q_j^S} S(Q_1 \ldots Q_J)\,dq_j - \sum_i \sum_j C_{i,j} Q_{i,j} \,, \tag{1}$$

subject to

$$Q_i^D \le \sum_j Q_{i,j} \tag{2}$$

$$Q_j^S \ge \sum_i Q_{i,j} \,. \tag{3}$$

$Q^D{}_i$ is the quantity demanded, $Q^S{}_j$ is the quantity supplied, $D(\cdot)$ is the demand function, $S(\cdot)$ is the supply function, *i* is the demand region, *j* is the supply region, and $C_{i,j}$ is the cost of transporting from region *i* to *j*. As suggested by Adams and Haynes (1987), this type of model does not need to have a social welfare interpretation, although it implicitly maximizes the yearly value of net market welfare, minus transportation costs.

The second important innovation was that TAMM took advantage of two layers of timber market behavior, end-product and stumpage markets. In the final solution to the

TAMM model, both markets in all regions must be in equilibrium in each period. Demand for stumpage is directly related to demand for end-products, such as lumber, plywood, oriented strand-board, and paper, and it is related to the capital (capacity) available to manufacturers in each period for production. Demand for stumpage is derived from the production function for solidwood products.

Stumpage supply functions in TAMM are represented by

$$Q^S(t) = g\left(P_s(t), Inv(t)\right), \qquad (4)$$

where $P_s(t)$ is the price of stumpage and $Inv(t)$ is the total timber inventory. $Inv(t)$ is determined in any period with the following growth-drain equation:

$$Inv(t) = Inv(t-1) - Harvest(t) + Growth(t). \qquad (5)$$

Stumpage supply will therefore shift in or out depending on the size of the total timber inventory. Inventories will shift depending on annual harvests, timber yield, regeneration effort, and land use change. TAMM incorporates exogenous projections of regeneration efforts and land use changes by using the ATLAS (Mills and Kincaid, 1992) inventory projection system. The ATLAS model keeps track of inventories over time for different ownerships and timber types.

The North American Pulp and Paper Model

The North American Pulp and Paper Model (NAPAP; Ince, 1994a, 1994b) is utilized by the US Forest Service to support the RPA Timber Assessment program. Although the NAPAP model itself is a relatively new addition to the modeling literature, it was developed out of a long line of modeling research, as outlined in Ince (1994b). NAPAP is an application of the Price Endogenous Linear Programming System for economic modeling (PELPS III, Zhang et al., 1993).

The theoretical structure of NAPAP is similar to TAMM, in that it is a spatial equilibrium and static simulation market model (following Samuelson, 1952). Whereas TAMM models timber stumpage and solidwood markets, NAPAP models pulp and paper markets. Because these two markets are related through price effects, use of residual outputs, and other factors, the US Forest Service has recently used TAMM and NAPAP together for purposes of market projection, as outlined in Ince (1994a and 1994b).

NAPAP attempts to solve a problem similar to equations (1) - (3) above over pulp and paper markets in North America. The model solves for trade flows between the US and Canada endogenously. While it includes supply and demand functions for other regions (Latin America, Europe, Pacific Rim, Other), these regions are incorporated exogenously.

NAPAP is highly disaggregated, containing much detail on pulp and paper markets. Market pulp, for example, is broken into five distinct commodities or separate manufacturing processes for five regions: softwood chemical, hardwood chemical, mechanical, recycled, and dissolving and special alpha. Pulpwood stumpage supply includes softwood roundwood, softwood residues, hardwood roundwood, and hardwood residues for five regions. Virgin wood fiber supply from pulpwood stumpage is determined endogenously with estimated equations, while recycled material supply is exogenously predicted. The reader is referred to Ince (1994b) for additional detail. As with TAMM, pulpwood inventories are projected over time with the ATLAS inventory model.

Despite similarities to TAMM, NAPAP employs a distinctly different capital adjustment mechanism. It utilizes Tobin's "q"theory (Tobin, 1969) to characterize annual capital adjustments. This theory suggests that the decision to purchase new capital relies on the shadow value of new capital relative to the costs of adding that new capital. Shadow values for adding new capital can be determined each period, and the costs of new capital can be projected to determine optimal levels of capital expenditures each period. The shadow value in this case refers to the marginal value to the one-period linear objective function of increasing capital one additional unit.

The Center for International Trade in Forest Products (CINTRAFOR) Global Trade Model

The CINTRAFOR Global Trade Model (CGTM) is an extensively revised version of the modeling effort undertaken by the International Institute for Applied Systems Analysis in the 1980s to develop a global trade model of the forest sector (Kallio et al., 1987). The effort involved many different experts in both forestry and timber market modeling from across the globe. The model is now maintained and utilized by CINTRAFOR at the University of Washington.

The CGTM model operates much like the two previous models in that it is a spatial equilibrium market model that attempts to maximize the sum of a set of regional or country level consumer's plus producer's surplus minus all transportation costs. It differs significantly from the two previous efforts in several major respects. First, it is global in nature; it includes data and trading between at least 40 regions of the globe. Prices and production levels are therefore determined both globally and regionally, based on the inter-regional trade patterns that maximize social welfare (equation 1 above) in any particular period. The CGTM model allows for regional log trading, in addition to end product trading (Cardellichio et al., 1989).

Second, the CGTM models both a solidwood and pulp and paper component simultaneously, although it does not solve the pulp and paper sector endogenously. While not solving both markets endogenously is a limitation of sorts, CGTM appears to have been one of the first of the timber models considered here that attempts to model these two markets together.

Finally, for the solidwood market, CGTM estimates only one demand function for final goods in each region, rather than a set of demand functions for different products. The demand function that is used is based on the major end products produced by that country or region. The main reason for this rests on data limitations associated with estimating demand elasticities for each region (Cardellichio et al., 1989)

The CGTM relies on timber stumpage supply functions that are estimated for different regions. While separate price elasticities for sawtimber stumpage are estimated and included for different regions, the model assumes that inventory elasticity is 1.0 in every region. This represents an empirical departure from the TAMM and NAPAP model, where inventory elasticities rely on estimated equations. Perhaps the main reason for this approach lies in the lack of data in many regions of the world to estimate this information. Future inventory levels, however, are projected for each region based on equations (4) and (5) above.

CGTM utilizes exogenous cost shifting and capacity expansion rates, which depend on the modeler's perception of potential future changes. While annual production levels will be dependent on the existing capital structure, future capital levels are based solely on exogenous modeler predictions. Although this is a disadvantage because it does not link capital formation to economic theory (as q-theory does in the NAPAP model), it provides a mechanism that can be adjusted for policy analysis purposes.

The Timber Supply Model

The Timber Supply Model (TSM) is described in Sedjo and Lyon (1990). It is distinctly different from the previous three models in many regards. First, employs optimal control methods in a rational expectations framework. Second, it considers only timber log markets, and it aggregates solidwood and pulpwood usages. Third, it differs from TAMM and NAPAP because it is global, but it doe not model trade explicitly, like CGTM. Finally, TSM allows the choice of timberland management (including regeneration and continuing management costs) investment to be determined endogenously by a rational expectations process.

The objective of TSM is to determine the path of timber prices and harvests that maximizes the net present value of net surplus (consumer's and producer's):

$$Max \sum_{0}^{T} \mathrm{r}^{t} \left\{ \int_{0}^{Q_t} D_t(n)dn - C_t \right\}, \tag{6}$$

where D_t (Q_t) is the demand function for industrial wood volume Q_t harvested in period t, and C_t is the total cost involved with harvesting and transporting timber to markets, and regenerating timberland in each period. Two laws of motion guide the movement of timberland acres from one age class to the next over time:

$$x_{h,t+1} = \left(A + BU_{h,t}\right)x_{h,t} + v_{h,t}e, \qquad \forall\ h,t \tag{7}$$

$$z_{h,t+1} = Az_{h,t} + w_{h,t}e, \qquad \forall\ h,t \tag{8}$$

where $x_{h,t}$ is the vector of timberland acres in type h at time t, $U_{h,t}$ is a vector denoting the proportion of acres that get harvested in each class and type h at t, $v_{h,t}$ is the area of timberland that is exogenously determined to be replanted at time t, and $z_{h,t}$ is a vector of management intensity levels for land already regenerated, and $w_{h,t}$ is a vector of management intensity for land regenerated in this time period. *A*, *B*, and *e* are matrices (or vectors) that describe the motion of acres from one age class to the next over time. Land that is harvested in any period is automatically regenerated with vector *A*, and $v_{h,t}$ represents an additional set of acres that are exogenously assumed to enter forestry, such as plantations.

This problem solves all time periods simultaneously to maximize discounted net surplus. Rational expectations implies that producers and consumers have perfect foresight and that they are making decisions today based on future prices and harvests. The price path that they use for decisions today is the same as the price path that maximizes (6). Although Sedjo and Lyon use a class of solution techniques for this problem that allows them to reduce the multi-period problem into a series of single period problems, their price path will be consistent with an algorithm that solves the problem over every period simultaneously.

By endogenously solving for management intensity, this model makes an important contribution to the literature. It is unclear, however, how to evaluate the path of management intensity predicted by the model relative to actual management because their management intensity measure is applied to all acres at once. There is no direct empirical measure available that relates to this. Unlike CGTM, the TSM model is more aggregated in that it uses a derived demand function for all logs consumed around the globe. There are no separate demand functions and elasticities for each region, and there are no separate projections of rates of change in demand for different regions.

Additionally, the TSM model does not incorporate any information on capital adjustment in the forest products production sector. Lyon et al. (1987) have extended the basic Sedjo and Lyon model to incorporate capital markets, but this framework has not been employed for global timber market analysis. The effect of this model attribute is seen in the rather large period-to-period adjustments that can occur in regional timber harvests over time. The original model also aggregated pulp and solidwood markets. The authors have recently disaggregated their model in order to separate these markets (Sedjo and Lyon, 1996), but those results are not considered here.

COMPARISON OF MODEL STRUCTURE

The theory behind the models can be compared by classifying them into two types: static simulation and optimal control. TAMM, CGTM, and NAPAP are static simulation models, while TSM is an optimal control model. As mentioned above, static simulation models are those that link together a set of single period problems which maximize consumer's plus producer's surplus. Consumer's and producer's surplus are defined as the area underneath an estimated demand function and above an estimated supply function.

Optimal control models, on the other hand, use dynamic optimization techniques to determine the path of price, harvest, and management that maximizes the net present value of consumer's and producer's surplus over all time periods into the future. They endogenously determine price, harvest, and management in each period, and both producers and consumers are assumed to be rational market players, who predict the future correctly on average. The model solution produces a set of first order conditions that defines harvest behavior in any given period.

At the most basic level, there are fairly significant theoretical differences between these two types of modeling techniques. Sohngen and Sedjo (1996) outline and discuss these differences more thoroughly, and they present an empirical comparison between the model types in simplified, single region models. While the static simulation and optimal control models will behave similarly under steady state conditions, price, harvest and inventory behavior differ when exogenous forces shift the models away from steady state conditions. The size of the differences depends on the exact perturbation considered. Model behavior varies most significantly when demand is assumed to shift outward and when the age distribution of younger inventory is affected by an exogenous shock. Smaller differences occur when inventory is affected by small annual perturbations over many years.

These differences arise from both the forward looking nature of the optimal control models and the nature of the supply specification in the models. When demand growth either jumps suddenly or the rate of growth increases, for example, optimal control models capture the effects of all future increases in demand in today's decisions. The result is that optimal control models predict smaller harvest increases today as producers hold timber a little longer in anticipation of future higher prices. These shifts are marginal for each owner, but can make significant differences in price and harvest behavior at the regional scale.

When exogenous forces impact a large number of young timber stocks, differences in both the forward looking aspect and the nature of the supply specification become important. Supply in the static simulation models is generally a function of price and total timber inventory. If a large area of younger timber is suddenly destroyed, then the supply function will shift out instantaneously, prices will jump upwards, and then increase rapidly until the affected acres again begin to accumulate substantial quantities of timber. Optimal control models adjust to this type of phenomena differently. Market players foresee a future shortage, so price levels likewise initially increase. The price jump is likely to be smaller (if all else is equal), as is the subsequent rate of price increase. This difference results from the fact that currently economically mature inventories have not been affected, but instead future inventories have been.

These differences relate mainly to how the models would react to policy changes or exogenous impacts on timber markets. The demand example, however, does suggest one possible difference in how that the theoretical structures of the models will affect baseline price predictions. All else being equal (exogenous projections of demand growth, timberland area and management, etc.), the optimal control models are likely to show lower long term trends in the growth of stumpage prices than static simulation models. The influence of terminal conditions on optimal control models should be noted as well, however, because they can influence the behavior of prices in the near term. The exact influence of terminal conditions depends on how far in the future they are applied. The further into the future they are applied, their impact will be lessened.

The model solution algorithms specify alternative models of harvest behavior. The solution to optimal control models suggest that the oldest timber in a region's timber inventory should be harvested first to maximize societies surplus. While this follows the Faustmann formula for determining the optimal rotation age, it clearly does not capture additional constraints that may be imposed on individual timberland owners, such as capital and cash constraints. The static simulation models, on the other hand, tend not to delineate clearly which timber is being harvested. They track only the total harvest flows, and apparently constrain the flows to be greater than the available timber inventory in any period. This does not capture individual capital and cash constraints either, but it does allow for harvests out of many age classes. The main impact of this difference is that harvests in optimal control models may vary more from year to year due to changes in the age class distribution over time, whereas harvests in the static simulation models will be smoother.

Both approaches provide benefits and limitations for policy analysis. Because timber is harvested strictly according to age class, it is usually clear in optimal control models how policy adjustments in one region will impact harvests in another. Also, the strong link to individual optimizing behavior (i.e. the Faustmann formula) suggests that these models are more capable of dealing with long term analysis. Although capital and cash constraints of landowners may be important for short term analysis, they are less of a concern for long term analysis.

Static simulation models utilize empirically estimated demand and supply relationships from historical data. These relationships are valid for the historical period, and potentially valid for the immediate future, but they may or may not hold up during the long term projection periods often considered. Also, static simulation models allow harvests from multiple age classes, but they do not present a theoretical rationale for which age classes will be harvested in any period. It is not clear that this is a better mechanism than the Faustmann formula for capturing capital and cash constraints. This harvesting behavior is often linked to other initial inertia conditions that are imposed to constrain harvest behavior in one region or another during the first few years of a model projection. The so-called inertial conditions may allow a closer approximation of harvest levels from different ownership types (public, industrial, non industrial private) for a few years, but the models provide little theoretical justification that these conditions will hold in the long run.

The multiple market layers of the static simulation models allow them to make projections in the different levels simultaneously, and to capture important linkages (Haynes, 1977). TAMM and CGTM, for instance, include end product and stumpage markets, while NAPAP includes end product and pulpwood markets. The solution algorithms vary between the models, but both markets must clear in each time period to determine the optimal harvest and price level. Although TSM has been extended to both pulpwood and sawtimber log markets (Sedjo and Lyon, 1996), the results from that model are not included in this analysis.[2]

[2] Results from TSM96 are not included here only because there is no historical data upon which to compare model results.

By including detailed data and information on capital markets, the static simulation models constrain harvests by the available capacity to produce end products. During the beginning period of a model run, this constraint may well be an important determinant of timber market behavior which the TSM model does not capture. Lyon et al. (1987) explored one form of capital market interaction by utilizing the TSM algorithm to solve both capital and log markets simultaneously, but that type of model has not been introduced at the global level to date.[3]

While modeling capital structures can be helpful for assessing short term behavior, the approach adopted by the static simulation models analyzed here departs from the capital theoretical approach dominant in the economics literature. Traditionally, where long term capital decisions are analyzed, dynamic, forward looking models are used. While NAPAP does include a technique (Tobin's q) that follows from this literature, it is implemented with a myopic shadow value. Thus, neither TSM, nor the static simulation models may adequately capture long term capital formation accurately in timber markets.

Some of these general points, and several additional differences and similarities are presented in Table 1. The models all are implemented at a different regional scope. TAMM and NAPAP are predominately North American models, although NAPAP does incorporate demand and supply functions for aggregated regions outside of North America. The three static simulation models capture inter-regional trade explicitly, although they represent regions differently. The models also incorporate different capital adjustment mechanisms. Timberland management intensity is endogenous only in the TSM model.

A general conclusion from the foregoing analysis is that optimal control models, by relying on theoretical structures strongly tied to individual optimizing behavior, are expressly intended to predict long run behavior. While landowners do not appear to follow the Faustmann model perfectly in current time periods, if land in forestry is to remain competitive in the long run relative to other uses, private landowners must adopt Faustmann practices. Static simulation models also are intended for considering long run situations, but they attempt to capture short term phenomena by including inertial constraints that limit trade or capital adjustment over time. Econometric specifications and sticky capital adjustment mechanisms may perform better relative to actual market behavior than the optimal control models because they capture landowner and producer capital and cash constraints, and they also capture regional trade. Over the longer run, these specifications may or may not remain consistent, particularly if price levels from region to region change significantly.

Table 1. Comparison of timber market models over several components

	TAMM	NAPAP	CGTM	TSM
Theory	Spatial equil.	Spatial equil.	Spatial equil.	Dynamic opt.

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3 While capital in TSM adjusts instantaneously as timber supply in the oldest age classes shifts, the modelers often report harvests as time weighted averages in order to capture sticky capital adjustments.

	(Samuelson)	(Samuelson)	(Samuelson)	(Hotelling)
Projection Method	Static simulation	Static simulation	Static simulation	Optimal Control
Scope	US-Canada	US-Canada- +	Global	Global
Regions	~8	~8	~ 40	22
Tracks Regional Trade	Yes	Yes	Yes	No
Market Structure	Multi-level	Multi-level	Multi-level	Delivered Log
Capital Adjustment	Adaptive	q-theory	Adaptive	Rational
Timber Inventory	Age-delimited	Age-delimited	Age-delimited	Age-delimited
Harvest Mechanism	N/A	N/A	N/A	Oldest Timber
Endogenous Management	No	No	No	Yes

COMPARISON OF MODEL PREDICTIONS

In this section, the models are compared and contrasted based on their performance over previous model projections. This allows us to begin addressing the third question in the introduction. The models are compared both to their counterparts, and to actual market data for periods of overlap. The intent of this section is not to determine which model has the "best" predictions, but instead to present previous model outlooks, and discuss the differences as they relate to model structure.

What complicates this analysis is that the model projections are a function of both theoretical and structural differences, as well as the specific set of assumptions relating to macro-economic activity (such as GNP growth, interest rates, per capita timber consumption, substitution elasticities, etc.) and management chosen by each modeler or modeling group. There is no way to control for these differences in this analysis, and it is quite possible that this "macro-assumption bias" may be a more important aspect of any differences than the theory. In order to make the major assumptions as transparent as possible, they are outlined at the beginning of this section for each model projection considered (Table 2).

Table 2. Underlying Assumptions of Important Driving Variables in the Eight Model Projections Included in This Analysis.

(Given as annual percentage changes, and all variables are for the US unless otherwise indicated.)

Parameter	TAMM 80	RPA80	RPA89	RPA93	TSM85	IIASA87	CGTM89	NAPAP
	Annual Percentage Change							
Population	0.62 %	0.62	0.58	0.51		1.00		0.51
GNP	2.60 %	2.60	2.72	2.72				2.72
Per Capita DPI	2.00 %	2.00	1.75	1.80		1.25		1.80
"Demand"	1.46 %	1.46			0.50			
Forestland	(0.05) %		(0.05)		0.00			
Timberland			(0.09)	(0.12)	0.00			(0.12)
South Plantations			1.38	1.30				1.30
Emerging Region Plantations					1.38	1.78*		

Furthermore, differences between the set of outputs available from each model makes it difficult to compare them directly. This pertains both to differences between models and to differences between specific model runs as the models have evolved over time. TAMM, for instance, was originally a softwood market model only, and incorporated hardwoods after the initial set of published model runs. It also is not always clear what actual historical data is most closely related to particular model output. The models are therefore compared over variables that have remained consistent over time, and that relate to data easily obtained. The following variables are used for comparison purposes: Southeastern US softwood stumpage or log prices, Pacific Northwestern west-side (west of the Cascade Mountains) US stumpage or log prices, total US timber harvests, Pacific Northwestern harvests (total for Washington and Oregon states), US total softwood harvests, and global timber harvests.

Model Run Descriptions

TAMM80: The TAMM80 results are from the baseline case reported in Adams and Haynes (1980). This paper outlines both the basic theory of the TAMM model, and it shows how the model simulates future market activity in a base case and several policy scenarios. Although the values shown in Table 2 cannot be found directly within the paper, it was assumed that the values were the same as those used in the US Forest Service (1980) RPA Assessment.

RPA80: This model run is the medium forecast provided by the US Forest Service (1980) for their RPA Assessment of the timber situation in the US. This forecast represents the first time that the TAMM model was used by the Forest Service, although they apparently used only portions of the TAMM solution reported in Adams and Haynes (1980).

RPA89: RPA89 is the second RPA Assessment report that utilized TAMM (Haynes, 1990). The scenario chosen is the baseline scenario used by the US Forest Service, although many alternative scenarios are presented in the document. Additional economic variables, such as housing starts and interest rates, are used to drive demand, but only a limited set are shown in Table 2. This study incorporated assumptions about changes in land management intensity and increases in southern pine plantations, which are presented in Table 2. Of particular note is that this study precedes the harvest reductions in the Pacific Northwest following the Spotted Owl controversy.

RPA93: This report updates RPA89 (Haynes et al. 1995), and it includes an iterative solution procedure that includes pulp and paper markets via the NAPAP model. In this paper, the name RPA93 refers solely to the sawtimber market aspect of that effort. Pulp and paper results are considered in the NAPAP model run. Assumptions over population and income growth, as well as land management intensity shifts and plantation establishment, were updated from the RPA89 run. The study follows the initial adjustment from the controversy over the Northern Spotted Owl and old growth harvests in the Pacific Northwest.

TSM85: The outlook presented is the base case scenario established by Sedjo and Lyon (1990). They do not explicitly predict GNP, per capita disposable income, or population growth, but instead predict an exogenous shift in demand. They predict that demand growth slows over time. Demand growth is initially 1% annually, but it declines to 0 % growth in a linear fashion after 50 years. Furthermore, they predict that plantations will be established within the emerging region at a rate of 200,000 hectares per year for 30 years. The percentage growth rates in Table 2 have been annualized to 50 years so that they compare to the data in RPA89 and RPA93 (i.e., they predict that plantation area will double over 50 years, so that the average annual growth rate over the projection period is 1.38%).

IIASA87: This model run was presented as the base case in Kallio et al. (1987). That study did not predict "global" demand growth variables, but instead predicted growth at the national or regional level. Demand growth figures for only the US are presented in Table 2. Their population growth assumptions are higher than most others, but their income growth is somewhat lower. Kallio et al. (1987) do not explicitly state the number of hectares added to timber plantations in the emerging region. They provide an estimate of the volume of timber potentially available in Brazil, Chile, and Australia-New Zealand (Table 21.7, page 526; Kallio et al., 1987), but this number is for both plantations and natural forests. I have presented the growth in this value predicted by the model over the model horizon for comparison purposes, but caution the reader against strictly comparing IIASA87 and TSM85 by plantation establishment.

CGTM89: This model run was presented in Cardellichio et al. (1989). It represents a largely revised version of the global trade model used in IIASA87. Although this study was predominately concerned with market behavior in the Pacific Rim countries, they calculated prices, harvests, and international trade patterns in 39 regions of the globe. It is unclear from Cardellichio et al. (1989) what their assumptions over demand changes and plantation establishment were.

NAPAP: The NAPAP model runs examined here are contained in Ince et al. (1994a,b). The three runs relate to their 1989 and 1993 baseline case predictions and a waste reduction prediction in 1993. The 1993 runs were done inter-actively with the RPA93 run, so that there is no overlap between harvests of stumpage for solid- and pulp-wood. They utilized the same set of base assumptions as were utilized in the RPA93 run.

Model Run Comparisons

The models are compared over several different variables. Because the models do not all present the same data, not all models are included in each comparison presented below. For example, the NAPAP model is compared separately from all other models because it considers only pulpwood markets.

The first comparison considers timber prices in the US South (Figure 1). Differences in model output is exemplified by the different types of prices reported. Explanations of these differences are given below. Actual US Southern softwood stumpage prices are presented for the years 1952 - 1995. Data from 1952 to 1989 was obtained from Adams et al. (1988) and Richard Haynes (personal communication). Data from 1990 to 1995 represents an average of stumpage prices obtained from actual timber sale data in Louisiana (Louisiana Department of Agriculture, various), and southern pine stumpage prices recorded for Alabama from Timber Mart-South (1996). Prices on average have increased 2.0% annually since 1952, although they experienced a fairly substantial depression in the 1980s. They have risen almost 10% annually since their low points in the 1980s.

Only the TAMM80 and RPA (80, 89, & 93) runs actually predict US Southern stumpage prices. TSM85, IIASA87, and CGTM89 predict some form of delivered log prices. The trend in log prices may differ from that of stumpage prices, depending on how harvesting and transportation costs change over time. Prices from each model are shown in Figure 1, however, in order to give the reader a sense for broad differences in trends predicted by the models.

The prices reported by TSM85 are global market clearing prices for both coniferous and non-coniferous logs on an international market. The price line shown represents long term, average delivered log prices. These do not correspond exactly to the actual US Southern stumpage prices shown in Figure 1 because those prices include short term, cyclical, and local fluctuations which the TSM model does not attempt to capture. In the long term, the TSM model suggests that the law of one price holds, so that long term trends in different regions and timber types around the globe should follow its prediction of the global price trend. For example, if prices in one particular region or type became relatively high, then alternative types would be substituted or logs would be delivered from other low cost producers in the world to limit price growth in that region. Stumpage prices may differ if harvest and transportation costs vary from region to region, but TSM85 does not attempt to predict alternative pathways for these costs. TSM85 predicts global average price trends (FAO, 1995a) fairly well. FAO data suggests that average global prices have in fact been relatively constant in real terms from the 1960s to the early 1990s.

Both the global and North American models all assume that free trade exists, although in reality quotas and import taxes often impose restrictions to this. If these are included in the models, price trends in different regions are likely to vary over time. The combined impact of domestic set-asides in the US and a Canadian import tax, for example, would create a wedge between prices in the US and Canada.

Table 3. Long-term Price Trends Predicted for US Southern Softwood Stumpage or Delivered Logs

(All values given as annual percentage change)

Year	TAMM 80[a]	RPA80[a]	RPA89[a]	RPA93[a]	TSM85[b]	IIASA87[b]	CGTM89[b]
Model Outlook	2.84 %	2.46	1.40	2.00	0.17	2.80	1.80

Notes: [a] Stumpage [b] Delivered logs.

TAMM80, RPA80, and IIASA87 predict the greatest long term price appreciation of the model outlooks considered, while TSM85 predicts the least (Table 3). The TSM85's lower prediction results from four different factors: lower predicted long term demand growth, predicted steady increase in plantation establishment in the emerging region (this point was noted by Binkley and Vincent, 1988), predicted increases in management intensity, and terminal conditions which impose a 0 % growth rate in demand after 50 years. While the plantation establishment rates in the TSM85 model run would appear to be fairly high (200,000 ha per year), actual plantation establishment in the tropical emerging region alone exceeded these annual rates in the decade of the 90s. 646,000 hectares were planted annually in South Africa, Insular Southeast Asia, and tropical and non-tropical South America between 1980 and 1990 (FAO, 1995b). RPA89 and RPA93 both predict relatively higher prices during the early part of the next century, with some price moderation as demand from the baby boomer era dampens out. In contrast to the earlier IIASA87 outlook, CGTM89 predicts fairly moderate price growth throughout the 1990s.

Table 4 compares the average rate of growth in southern US softwood prices over two time periods which overlap with the actual data. Actual prices between 1952 and 1990 increased approximately 2.0 % annually. TAMM80 and RPA80 predicted the average rate of growth for the period 1980-1995 fairly accurately although they failed to capture either annual adjustments or the path of change.

Perhaps the most important conclusion of Figure 1 and Table 4 is that no model accurately predicts short term adjustments. No model predicted the low cyclical prices during the 1980s, nor did they predict the large runups in the late 1980s and early 1990s due partially to the harvest adjustments from the Spotted Owl controversy. These changes relate either to cyclical or to random market events. None of the modelers actually suggest that their models should perform well in this regard, and we should not expect the models to do so. RPA93 incorporated the harvest adjustments in the early 1990s, but after the fact.

Table 4. Short- and Medium-term Price Trends for US Southern Softwood Stumpage or Delivered Logs.

(All values given as annual percentage changes.)

Year	Actual[a]	TAMM 80[a]	RPA80[a]	RPA89[a]	RPA93[a]	TSM85[b]	IIASA87[b]	CGTM89[b]
1980-1995	4.51 %	5.41	4.06	--	--	--	--	--
1990-1995	11.9 %	2.12	2.09	2.45	8.68	0.15	1.78	1.85

Notes: [a] Stumpage [b] Delivered logs

Price paths for Pacific Northwestern softwoods for the same set of models are shown in Figure 2 (again, only the TAMM and RPA runs are stumpage prices, while IIASA87, CGTM89, and TSM85 are delivered log prices). An interesting trend begins to emerge in Figures 1 and 2: predictions of price growth by the models have declined over the years. The earliest model outlooks suggested that prices would grow significantly, yet later model outlooks predicted much more modest growth, particularly in the long term. RPA93, for example, suggests that prices will not increase significantly in the Pacific Northwest over the next 50 years, whereas TAMM80 predicted fairly substantial growth. Given that the demand assumptions (Table 2) do not change significantly over the time period, these differences are presumed to arise from updated assumptions on timber management, substitution possibilities, revealed information about the pace of technological change, as well as better modeling of the resource situation in Canada. Also, RPA93 projections are linked to the NAPAP model, which allows a fairly detailed look at pulp and paper markets, where many of these substitution possibilities are occurring through waste paper recycling.

Projections of the quantity of timber harvested in the US similarly trend upward in all of the models (Figures 3 - 5). Figure 3 presents actual softwood harvests on US timberland and projected harvests for the TAMM80 and RPA80 model runs (the original runs of the TAMM model included only a softwood market; hardwoods were added later). Interestingly, while these two outlooks do not predict any of the cyclical or random behavior associated with timber markets, they do track average softwood harvests during the overlapping period pretty well.

Figure 4 shows the total historical and projected US timber harvests (softwoods and hardwoods), as predicted by recent US Forest Service outlooks. The historical data was obtained from Richard Haynes (personal communication). The early part of the projection for RPA89 coincides with historical data because the modelers had several years of historical data to validate their model run. RPA93 substantially reduced earlier RPA baseline US harvest projections, a result of the reduction in federal timber harvests that occurred in the early 1990s, and the prediction that these reductions would continue indefinitely.

Figure 5 compares US total timber harvests from the TSM85 and CGTM89 model runs with FAO (1994) data.[4] The CGTM model failed to capture the large reductions in US timber harvests that occurred in the early 1990s. The actual reductions, however, are related to the changes in federal timber sales during that period, the scale of which the modelers could not have predicted at the time published.

TSM85 predicted a fairly large decline in US harvests in the late 1980s and 1990s. These reductions were predicted to occur mainly in the South, and they resulted from changes in the age class distribution of the timber. This relates to basic differences between the models. TSM harvests timber based on the age class distribution, starting with the oldest timber first. If the model encounters age classes with few acres and little volume, then it will adjust harvests to another region with relatively more timber available in mature age classes. Thus, harvests in the TSM model can be expected to shift freely across global regions in response to shifts in the age distribution. In the other models, harvests will not shift as freely because they are not limited to the oldest age classes.

All three global outlooks (TSM85, IIASA87, and CGTM89) predicted increases in harvest levels between 1985 and 1995 (Table 5), and in the long run. TSM85 predicts lower short term and long term growth in global harvests than the other global models. These differences result from the prediction of lower demand growth and an eventual stabilization of demand after 50 years. This result is interesting given that the TSM85 outlook suggests both low demand growth and high plantation establishment. The implication is that the best investments in forestry management in the future will occur in tropical plantations. Despite stable global harvests, production shifts from temperate forests towards emerging region plantations.

Table 5. Comparison of Actual and Predicted Trends in Global Timber Harvest for Three Timber Market Models

(All values are annual percentage changes.)

Year	FAO Actual	TSM85	IIASA87	CGTM89
1985-1995	0.74 % *	1.02	1.64	1.58
LT Trend	--	0.50	1.39	1.43

* FAO (1994) Actual data only for time period 1985-1992.

The three static simulation timber market models clear both raw material and end products markets during each period and they predict price paths and consumption patterns for these end-products. Historical trends in lumber prices suggest that prices have risen 1.5% annually since 1850 (Ulrich, 1990). Much of this price growth, however, occurred between

[4] Note that there are differences between Forest Service and FAO United States timber harvests in figures 4 and 5. These differences result from converting board feet to cubic feet.

1800 and the 1950s, when prices hit a peak and then resided. Several periods of price appreciation occurred during the inflationary times of the 1970s, but they retreated again during the recession in the early 1980s. Most recently prices peaked again in 1994, but began to soften in 1995.

Predictions of lumber price trends for several time periods are presented in Table 6 for the TAMM80, RPA89, RPA93 and IIASA87 model outlooks. TAMM80 predictions suggested that lumber prices would rise in the future at approximately historical rates of price appreciation, while subsequent iterations of the TAMM model in RPA89 and RPA93 have revised this estimate downward. The IIASA87 outlooks suggests very modest increases in lumber prices. This is interesting given the significant increases in log prices predicted by that model. This difference is likely related to the inclusion of global trade and the model's treatment of technological change, although the exact reason is not clear.

Table 6. Comparison of Actual and Predicted Lumber Price Indices for the United States for Selected Time Periods

(All values given as annual percentage change.)

Year	Actual	TAMM80	RPA89	RPA93	IIASA87
1985-1995	2.50 %	2.04	--	--	0.08
1990-1995	6.25 %	1.94	1.04	--	0.21
1993-1995	(10.2) %	1.88	1.02	2.40	0.21
LT Trend	--	1.48	0.63	0.75	0.25

The NAPAP model has not figured significantly into the discussion so far because the comparison focused on earlier model predictions for which there is substantial overlap between actual price data and predicted series. The NAPAP model, however, plays a part in the RPA93 model run above because TAMM and NAPAP were run interactively. Market clearing conditions were met simultaneously in each market, and inventories were drawn down appropriately.

Historical and projected price indices for delivered southern softwood pulpwood are drawn from NAPAP and presented in Figure 6. These prices represent an average for the entire South. Comparable historical data could not be obtained for this study. The NAPAP model is interesting to consider here, however, because it is the only model to predict near term decreases in prices. The price growth that occurs late in the model forecast is somewhat curious, given that the authors have imposed the assumption that demand growth declines 0.6% annually after 2000, and the model predicts increased softwood pulpwood supplies in the south, and increase recycled paper consumption. This change in trend may be caused by a shift in the balance of trade with other countries.

Predicted price trends are influenced significantly by the recycled paper market in NAPAP. The recovered paper utilization rate is projected to increase 0.9 % annually during the projection period in NAPAP. The combined effects of lower future prices and increased recycling rates serve to significantly reduce woodpulp imports over the long run. With even greater assumptions of recycled paper utilization in NAPAP waste reduction scenario, long term prices and woodpulp imports are affected even more.

DISCUSSION AND CONCLUSION

In this section, several of the differences noted in Table 1 are re-visited to assess whether or not the data in the previous section verifies any of the differences considered earlier. One way to compare the static simulation and optimal control models is to consider how they have performed in three different time periods-- short term (1-5 years); medium term (5-10 year); and long term (10-50+ years). Although the static simulation models often incorporate inertial constraints in order to model the initial periods after the model run begins, they are not intended as short run models. The results of the previous section suggest that none of the models is well suited to capture short term variations in prices and quantities caused by cyclical and random events. Prices adjust from period to period based on many different variables relating to the psychology of markets, and it is nearly impossible for modelers to foresee, let alone capture, the vagaries of these fluctuations.

Because the modelers are often working from assumptions on long term average economic growth, all models are perhaps most appropriately applied to medium and longer term analysis. In these longer time frames, annual fluctuations are overshadowed (in most cases) by trends in variables that drive consumption of wood products. It was argued earlier that optimal control models may best be suited for long term analysis because they provide a structured theory for predicting harvest behavior far into the future, when econometric relationships may no longer be valid. While this theoretical result holds, it is difficult to determine if this is the case because the model results above rely on a number of alternative macro-economic assumptions made by the modelers. These different input assumptions have a more direct effect on controlling the model's behavior than the model theory or structure.

It is clear, however, that optimal control models have a profound impact on the pattern of timber harvests from region to region. These differences relate mainly to changes in the age distribution of timber inventories over time. If the role of plantations continues to expand in global markets, then optimal control formulations may be particularly useful in projecting long term regional harvests and supply potential , as the age distributions of plantations around the globe will vary based on planting rates and timber type. Potential future expansions of such approaches may include attempting to determine endogenous rates of plantation establishment, in addition to the endogenous mechanism for timber management currently employed in TSM.

Incorporating a global scope and trade beyond North America does not appear to aid models in predicting behavior in US markets. One reason for this is that the North American models have adequately incorporated exogenous models of end product and log market behavior in other regions of the world. This argument, however, may capture current predictions, but consideration of global issues is certainly important for future analysis. If, as predicted by some models (Sedjo and Lyon, 1990, 1996), the emerging region becomes a bigger player in global markets through timber plantations, well developed global models may provide important insight into price behavior within the US. In addition, interesting questions abound relating to the Siberian forests of Russia, which are predominately old growth, the tropical log trade, and growing demand in countries of the Pacific Rim. Understanding how these prices affect timber markets in the US may be crucial to developing a fiber supply strategy for the future.

Multi-market level models provide additional information relating to end product prices, but their predictions must capture important structural changes that may be occurring in end-product markets to be useful for policy analysis. In this regard, as the multi-market models have developed over time, they have tended to become more and more complex, as they attempt to capture the panoply of different products and substitution possibilities that are available. The analysis in the previous section provides no clear evidence one way or another that multi-market models produce better results than does the single market level model.

Related to this issue is the question of modeling capital formation. The modelers in this paper have chosen a variety of methods to model capital formation, including assuming that capital adjusts instantaneously with the available merchantable timber (TSM) to making exogenous predictions (CGTM). As with the question of number of market levels, there is no clear evidence in the above analysis that more sophisticated models produce better results. The changes that occurred in the 1990s appear to have caught all of the models by surprise, and better modeling techniques are not likely to allow us to capture unforeseen events. Capital adjustment mechanisms may provide useful information during the early periods of a model projection, but their usefulness may be limited during later periods when random events are likely to alter the very structure of timber markets.

In addition to these differences, the problem of modeler bias enters the calculus of comparing the model results above. The results of the TSM85 run above are developed from generally lower predictions of demand growth, high plantation establishment, and terminal conditions that specify 0 % long term demand growth. The low demand and decreasing demand assumptions result from the thought that substitute products will enter markets as prices rise, thereby limiting the expansion of demand for industrial wood products. As Binkley and Vincent (1988) point out, however, under the higher demand growth assumptions in Sedjo and Lyon (1990), price growth is closer to the other models considered here.

Timber market modelers have attempted to limit their exposure to being wrong by presenting many different scenarios along with their "best guess" or "baseline" prediction. Efforts like this are helpful for readers and users of the information, and they provide additional information upon which to compare the models. In particular, an interesting future analysis of these models might be to compare a scenario analysis to a natural experiment where the scenario actually came true. This would shed light on how well the model predicted market adjustments in response to the exogenous force or alternative prediction.

An interesting trend in Figure 1 can be seen by looking at the separate model projections as a time series. Modelers have become less bullish on the prospects for prices in timber stumpage markets in the US over time. The TSM85 model stands out as the least bullish in the long term, but other more recent outlooks tend to predict slower long term growth in timber prices. An exception is the RPA93 model run which predicts higher long term growth than the RPA89, but most of this growth occurs in the early periods, and long term trends are similar to RPA89. Interestingly, in the RPA assessments, these lower projections result not from slower population or GNP growth, but they result from predictions of greater substitution possibilities, particularly in recyclable products and structural panel boards, greater recovery of raw wood materials, and the increase in timber plantations in the US South as a source of wood fiber. In the TSM85 run, they result from a combined prediction of low demand growth and high plantation establishment in the emerging region.

From a modeling perspective, this suggests that what is perhaps most important for analyzing long term fiber supply is to better understand the underlying determinants of market behavior. These determinants include, but are not limited to: supply issues such as the environmental pressures to reduce timber harvesting and particularly, clear-cutting; foreign trade disputes; foreign timber supply, including plantation establishment in the emerging region, as well as elsewhere; timberland management practices, including plantation establishment in the US; recycling behavior; substitution possibilities; technological change; non-industrial private timberland harvest behavior; etc. Many of these affect the assumptions that go into our market models, or they affect our theoretical models. There does not appear to be any overwhelming empirical evidence that one particular model, theoretical or otherwise, produces better results than the others. There does appear to be evidence, however, that modelers need to carefully consider their input assumptions, particularly as they relate to the factors suggested above.

REFERENCES

Adams, D. M., and R. W. Haynes. 1980. The 1980 Softwood Timber Assessment Market Model: Structure, Projections, and Policy Simulations. *Forest Science* 26(3): Monograph 22. 64 p.

Adams, D.M., and R. W. Haynes. 1987. Interregional Modeling. In *The Global Forest Sector: An Analytic Perspective*, edited by M. Kallio, D. P. Dykstra, and C. S. Binkley. Vienna: International Institute for Applied Systems Analysis.

Adams, D. M., K. C. Jackson, and R. W. Haynes. 1988. Production, Consumption, and Prices of Softwood Products in North America: Regional Time Series data, 1950-1985. *Resource Bulletin* PNW-RB-151. Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Adams, D.M., and R. W. Haynes. 1990. Future Development of the Douglas-fir Region Forest Economy under Changing Public Policies and Private Responses. *Western Journal of Applied Forestry* 5(3): 64-69.

Adams, D.M., and R. W. Haynes. 1991a. Softwood Timber Supply and the Future of the Southern Timber Economy. *Southern Journal of Applied Forestry* 15: 31-37.

Adams, D.M., and R. W. Haynes. 1991b. Estimating the Economic Impacts of Preserving Old-Growth on Public Lands in the Pacific Northwest. *Northwest Environmental Journal* 6(2): 439-441.

Binkley, Clark S., and Jeffrey R. Vincent. 1988. Timber Prices in the U.S. South: Past Trends and Outlook for the Future. *Southern Journal of Applied Forestry*. 12(1): 15-18.

Box, G. E. P., and G. M. Jenkins. 1970. *Time Series Analysis, Forecasting and Control*. San Francisco: Holden-Day.

Cardellichio, Peter A., Chang Yeo Youn, Darius M. Adams, Rin Won Joo, and John T. Chmelik. 1989. A Preliminary Analysis of Timber and Timber Products Production, Consumption, Trade, and Prices in the Pacific Rim Until 2000. *CINTRAFOR Working Paper,* No. 22. Seattle: University of Washington, College of Forest Resources.

FAO. 1995a. Forest Products Prices, 1971-1992. *FAO Forestry Paper No. 125*. Rome: The Food and Agriculture Organization of the United Nations.

FAO. 1995b. Forest Resources Assessment 1990: Global Synthesis. *FAO Forestry Paper 124*. Rome: The Food and Agriculture Organization of the United Nations.

FAO. 1994. FAO Yearbook, Forest Products. *FAO Forestry Series No. 27*. Rome: The Food and Agriculture Organization of the United Nations.

Gilles, J. K., and J. Buongiorno. 1987. PAPYRUS: A Model of the North American Pulp and Paper Industry. *Forest Science.* Monograph 27.

Haynes, Richard W. 1977. A Derived Demand Approach to Estimating the Link Between Stumpage and Lumber Markets. *Forest Science*. 23: 281-288.

Haynes, Richard W. 1990. An Analysis of the Timber Situation in the United States: 1989-2040. *General Technical Report* RM-199. Ft. Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Haynes, Richard W., Darius M. Adams, and John R. Mills. 1995. The 1993 RPA Timber Assessment Update. *General Technical Report* RM-259. Ft. Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Ince, Peter J. 1994a. Recycling and the Long-Range Timber Outlook. *General Technical Report* RM-242. Ft. Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Ince, Peter J. 1994b. Recycling and the Long-Range Timber Outlook, Background Research Report, 1993 RPA Assessment Update, USDA Forest Service. *Research Paper* FPL-RP-534. Madison: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Kallio, Markku, Dennis P. Dykstra, and Clark S. Binkley, eds. 1987. The Global Forest Sector: An Analytic Perspective. Vienna: International Institute for Applied Systems Analysis.

Louisiana Department of Agriculture and Forestry, Office of Forestry. Various Years. Quarterly Report of Forest Products. Baton Rouge, LA.

Lyon, K. S., R. A. Sedjo, and A. P. Bambang. 1987. An Optimal Control Model for Analysis of Timber Resource Utilization in Southeast Asia. *Natural Resource Modeling*. 2(1): 55 - 80.

Mills, J. R., and J. C. Kincaid. 1992. The Aggregate Timberland Assessment System: A User's Guide. *General Technical Report* PNW-GTR-281. Portland: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Samuelson, Paul A. 1952. Spatial Price Equilibrium and Linear Programming. *American Economic Review*. 42: 283-303.

Sedjo, Roger A., and Kenneth S. Lyon. 1990. The Long-Term Adequacy of World Timber Supply. Washington: Resources For the Future.

Sedjo, Roger A., and Kenneth S. Lyon. 1996 Timber Supply Model 96: A Global Timber Supply Model with a Pulpwood Component. *Discussion Paper* 96-15. Washington: Resources For the Future.

Sohngen, Brent. L., and Richard W. Haynes. 1996. The Potential for Increasing Carbon Storage in United States Unreserved Timberlands by Reducing Forest Fire Frequency: An Economic and Ecological Analysis. *Climatic Change*. In press.

Sohngen, Brent L., and Roger S. Sedjo. 1996. A Comparison of Timber Market Models: Static Simulation and Optimal Control Approaches. *Forest Science.* In Press.

Timber Mart-South. 1996. Stumpage Price Mart, Standing Timber, Quarterly and Summary Data. Timber Mart-South, P.O. Box 1278, Highlands, NC 28741.

Tobin, J. 1969. A General Equilibrium Approach to Monetary Theory. *Journal of Money, Credit and Banking*. 1: 15-29.

Ulrich, Alice H. 1990. U.S. Timber Production, Trade, Consumption, and Price Statistics, 1960-1988. Miscellaneous Publication 1486. Washington: U.S. Department of Agriculture, Forest Service. 80 p.

U.S. Forest Service. 1980. An Assessment of the Forest and Range Land Situation in the United States. Washington: U.S. Government Printing Office.

Winnett, S. M., R. W. Haynes, and W. G. Hohenstein. 1993. Economic Impacts of Individual Climate Change Mitigation Options in the U.S. Forest Sector. *Climate Research* 3: 121-128.

Zhang, Dali, Joseph Buongiorno, and Peter J. Ince. 1993. PELPS III: A Microcomputer Price Endogenous Linear Programming System for Economic Modeling. *Research Paper* RP-

FPL-526. Madison: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Figure 1: Timber price outlook comparison for US Southern softwood stumpage or delivered logs.

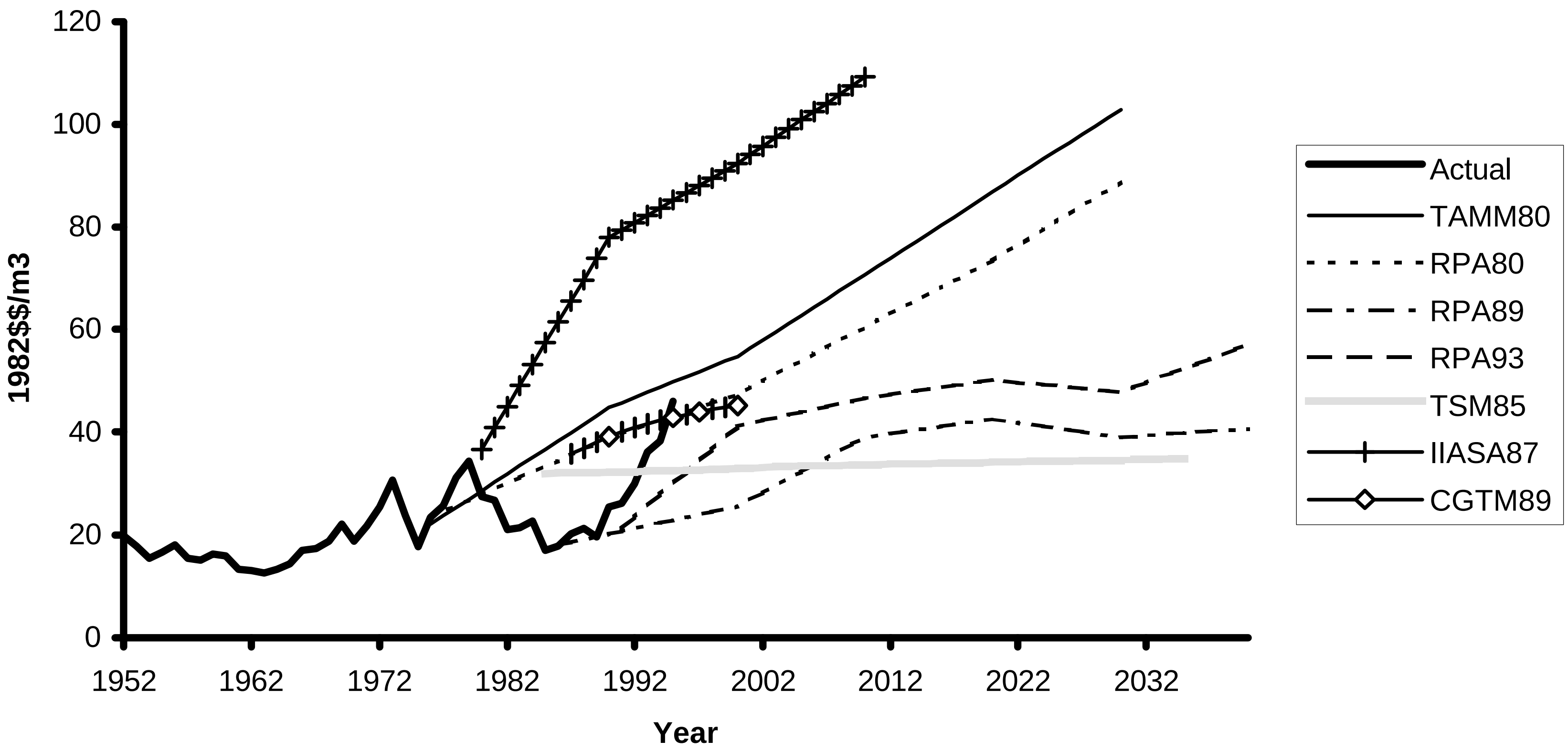


Figure 2: Timber price outlook comparison for US Pacific Northwestern West-side softwood stumpage or delivered logs.

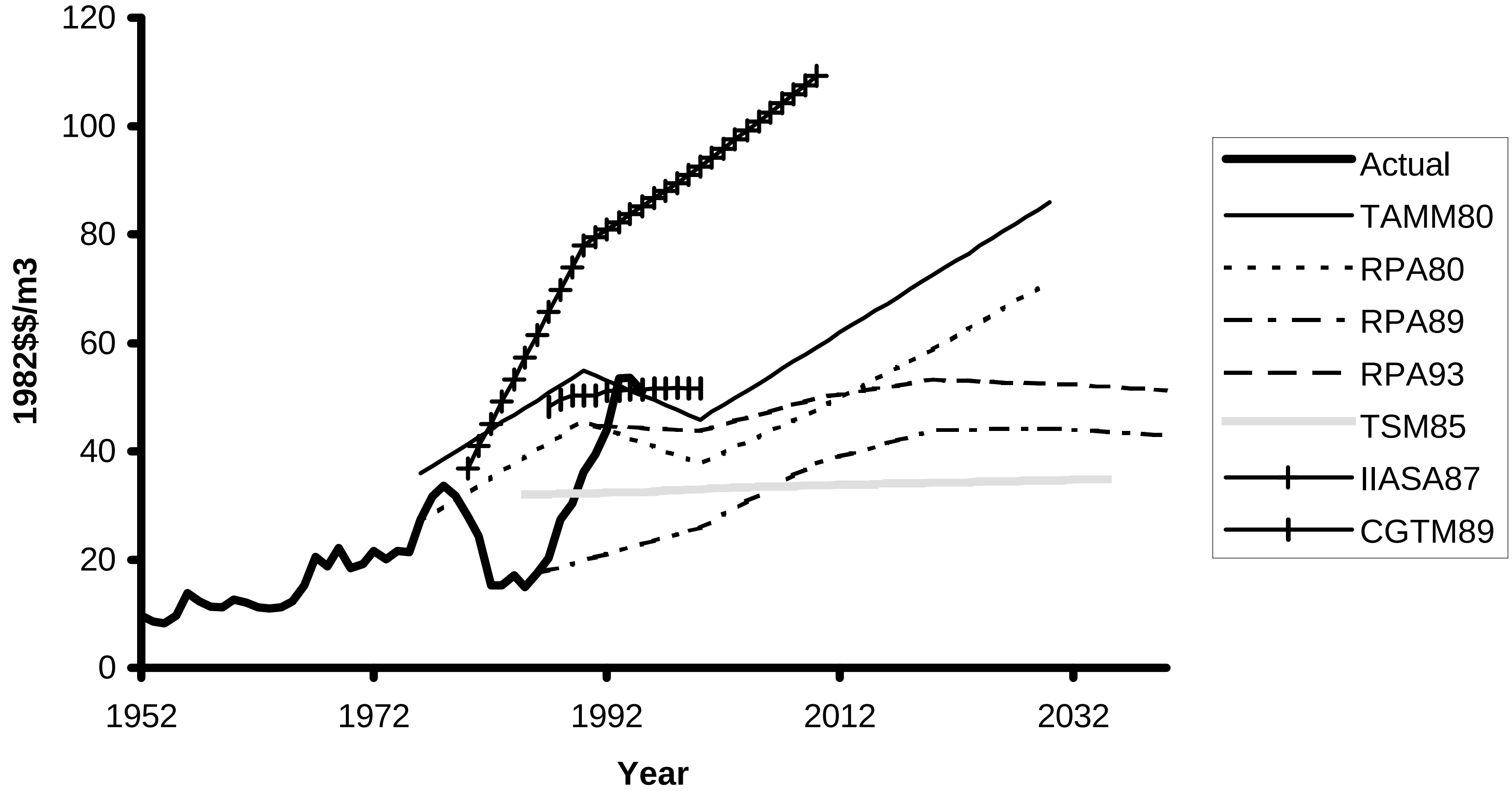


Figure 3: Comparison of actual and projected total softwood harvests for the US.

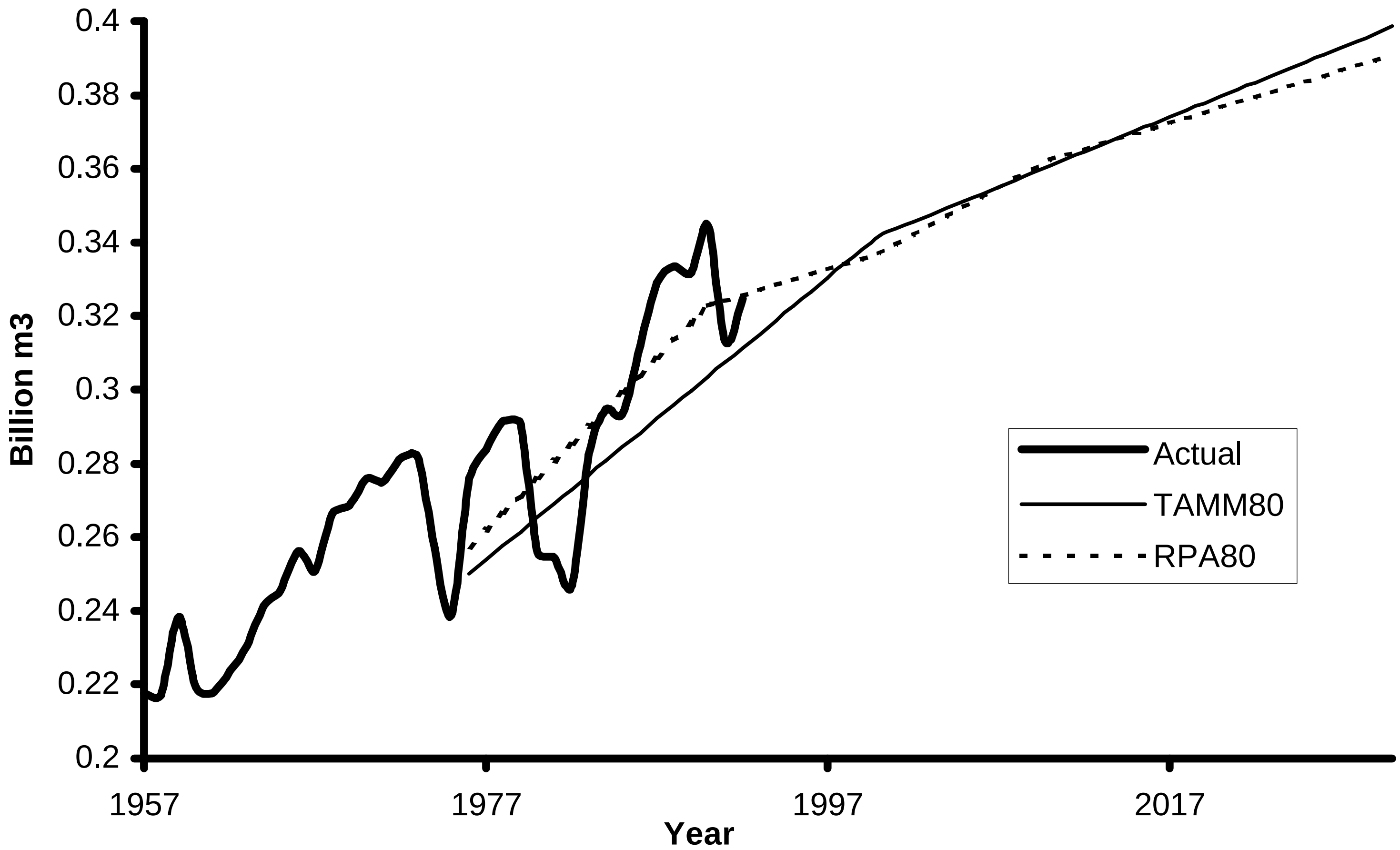


Figure 4: Actual and projected total timber harvests for the US for two recent Forest Service outlooks. Historical data is from Haynes (personal communication).

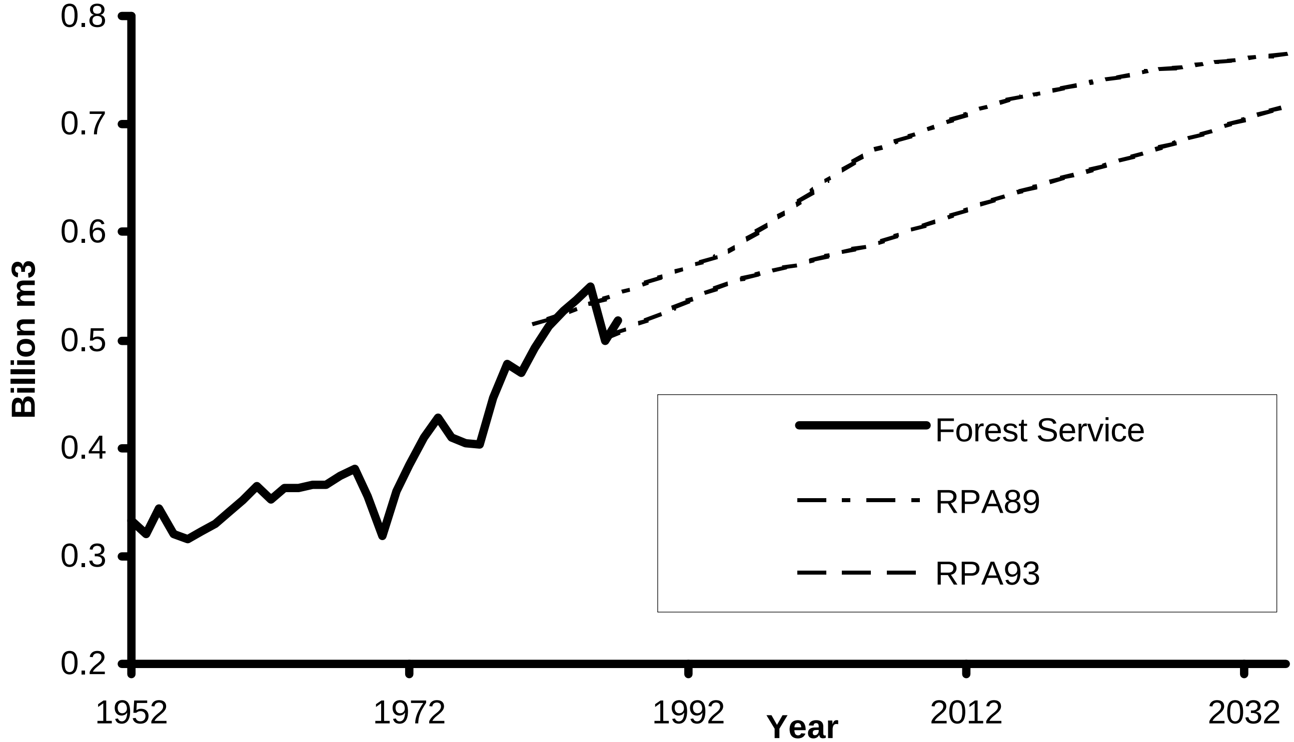


Figure 5: Historical and predicted total United States timber harvests for two global timber models. Historical data is from FAO (1994).

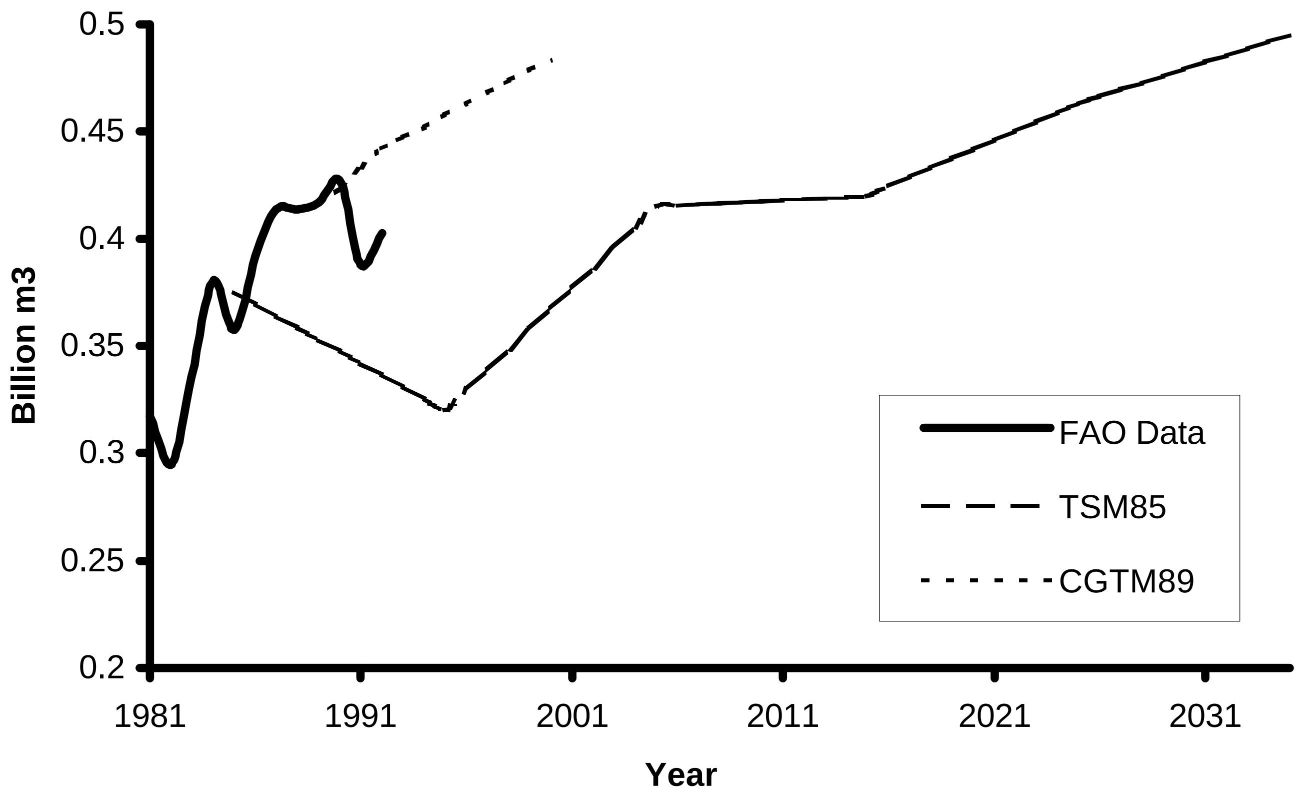
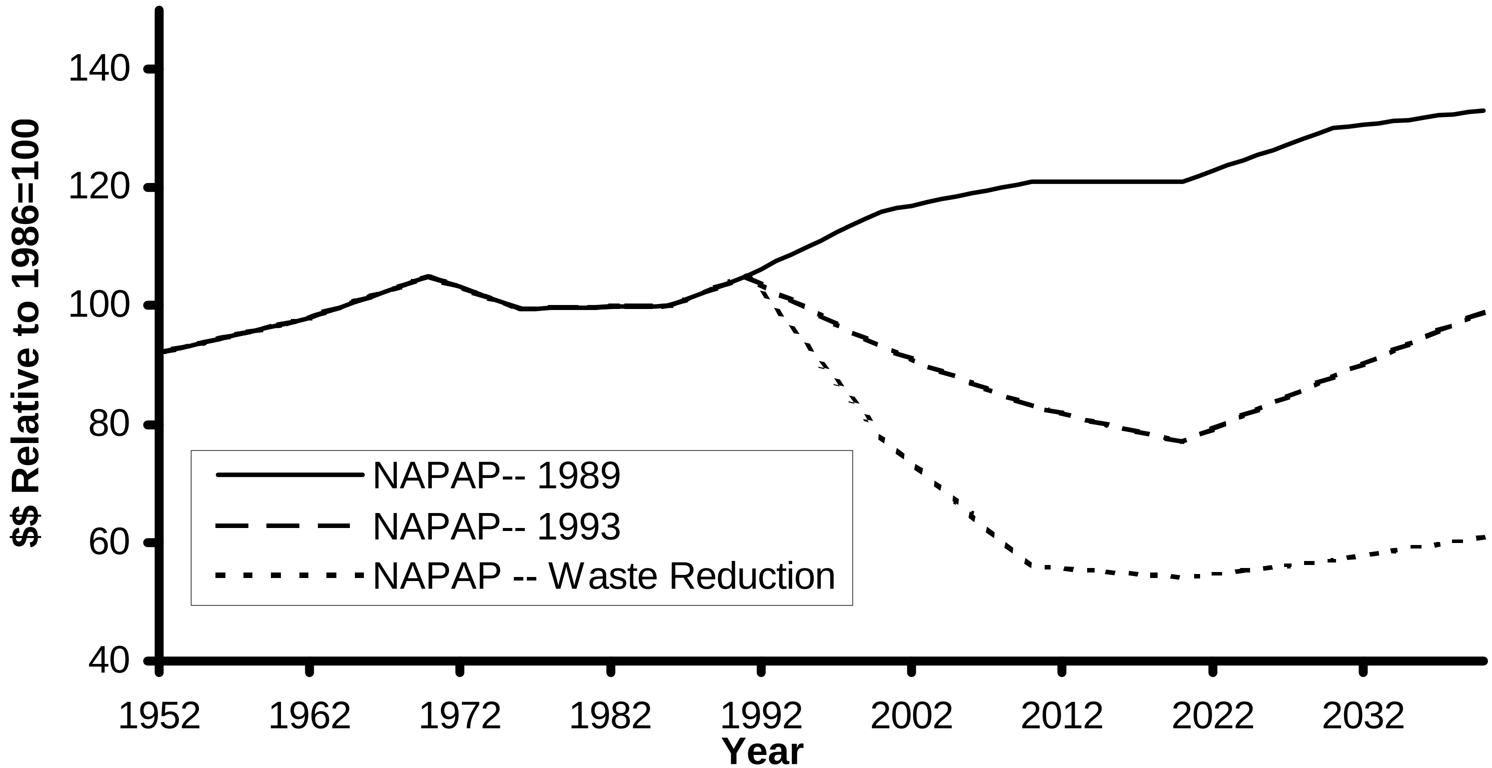


Figure 6: Historical and predicted index of southern softwood delivered pulpwood prices by different scenarios of the NAPAP Model.



4. Long-Term Projections of the U.S. Forest Sector: The Structure of the Timber Assessment Market Model[1]

Darius M. Adams and Richard W. Haynes[2]

The Timber Assessment Market Model (TAMM) was developed to support the quinquennial RPA Timber Assessments and Assessment Updates conducted by the USDA Forest Service.[3] The original objectives for its construction were to provide consistent long-range projections (one to five decades) of trends in forest products consumption, production, and prices and of associated states of the forest resource base and a vehicle for evaluating the impacts of a broad range of alternative forest policies on these trends.

Over the past 15 years, TAMM has been used in four RPA Assessments and Updates and to provide projections in a large number of special policy analysis projects conducted by the Forest Service (USDA Forest Service 1982, Haynes and Adams 1985, Haynes 1990, and Haynes, Adams, and Mills 1995). It has also been employed by an array of other public agencies, private firms and environmental groups to examine issues ranging from log export policies to the impacts of carbon sequestration through tree planting. This paper describes the current structure of TAMM, outlines plans for its development for the 1997-98 Timber Assessment, and offers some observations on the long-term projection process in the U.S. forest sector.

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, and Adams and Haynes 1996). TAMM 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. Projections of fiber products and fuelwood which were part of the earliest version of TAMM are now derived from separate models,

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[1] Development of TAMM and its operation as part of the Forest Service's Timber Assessment has been a team effort of the broadest sort, involving researchers, programmers, graduate students and research associates in both the U.S. and Canada. The authors acknowledge the contributions of these people without which the model could not have been developed. We wish to give special thanks to the two lead computer programmers Jonna Kincaid and Eric Jensen who, over the past 15 years, have played a major role in shaping TAMM and insuring its continued flexibility as an analytical tool.

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[3] 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 Nations' 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.

NAPAP (Ince 1994) and NAWEM (Skog 1993), which are linked to TAMM through the demands for, and prices of, roundwood and residues.

Some of the broad aspects of TAMM's structure, which serve to characterize the nature of TAMM as a market model and (in some instances) differentiate it from other models presented in this workshop, have remained essentially fixed since its earliest development:

(i) use of a spatial equilibrium format, with geographically dispersed demands and supplies, assuming competitive markets for all products;

(ii) dynamic adjustment of certain elements of demand and supply using mechanisms based on past market behavior (assuming limits on producer knowledge) rather than intertemporal optimization (assuming perfect knowledge);

(iii) multiple market levels (products, logs, stumpage) and species (hardwood and softwoods differentiated);

(iv) multiple timber owners, public and private, with potentially different management objectives;

(v) a timber resource model structure in which timber growth and inventory levels are endogenous;

(vi) production technologies for solidwood (and, before NAPAP, fiber) products in which the wood input/product output ratios (also called product recovery factors) are not price sensitive and determined outside the model, i.e., wood and other factors are separable in production;

(vii) private timber management investment decisions are determined outside the model;

(viii) the boundary between the model and external world in the solidwood sector has been at the end-use demand industry level and the output of these industries (such as housing) has been exogenous (up to this point demand has not extended to consumer demand for housing and other "final" products); and

(ix) the geographic focus has been on the U.S. and Canada with product flows to and from off-shore points treated as exogenous.

Within the broad outline set by these characteristics, TAMM (like many other spatial models) can be viewed as having a modular structure:

(1) product demands, one set for the "highest" market level considered and possibly additional demand relations for other access points to the streams of product flows, such as product export demands;

(2) product supplies, in the TAMM structure these include specialized price-sensitive relations for the major products, and possibly additional supply relations for other inputs to the supply stream, such as product import supply;

(3) log demands, in TAMM derived from assumed fixed input/output relations between product outputs and log input requirements, but may also include fixed or price-sensitive log export demands;

(4) log and/or timber supplies, a mixture of price-sensitive relations and exogenous flows describing the volumes of timber available for immediate harvest and/or the volumes of logs delivered to mills and may include log import supplies; and

(5) timber inventories, modeled using the ATLAS system (Mills and Kincaid 1992).

Throughout TAMM's history the behavioral constructs developed to fill these various modules have not been restricted as to format. As one example, the product demand relations for softwood lumber and structural panels used in the Forest Service's 1995 Timber Assessment Update (Haynes, Adams and Mills 1995) derived from Spelter's diffusion models (Spelter 1984, 1985, 1992) which have a nonlinear form and price elasticities that vary with volume/price, while the demand relations for hardwood lumber were of the constant elasticity form. The basic modeling philosophy in TAMM's development has consistently been one of flexibility, selecting first the most useful modular structure then adapting interfaces with the remainder of the model in whatever ways were needed to accommodate the desired approach. This has meant that TAMM has not developed as a general modeling framework applicable to a wide range of spatial modeling problems but as a specific and eclectic model of U.S. and Canadian forest sector markets. The contrast here would be with a model structure such as PELPS (Zhang et al 1993), where demands and supplies are assumed to be expressed in a specific functional form and the overall system was intended for application to any sufficiently stylized set of spatial markets.

Beyond these basic elements, the structure of virtually every module in TAMM has changed, in some cases dramatically, over time. A brief chronology of TAMM development by sector is shown in Table 1.

Table 1. Chronology of major structural changes by module in the Timber Assessment Market Model since initial development.

Product demand (excluding hardwood solidwood) simple linear and/or fixed elasticity demand functions for solidwood with no end-use detail (aggregate); fixed consumption volumes for fiber products Spelter's diffusion model for softwood lumber and structural panels NAPAP price-sensitive, constant elasticity demands for fiber products	Stumpage supply simple linear or nonlinear (ad hoc) private supply relations involving price and inventory; public sector cut exogenous supply relations derived from discrete intertemporal optimal supply theory, objectives vary by owner; public harvest and bid prices endogenous in key western regions using models of Adams and Haynes (1989) and Adams, Binkley and Cardellichio (1991)
Product supply (excluding hardwood solidwood) simple linear (ad hoc) product supply relations with cost and margin accounting (reality checking) capacity change based on rational expectations model and minimum acceptable margin supply relations derived from basic production theory (consistent with desired technology limitations) with cost and margin accounting capacity change based on accelerator model with minimum acceptable margin	Inventory module TRAS, size class model with no clear impact of changing management intensity ad hoc adjustment of TRAS growth rates to represent management ATLAS age class model, with both even-aged and partial cutting, and explicit management investment impacts
Hardwood sector independent model paralleling main TAMM, ad hoc linear supply and demand structure (no grade detail) all products Binkley & Cardellichio hardwood lumber model with grade and end-use detail integrated in main TAMM solution; fiber demand exogenous constant elasticity product demand by end-use category, supply relations paralleling softwood sector (no grade detail)	Model solution process TAMM solved with reactive programming (RP); fiber products not sensitive to price TAMM solved with RP; NAPAP solved with PELPS LP; iterative solutions using full projections of both models until convergence TAMM solved with CS+PS nonlinear objective (GAMS/MINOS); NAPAP solved with PELPS LP; aggregate solution using full projection iterations

TAMM STRUCTURE: RECENT DEVELOPMENTS AND FUTURE PLANS

Structure of Key Modules

The current **solidwood products demand** module employs Spelter's diffusion model of demands for softwood lumber, softwood plywood and OSB/waferboard (Spelter 1984, 1985, 1992). Spelter's model considers the demand for each product category separately in an array of end-uses (various components of single-family home construction, residential upkeep and alteration, multi-family and mobile units, nonresidential construction, manufacturing, etc. a total of 18 uses in all). Price-based substitution among lumber, plywood and OSB (and several non-wood factors as well) is a central element of Spelter's model. The (factor) demand curves are derived in an *ad hoc* fashion, however, rather than from a traditional production theoretic model of the sectors in question. As a consequence, the aggregate demands for softwood lumber, softwood plywood and OSB in the original form of Spelter's models are not symmetric in their cross-price partial derivatives. This poses problems for determination of spatial equilibrium (as noted below). It is important to emphasize nonetheless that this model does have non-zero cross-price partials unlike most other publicly available models of the solidwood or fiber products sectors, of either domestic or international scope.

The various phases of price-driven product diffusion (or product life cycle) are emulated in Spelter's model by embedding the relative price terms in a logistic function. To simplify computation of surpluses in the determination of spatial market equilibrium, we linearize the demand functions at the price-quantity points of last period's market solution. The national demand relations from Spelter's model are disaggregated across demand regions in TAMM by a process that links regional to national (average) prices[4] and assumes that regional consumption shares for each class of product (softwood lumber, plywood, etc.) evolve along exogenously specified paths (see Adams and Haynes 1996 for details).

The resulting linearized and disaggregated demand functions are also not symmetric in cross-price partials. As Takayama and Judge (1971) point out, this does not preclude the existence of a spatial equilibrium. But since the demand functions are not integrable, we can not employ the traditional scheme of maximizing the sum of producers' and consumers' surpluses subject to various volume flow constraints to find equilibrium demand, supply and trade quantities. We adopt instead Takayama and Judge's (1971) "net revenue maximization" approach. This involves two steps.

(1) Rather than consumers' plus producers' surpluses, interregional shipments are determined so as to maximize "net revenue" defined as the sum over all the product markets of total consumer payments (price x quantity) less producer variable costs less transport costs. Like the consumers' plus producers' surplus objective, net revenue here has no necessary welfare or market structure implications. It is simply a device to drive the market trading process. Integrability is still required to find a unique maximum of this objective, however. This is obtained *in the objective function*

[4] Spelter's is a model of national demand and uses average national prices and price indexes of the various goods involved.

only by arbitrarily setting the various pairs of cross-price partials in the demand equations equal to the average of the original (possibly different) values.

(2) To emulate a competitive market solution, we impose the "price balancing" conditions derived from the dual of the traditional competitive (surplus maximizing) problem as additional constraints and explicitly introduce equilibrium prices as variables in the optimization. Ignoring the multi-stage (products, logs, stumpage) nature of the TAMM market solution problem, there are, in general, demand prices and supply prices to consider. Via constraints we require that the demand price used in the computation of gross revenue (computed in the constraints from the original demand equations unadjusted for their asymmetric cross-price partials) be the same as the shadow price of an additional unit of a good for consumption. Supply prices derived in the computation of total variable costs must be the same as the shadow price of an extra unit of a good produced. And equilibrium demand and supply prices can differ by no more than unit transport costs.

These features are illustrated in the tableau in Table 2. The italicized demand functions, *PD*, appear in the objective and have been adjusted as described in (1) above. The original functions, PD, appear in the demand price balance constraints as noted in (2) above. Because we solve simultaneously for product and stumpage market equilibria and recognize both production capacity and timber inventory as bounds on product output and timber harvest, there are three additional prices in the objective (PK*, PI* and ps*) and one additional price balance constraint (the stumpage price balance relation). This problem is identical to that solved by the reactive programming scheme used in earlier versions of TAMM (Brooks and Kincaid 1987). Solutions are obtained using the MINOS5 solver in GAMS (Brooke, Kendrick, and Meeraus 1992).

For the 1997-98 Timber Assessment, the solidwood demand module is being revised to include an expanded treatment of the residential construction sector which will allow consideration of new technologies such as engineered wood and new building systems for single and multi-family dwellings. These improvements are being developed by Henry Spelter at the Forest Service's Forest Products Laboratory. In this approach, an additional market level, that for various types of housing as part of consumer expenditure and investment decisions, will be added to the model. Facing this demand, housing production will be described in activity analysis format, representing the vast array of systems that can be combined to produce a unit of housing. Each system has characteristic requirements for subsidiary inputs (such as wood products and non-wood substitutes) giving rise to derived demand for products such as lumber or OSB. Demand for other classes of end-uses will be represented with updated versions of existing diffusion models. The result will be a mixed demand system with varying market levels in the several end-uses employing an array of functional representations. Our intent is to impose as little additional simplification on this system as possible, being aided in this resolve by use of the nonlinear programming solution procedure.

Table 2. TAMM solution tableau for case of asymmetric cross-price partials in demand: the primal-dual "net revenue" approach.

	PRODUCT DEMAND	PRODUCT SUPPLY	STUMPAGE SUPPLY	TRANSPORT COSTS	EQUIL DEMAND PRICE	EQUIL SUPPLY PRICE	SHADOW PRICE CAPACITY	SHADOW PRICE INVENTORY	EQUIL STUMPAGE PRICE		RIGHT-HAND SIDE AND DESCRIPTION	
OBJECTIVE	$S_j \mathit{PD}_j D_j$	$-S_i PSN_i S_i$	$-S_i ps_i s_i$	$-S_i S_j C_{ij} T_{ij}$	$-S_j PD^*_j EM_j$	$-S_i PS^*_i EX_i$	$-S_i PK^*_i K_i$	$-S_i PI^*_i I_i$	$-S_i ps^*_i XC_i$			
PRODUCT DEMAND BALANCE	D_j			$-S_i T_{ij}$						£	EM_j	EXOGENOUS PRODUCT IMPORTS
PRODUCT SUPPLY BALANCE		$- S_i$		$+S_j T_{ij}$						£	EX_j	EXOGENOUS PRODUCT EXPORTS
PRODUCT SUPPLY CAPACITY		S_i								£	K_i	CAPACITY
STUMPAGE MARKET BALANCE		$r_I S_I$	$- s_i$							£	XC_i	EXOGENOUS CUT
HARVESTABLE VOLUME LIMIT			s_i							£	I_i	AVAILABLE INVENTORY
DEMAND PRICE	$- PD_j$				PD^*_j					3	0	
SUPPLY PRICE		PSN_i				$- PS^*_i$	PK^*_i		$r_I ps^*_i$	3	0	
STUMPAGE PRICE			ps_i					PI^*_i	$- ps^*_i$	3	0	
DEMAND-SUPPLY PRICE DIFFERENCE					$- PD^*_j$	PS^*_i				3	$- C_{ij}$	TRANSPORT COST

D, S, and s are, respectively, demand, supply, and stumpage quantities. PD (and *PD*), PS, and ps are the prices of demand, supply and stumpage and are functions of activities D, S, and s, respectively. Note that the functions *PD*, of factor demand curves, are adjusted as described in the text to render their cross-price partial derivatives of endogenous products symmetric. The functions PD are not so adjusted but appear as in their original form. PD*, PS*, PK*, PI* and ps* are the spatial equilibrium prices of demand, supply, capacity, inventory and stumpage, respectively. Explicit endogenous variables are D, S, s, T AND PD^*, PS^*, ps^*, PK^* and PI^*.

In Forest Service timber assessment projections, it has been customary to treat trends in the technology of wood products processing and logging by means of specific scenarios of the impacts of future technical developments on the use of the wood (log) input. 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, the current **solidwood products supply** module assumes that product output is obtained in fixed proportions to log input (the product recovery factor linkage) but in variable proportions to all other factors, implying that logs are separable from other inputs in production. Details of the derivation of relations in this module are described in Adams and Haynes (1996). These are econometric relations with parameters estimated using historical time series data.

This approach suffers from a number of limitations, including the arbitrary nature of the treatment of wood and non-wood input substitution and the difficulty of modeling emerging products such as OSB, LVL and engineered beams for which there is only very limited time series data on output and costs. To partially overcome these problems, the 1997-98 Timber Assessment will experiment with the use of activity analysis representations of a range of specific manufacturing technologies (each with different input mixes) to describe the production of certain existing and emerging products. This approach has been widely applied in the forest sector (for example, in the original IIASA GTM[5]) and does have limitations [see Cardellichio and Adams (1990) for a critique]. Use in TAMM will produce an overall supply representation comprising a mix of both continuous and discrete functional forms. As with demand, this should not pose problems in model solution given the nonlinear programming approach.

One of the most widely criticized aspects of early versions of TAMM was the form of its **timber supply module** particularly the supply relations for private timber owners.[6] The structures of the supply relations were admittedly *ad hoc* and the functional forms used were restrictive (the elasticity of harvest with respect to inventory was constrained to 1 to avoid collinearity when including inventory as an explicit regressor). In the most recent version of TAMM private timber supply functions are derived from explicit hypotheses of intertemporal harvest behavior for industrial and nonindustrial owner classes. The resulting relations link harvest to prices, inventory, interest rates and, for nonindustrial owners, income from nonforest sources. We have retained the inventory elasticity restriction, however, estimating the relations using the ratio of cut to inventory as the dependent variable.

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[5] The Global Trade Model developed during the early 1980s as part of the Forest Sector Project at the International Institute for Applied Systems Analysis is described in Kallio, Dykstra, and Binkley (1987).

[6] In the original version of TAMM, private stumpage supply was taken as a function only of inventory and relative stumpage price with no explicit optimizing theory of supply behavior. Subsequent work (see, for example, Binkley 1981, Hultkranz and Aronsson 1989, Kuuluvainen 1990, and Ovaskinen 1992) suggests that for both present value and intertemporal utility maximization objectives these original forms suffered primarily by failure to include certain variables in addition to price and inventory.

Model Solution

In the 1993 Timber Assessment Update the pulpwood sector, modeled by NAPAP, and the solidwood sector, modeled by elements of TAMM, were linked in solution using a variant of the Gauss-Seidel method [see Fromm and Klein (1969) for a general discussion of the approach and determinants of convergence]. A full 50-year projection was made with NAPAP using initial estimates of required inputs from TAMM. The resulting elements of NAPAP required by TAMM were then used to make a full 50-year projection with TAMM (this includes inventory projections). The process was then continued, trading full projections between the models until the solutions "stabilized". This usually required three to four iterations. While this can be a cumbersome approach, modifications in the input and output routines of the two models were made to smooth the transfer of results and the process eventually conducted on a single microcomputer.

Several elements used in the NAPAP model (residue production at solidwood mills, sawtimber stumpage price, and timber inventory) should be determined jointly (simultaneously) with elements used in the TAMM solidwood modules (pulpwood and residue prices and pulpwood harvest) in each projection time period. Ideally, this would be accomplished by merging the two models into a single simulator with a single solution process. While simultaneous solution remains a goal for the future, the process envisioned for the 1997-98 Assessment will involve closer integration of TAMM and NAPAP but stops short of contemporaneous linkage.

Figure 1 illustrates the approach. Since both models use annual simulation cycles, we replace the dual cycles with a single loop. Separate annual solutions are retained (NAPAP using LINDO and TAMM using GAMS/MINOS), but information is shared with only a single year's lag. In a typical annual cycle, NAPAP is solved using start of period timber inventories (these were determined by TAMM/ATLAS in the previous period and so involve no time lag) and last period's sawtimber stumpage prices and residue production at solidwood mills. Pulpwood harvest and pulpwood and residue prices from this solution are then passed to TAMM/ATLAS for its solution and the cycle repeated. Given the focus of the Timber Assessment on long-term trends and the general absence of cycles in exogenous input, we believe the differences between solutions obtained in this fashion (by replacing certain contemporaneous values with one year lagged solutions) and fully simultaneous ones to be minimal. Hence no iterative scheme is envisioned.

This configuration of the overall simulator and the software to be used allows considerable flexibility in dealing with differences in methods of module construction and changes in model structure over time. For example, the revised model of the residential construction sector described above is being developed in the PELPS separable programming framework. This model will have to be linked to those for other end-uses of solidwood products in the TAMM solution. But PELPS generates its LP problems in the standard MPS format (for transfer to LINDO) and it is readily possible to convert this format to one usable by GAMS/MINOS. Thus we can retain all the input and matrix generation elements of this new model rather than devising completely new approaches specifically for GAMS. Further, once an annual solution is obtained, key results can be transferred back to the PELPS framework to complete any period-to-period dynamic adjustment processes, such as capacity change.

In the longer term, work underway at the Forest Service's Forest Products Laboratory aims to fully link the sawtimber (softwood lumber, plywood and OSB) and pulpwood sectors in a simultaneous solution (including interaction with the timber sector) using the PELPS framework. This model would supplant large segments of the current version of TAMM, leaving non-structural panels, hardwood lumber markets and inventory accounting. This is readily accommodated in the overall model structure by modifying the information flows shown in Figure 1 as required for the markets solved in PELPS (labeled NAPAP in the Figure) and TAMM.

A final aspect of model solution, that has presented difficulties for some time, results from the difference in time steps in the market model (annual) and the ATLAS timber inventory model (5 or 10 year periods). To accommodate this difference, TAMM includes a simple linear growth-drain equation that provides inventory estimates in years between ATLAS updates. Harvest (drain) is known directly from TAMM/NAPAP but growth varies over time with residual growing stock (as well as changes in management inputs and the extent of the timberland base). As a consequence, an iterative procedure is required to produce a model solution, substituting revised growth estimates in the growth-drain model until changes in these values fall within some tolerance between iterations. In regions where timberland area and/or the aggregate level of management intensity can vary markedly from period-to-period, growth of the inventory will also vary significantly over time. In light of this behavior, we have found that an iterative process in which the entire 50-year sequence of growth values is exchanged leads to the most rapid convergence. In most cases not more than three iterations are required.

Research now underway at the Forest Service's PNW Research Station is examining the possibility of changing the ATLAS time cycle to one year. This would require conversion of inventories to annual age intervals and specification of yield functions on an annual basis as well. If results of this effort appear promising, we will adopt the annual cycle model in TAMM and eliminate a further need for iteration in model solution.

SOME THOUGHTS ON PAST PROJECTIONS AND FUTURE PROBLEMS

Exogenous Inputs

Projections made with TAMM in the past have been frequently criticized for their failure to track actual historical developments and to adequately portray the nature and causes of on-going market and resource changes in a variety of ways, with particularly vitriolic criticism of certain of our regional projections. This scrutiny is, of course, absolutely essential if the model is to be improved and the projections to be made as useful as possible to clients in the public and private sectors. It also raises questions about the process of making projections and the role that models like TAMM play in such processes. For example, the projections made using TAMM for the *South's Fourth Forest* (USDA Forest Service 1988) appeared to face only limited criticism due in part to the open and inclusive process used in the study. Different types of meetings were used to discuss both model development and refinement as well as different views on various assumptions used in the projections. In contrast, the projections, again made with TAMM, for the *1993 RPA Timber Assessment Update* (Haynes et al 1995) have received more criticism, perhaps because of the relatively limited forms of review opportunities made available to users during the study process.

But while criticism of projections is important, we fear that the full value of oversight is often lost when the focus of review is less than comprehensive. Specifically, it is often too easy to condemn selected aspects of model structure as the source of perceived problems without considering the role played by exogenous inputs. In a model as extensive as TAMM/NAPAP there are many such inputs but those of greatest concern in our view are the macroeconomic, private timber investment and public timber policy forecasts. The Timber Assessment attempts to partially illustrate impacts of these types assumptions by including a large array of "alternative scenarios" in which one or a limited number exogenous inputs are changed and the resulting projection compared to the "base".

To illustrate some of the issues here, Figures 2 and 3 compare projections from the 1980 Timber Assessment (USDA Forest Service 1982), the first based largely on projections from TAMM, and the 1993 Timber Assessment Update (Haynes, Adams and Mills 1995), the most recent. In Figure 2 note the dramatic differences in projections of housing activity, upkeep and alteration expenditure, GNP growth and the levels of public timber harvest. Keep in mind that exogenous inputs for the 1980 Assessment were actually prepared in the late 1970s, well before the "Volker Revolution" and the "northern spotted owl" became household phrases. Private management investment is not shown. In the 1980 Assessment no explicit representation of management inputs was possible. It was assumed that the effects of management inputs were embodied in some way in the growth functions describing the inventory and that, ". . . management in the future would continue at levels much the same as we have observed in the past." In the 1993 Update, management inputs are explicit and, in the key areas of the South, entail continued major planting on industrial lands and continued public subsidies of NIPF planting at average historical levels.

These input assumptions are markedly different and, quite apart from the changes in model structure (which have been dramatic over the past 15 years), account for a substantial part of the differences observed in the projected prices, harvests and inventories shown in Figure 3. This is obvious, but it is very commonly overlooked in critiques of the Assessment's projections.

Model Objectives, Scope and Use

During the 1960s when computer-based economic modeling was gaining rapid momentum, debate regarding the relation of the purpose or intended application of models and their form/structure was common in the literature. This issue is not much discussed today, though it is of no less importance. It is generally presumed that model users have somehow considered the linkage of problem and tools of analysis and adopted the appropriate tool. In the case of forest sector modeling, it is not evident that this is always the case. The tendency is to believe that a model is applicable if its simulation cycle is shorter than the cycle appropriate for the problem at hand. Thus TAMM might be used to examine some policy change whose major impacts are expected to occur during the first five years following its enactment just because TAMM has an annual simulation cycle.

TAMM was developed to provide projections of long-term trends in forest sector markets for periods as long as 50 years because evidence on trend development was thought to be sufficient to meet the needs of the legislation requiring the conduct of the Timber Assessment. As a consequence, TAMM does not recognize an array of elements of actual markets that may be critical to the explanation of short-term market cycles or adjustments (inventories and unfilled orders at mills, product grades, considerations beyond stand age in decisions to harvest, etc.). This suggests some caution in the application of TAMM to the analysis of problems with short time horizons. Conversely, it also suggests that TAMM's success or failure in tracking some particular market develop may not be useful evidence of its utility or lack thereof if the development is not related to the original purposes for the model's construction.

Model Control in Long-Term Projections

Given the intended length of the projection period for which TAMM was built (50 years), it is nearly certain that some elements of projected system behavior (and/or exogenous input) will move beyond the ranges of historical observation during the course of a projection. Since the parameters of most behavioral equations in TAMM are estimated from historical data (often over a period of much less than 50 years), this prospect raises potentially significant issues of "model control". For example, suppose the behavioral relation (f^h) estimated from historical data linking two endogenous variables (x_1, x_2) and one exogenous variable (z) is $x_1 = f^h(x_2, z)$. The response of x_1 to x_2 based on historical experience is $\P f^h/\P x_2$. Should this response remain the same if x_2 were to double or triple relative to historical average levels? Should the model act in some way (through feedback or other interactions) so as to preclude x_2 from ever reaching two or three times historical levels? Similar concerns might be raised with respect to $\P f^h/\P z$. The modeler's dilemma here is whether to simply allow these responses to persist or to intercede in model operation to increase or decrease them so as to produce behavior more nearly consistent with user and modeler judgment regarding the underlying processes.

As a practical instance, we have often encountered these problems in TAMM projections of private timber harvest. Consider a scenario in which (exogenously specified) timber management investment on industrial private lands increases by some amount relative to historical levels. Over time this will gradually increase the volume of inventory and elicit some increased harvest response (since harvest is positively related to inventory in our supply models). In some cases increased harvest is much less than increased growth and the inventory accumulates sharply relative to harvest (and any historical experience) with increasing acres in older age classes. For this specific case of industrial owners, this behavior departs dramatically from historical experience (industrial owners have seldom allowed inventory to accumulate in ages much beyond minimum merchantability).

The model probably fails to "correct" this particular problem because it does not fully capture the linkage between management investment and harvest behavior, uses erroneous functional relationships between harvest and its determinants, or both. Absent the ability to employ a "better" theory, what should be done? In TAMM projections, we have handled these cases by establishing bounds on the ratio of private harvest to inventory based on average historical experience. We adjust the model by raising the responses of harvest to inventory until the cut/inventory ratio moves back into the constraint range. This is a practical solution but it lacks any theoretical support and elevates the historical range of the cut/inventory ratio to a position of considerable, perhaps unwarranted, importance.

We suspect that virtually all long-range projection models have encountered problems of this sort, though we have seldom heard them described. We also believe that the fundamental source of these control problems does lie in the failure of the model to explain dynamic behavior; instances where real world producer decisions involve aspects of intertemporal expectations or adjustments that aren't captured in static econometric specifications. In our experience this problem is sufficiently pervasive and important to warrant much greater attention that it has received.

Living With a Shrinking Data Base: Modeling Without Data

One of the incidental victims of declining public spending on domestic programs has been the collection of data on virtually all aspects of production and trade in forest products markets. And with the sharp reduction in public timber sales programs in the U.S. we have only a limited public source of information on timber prices, log and haul costs or production costs in many regions. In some cases critical public sources can be replaced by data from private institutions and/or associations. But even with this, the loss of public data looms as a major concern in any future efforts to maintain on-going forest sector models either by public agencies or private firms and institutions.

The Future of Eclectic Modeling

At the start of this paper we described the basic modeling philosophy in the development of TAMM as one of flexibility, adapting methods and procedures in whatever way was needed to incorporate the best available approaches for specific modules. This certainly has not lead to an "orderly" model structure, as all past users of TAMM will attest. Messiness notwithstanding, we believe the current tide of developments in computer hardware and software will continue to make it increasingly easy to meld whatever array of models and methods the modeler desires. In its current form, TAMM/NAPAP combines routines written in four different computer languages, employs two optimizers to find market solutions and moves in and out of two different operating systems in the course of a projection. Simplicity and parsimony must continue to be important tenets of model building generally but they need not be the dominant concerns. Particularly in the knowledge rich environment of the North American forest products sector, it would seem to be most productive to make use of whatever information may be available rather than hew to some specific model form or method.

Figure 1 is available from the authors.

Figure 2 is available from the authors.

Figure 3 is available from the authors.

LITERATURE CITED

Adams, D. M., C. S. Binkley, and P. A. Cardellichio. 1991. Is the Level of National Forest Timber Harvest Sensitive to Price? *Land Economics* 67(1): 74-84.

Adams, D. M. and R. W. Haynes. 1980. The 1980 Softwood Timber Assessment Market Model: Structure, Projections, and Policy Simulations. *Forest Science Monographs* 26(3): 1-22.

Adams, D. M. and R. W. Haynes. 1989. A Model of National Forest Timber Supply and Stumpage Markets in the Western United States. *Forest Science* 35(2): 401-424.

Adams, D. M. and R. W. Haynes. 1996. *The 1993 Timber Assessment Market Model: Structure, Projections and Policy Simulations.* General Technical Report PNW-GTR-358. Portland, OR: USDA, Forest Service, PNW Research Station.

Binkley, C. S. 1981. *Timber Supply from Private Nonindustrial Forests: A Microeconomic Analysis of Landowner Behavior*. Bulletin No. 92. New Haven: Yale University, School of Forestry and Environmental Studies.

Brooke, A., D. Kendrick, and A. Meeraus. 1992. *GAMS: A User's Guide, Release 2.25.* San Francisco, Ca: The Scientific Press.

Brooks, D. J. and J.; Kincaid. 1987. *REACTT: An Algorithm for Solving Spatial Equilibrium Problems.* General Technical Report PNW-GTR-204. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northeast Research Station.

Cardellichio, P. A. and D. M. Adams. 1990. An Appraisal of the IIASA Model of the Global Forest Sector: Advances, Shortcomings, and Implications for Future Research. *Forest Science* 36(2): 343-357.

Fromm, G. and L. R. Klein. 1969. Solutions of the Complete System. In *The Brookings Model: Some Further Results*, edited by J. S. Duesenberry, G. Fromm, L. R. Klein, and E. Kuh. Chicago: Rand McNally and Co.

Haynes, R. W. 1990. *An Analysis of the Timber Situation in the United States: 1989-2040.* General Technical Report RM-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Haynes. R. W. and D. M. Adams. 1985. *Simulation of the Effects of Alternative Assumptions on Demand-Supply Determinants on the Timber Situation in the United States.* Washington, DC: U.S. Department of Agriculture, Forest Service, Forest Resources Economics Research.

Haynes, R. W., D. M. Adams, and J. R. Mills. 1995. *The 1993 RPA Timber Assessment Update*. General Technical Report RM-259. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hultkranz, L. and T. Aronsson. 1989. Factors Affecting the Supply and Demand of Timber from Private Nonindustrial Lands in Sweden: An Econometric Study. *Forest Science* 35: 946-961.

Ince, P. 1994. *Recycling and Long-Range Timber Outlook.* General Technical Report RM-GTR-242. Fort Collins, CO: USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Kallio, M., D. Dykstra, and C. Binkley. 1987. *The Global Forest Sector: An Analytical Perspective.* John Wiley & Sons, Ltd.

Kuuluvainen, J. 1990. Virtual Price Approach to Short-Term Timber Supply under Credit Rationing. *Journal of Environmental Economics and Management* 19: 109-126.

Mills, J. and J. Kincaid. 1992. *The Aggregate Timberland Assessment System--ATLAS: A Comprehensive Timber Projection Model.* General Technical Report PNW-GTR-281. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Ovaskainen, V. 1992. Forest Taxation, Timber Supply, and Economic Efficiency. *Acta Forestalia Fennica* 233. 89p.

Skog, K. 1993. Projected Wood Energy Impact on U.S. Forest Wood Resources. In: *Proceedings of the First Biomass Conference of the Americas, August 30-September 2, 1993, Burlington, VT.* Golden, CO: US Dept. of Energy, National Renewable Energy Laboratory.

Spelter, H. 1984. Price Elasticities for Softwood Plywood and Structural Particleboard in the United States. *Canadian Journal of Forest Research* 14: 528-535.

Spelter, H. 1985. A Product Diffusion Approach to Modeling Softwood Lumber Demand. *Forest Science* 31(3): 685-700.

Spelter, H. 1992. Technology-Driven Substitution in the Forest Sector: The Variable Price Elasticity Model Revisited. In *Forest Sector Analysis: Proceedings of P06.02 FORESEA, IUFRO centennial 1992, 30 August-4 September; Berlin, Germany,* edited by Lars Lönnstedt. Uppsala, Sweden: Swedish University of Agricultural Sciences, Forest-Industry-Market Studies: p 24-29.

Takayama, T., G. G. Judge. 1971. *Spatial and Temporal Price and Allocation Models.* Amsterdam: North-Holland Publishing Co.

USDA, Forest Service. 1982. *An Analysis of the Timber Situation in the United States, 1952-2030.* Forest Resource Report No. 23. Washington, DC.

USDA, Forest Service. 1988. *The South's Fourth Forest: Alternatives for the Future*. Forest Resource Report No. 24. Washington, DC.

5. The Cintrafor Global Trade Model and the Forest Sector Assessment Process

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Abstract

The paper describes the Cintrafor Global Trade Model (CGTM) within the process of producing an assessment on alternative outlooks and policies affecting raw material supplies. The assessment process is first described followed by a technical description of the CGTM and its components. The result of a recent model update suggests continued upward price pressure for softwood lumber markets in North America and Asia. European lumber markets remain flat. Log prices in North America rise with the exception of Canada's Interior region, where the log market is isolated by log trade restrictions. A potential implication is greater competitiveness in lumber manufacturing for mills located in Canada. The assessment process is revisited with discussions on similar processes implemented in other sectors. The paper presents the need for the forest sector process to expand in number of alternatives and policy measures and to remain open for questions with examples in the environmental and social benefits areas.

INTRODUCTION

Forest sector models are only one component of an assessment process that evaluates fiber supply issues in North America. Another essential component includes policy makers and users who initiate the process by raising questions concerning the future of raw material supplies, the impact of alternative policies on supply, or the direction of forest products markets. Models are useful to help these participants better understand the impact of policy alternatives and other changes. Hence modelers, policy makers and those who have a vested interest in the forest sector are all essential participants during an assessment process.

Forest sector models can play a significant role during the assessment process. They supply information concerning the future development of fiber resources and the direction of forest products markets. They identify uncertainties and opportunities associated with alternative policies which affect future outlooks of raw materials and market development. They produce a relevant baseline from which policy makers weight alternative actions. Yet, for the most part, existing forest sector models have been developed to answer specific questions. The Cintrafor Global Trade Model (CGTM) (Cardellichio et al. 1989) is a modified version of the International Institute for Applied Systems Analysis' global trade model (Kallio, Dystra and Binkley 1987), and, in its case, forest products trade patterns and competitiveness of U.S. industry in domestic and international markets were primary concerns of users.

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Understanding the sorts of questions forest sector models can answer becomes important in the assessment process.

While the process associated with producing a relevant baseline has been important in the past, its importance appears to have diminished in recent USFS timber supply assessments. Limited input from policy makers and stakeholders other than the immediate users of models have been utilized. Use of a forest sector model should not take place in isolation. Stakeholder should be linked with the modeling effort (Perez-Garcia 1996b). Otherwise, the relevancy of the baseline conditions produced by the model and from which policy impacts are measured is diminished.

Placing the CGTM in the Assessment Context

The paper describes the CGTM within the context of an assessment process. It does so recognizing that the CGTM is just one of a host of forest sector models that can be used to construct a relevant baseline condition and provide comparable evaluations of policy and other changes. Hence the paper places equal importance on the model and the linkage between the model and the assessment process. The next section briefly describes the assessment process within which the CGTM can address specific questions forest sector policy decision makers and stakeholder have. Section 4 describes the model structure, the data requirements and key model assumptions. Section 5 describes output from the model, and the input this modeling output can provide to others involved in the assessment process. Sections 6 and 7 provide examples of processes implemented in other sectors, added complexity required to answer environmental and social questions and their respective output measures.

The Assessment Process

A forest sector model can produce a wide array of policy impacts by manipulating any number of the many input assumptions and structural relationships inherent in the model's development. For instance, one can make price projections behave differently depending on demand growth or inventory behavioral assumptions. The large number of assumptions complicates policy analyses and makes good science--i.e. reproducible results--difficult to impose on assessment processes. Even interested users may lack the patience to understand all of the economic, environmental and forest sector initial conditions. This is a major limitation of using any large forest sector model in policy analysis; no systematic approach exists to test all input assumptions.

It is a time-consuming effort to understand the workings of a large forest sector model. The benefits associated with achieving the goal of reproducible results may not seem worth the effort; however, the next best step--understanding the differences in results--is important. This is best accomplished by developing a set of scenarios that represent alternative input assumptions. One approach to develop this set is for the analytical system, the data and the reference baseline to receive critical, independent reviews by public policy participants--those individuals and organizations directly affected by policy. A scientific and user peer review is often pursued in developing models; frequently it includes a review of the data used to establish relationships in the model. The review process needs to be extended to include the reference baseline constructed by the model which differs with alternative input assumptions. The reference baseline is the point from which policy impact measure are developed. A reviewer panel should include social scientists, public policy participants and those stakeholders that are likely to be impacted by policy changes.

Figure 1 summarizes areas to improve reviews of the assessment process. Analytical systems, which may include models or groups of models linked together, are used to develop policy impact measures. Model develop and linkages between models that define the analytical system normally go through a peer review process. The analytical system is then used to form a reference baseline. Often, the reference baseline is not subject to critical review of alternative input assumptions. The lack of a peer review of the reference baseline can lead to the dismissal of policy assessment outcomes.

Deciding what questions should be asked and what policy measures to evaluate should also be developed with the input of a review panel. Since CGTM and many other models were developed to meet specific objectives and answer certain questions, it is always important to determine if the particular model is the best or even suitable for any particular evaluation. A clear description of the underlying theory and input assumptions allows policy makers to judge the acceptability of models to assist them in answering their questions.

The CGTM Structure: Underlying Theory and Sub Models

The CGTM models the impact of changes in regional supply and demand around the world. The principle output are prices, trade flows and revenues for standing timber, logs, and primary products. It characterizes the impact on three stages of production and consumption: the timber producer, the processor and the intermediate or final product consumer. The CGTM determines the set of prices that minimizes costs while maximizing consumer's and producer's surplus by using an optimization program. Its structure is describe in greater detail in Cardellichio et al., (1988, 1989) and Kallio, Dystra and Binkley (1987).

The CGTM computes market equilibria for regional forest products sectors considering constraints on processing capacity and available wood resources. It solves for equilibrating prices, production, consumption and trade levels for each region period by period. It increases (decreases) future processing capacity when profit (costs) increase and past utilization is above (below) the historical trend level for capacity utilization. It emulates multi-product and market behavior for the timber resource and intermediate wood products sector.

The logic of the model is as follows. The demand for forest products in each region may be met by its own domestic production or by imports from other regions. A region will import some or all of its consumption needs if the price of the domestic product is higher than the cost associated with purchasing it outside of the region and transporting it home, including trade-related costs. Increases in imports force down domestic prices until market prices are in equilibrium: the price in the importing region is equal to the price in the exporting region plus all trade costs. The competitive market structure imposed on the model assures that final demand is met employing the least costly producer after accounting for transportation costs.

Figure 2 presents the model's optimization mechanics in a very unsophisticated format. The graph represents global demand and supply for a forest product such as lumber. In CGTM the global demand and supply are comprised of the sum of regional demand and supply. What the model accomplishes is to extend the area underneath the demand function and above the supply function by locating the cheapest fiber source--i.e. pulling the supply function downwards as far as possible. This mathematical problem--finding the maximum sum of consumers' and producers' welfare within the constraints imposed by fiber availability and processing capacity--is equivalent to a competitive market solution (Samuelson 1952).

Figure 2 demonstrates another feature of the CGTM. All spatial equilibrium models predict a single price for a product in markets with trade activity. The amounts produced, consumed and traded are a result of this global market clearing price. However, the global price determined by the model is a long-term phenomena, one which we rarely observe in current markets even with the short-term price responsiveness embedded in the model. This is because the trade model instantaneously adjusts both prices and quantities to conform to the price equilibrium assumption; whereas in reality, trade inertia, inventory adjustments and other factors prevent the instantaneous adjustment predicted by the model.

Nevertheless, it is not a given that the trade model will produce a single global price. Differences in price behavior among regions can occur due to changes in regional resource availability, cost structure and transportation costs, all of which affect trade flows. If, for example, Chile were to terminate its log exports to Asian trading partners, it's domestic log price would no longer move in tandem with log prices in other Asian markets. Reasons for its curtailment of log shipments overseas may depend on available domestic fibers for domestic consumption, among other reasons. Under such circumstances, one may observe differences in price behavior across regions that are still consistent with spatial equilibrium in a global context. These price differences are important characteristics of global competitiveness.

The production and distribution levels in the CGTM are timber supply, processing supply, consumer demand and trade in the product and log markets. The various components are linked within an competitive market setting where price arbitrage forces price equilibrium among trading regions. The equilibrating mechanism operates in both the product and log markets in the CGTM. Derived demand for wood raw materials links the solidwood product, sawlog and pulpwood markets. Each component of the model is described further below.

Timber Supply. Timber supply behavior is described through forest growth and timber supply components. The timber supply equations specify harvests in each region given information on log prices, forest inventory levels and other information. Depending on the particular region, the CGTM uses one of four log supply functions.

The most common supply specification (used in most of the US regions, Finland, Sweden, Western Europe and Japan) estimates the quantity supplied as a positive function of both log prices and the level of growing stock inventory. Increases or decreases in timber inventory, determined by growth and yield models and removals information, shift the supply curve in or out, period by period. Growth and yield models, which describe regional inventory and have been linked to CGTM to determine the magnitude of inventory changes and forest structure detail, are briefly described in the model's dynamic section below.

The second supply specification has an upward sloping curve but also places an upper harvesting limit to log supply. If a region is operating below the limit on harvests, timber supply will respond positively to increases in log prices. When harvest levels hit the limit, further increases in timber prices have no effect on harvest levels. The upper limit on harvests can be thought of as the maximum allowable annual cut (AAC) on the mature or harvestable inventory. Timber supply in Chile and New Zealand, and more recently Canada, is modeled in this fashion.

A third specification fixes log supply at a predetermined level for each period of the simulation. In any one period, log supply is wholly unresponsive to price changes. Examples of regions utilizing this strict AAC supply specification include China and the CGTM-defined Eastern European region where planning rather than prices determine harvest levels. Public timber supply regions in the US are also specified using projected annual cut levels. The specified levels reflect a combination of constraints based on physical productivity of the forest, the infrastructure available to access the forest, and policies which restrict industrial access to timber.

A fourth alternative for log supply assumes that log supply is perfectly elastic, so log supply is determined by product supply. An example is Brazil's solidwood hardwood forest sector where log supply is not a constraint on the production of hardwood solidwood products. In the case of Brazil, log supply behavior is implicit in product supply behavior.

Table 1 reports timber supply parameters for important softwood producing regions around the globe using 1993 data. Each of these alternative supply representations identifies a special case of a generally rising cost curve in which harvesting limits are imposed to model the most appropriate supply behavior for each region and public ownerships.

Processing Supply. Each region's processing supply curve is calibrated to 1993 conditions using production level, manufacturing cost and installed capacity level (Table 2). Recovery factors, which relate the lumber recovery ratio of the region, are also presented in Table 2. Supply of a product is considered a function of prices, wood costs, other manufacturing costs, other wood product revenues and milling capacity. Total processing capacity in a region acts as a constraint to total lumber and plywood manufacturing activity. Wood costs, and any revenues obtained from the sales of chips and residues associated with manufacturing, determine the position of the product supply function. Higher wood cost shifts the capacity-constrained product supply curve upwards with capacity utilization determining the level of product output.

Table 1. Parameters for Important Softwood Log-Supplying Regions in the CGTM: 1993

Region	Log Price $US1980/m3	Price Elasticity	Log Production Million m3	Previous Period Inventory Level Million m3
U.S. PNW[a]	$79.55	0.79	32.458	811.5
Eastside U.S. West[a]	$58.74	1.22	5.581	230.1
Interior U.S. West[a]	$50.09	0.74	17.674	785.1
U.S. South[a]	$37.73	0.56	93.669	2529.0
U.S. North[a]	$36.95	2.16	8.374	1038.0
Coastal B.C.[b]	$67.52	4.04	18.184	25.1
Interior B.C.[b]	$39.54	7.35	56.355	67.1
Eastern Canada[b]	$38.92	3.12	30.535	65.0
Chile[b]	$55.74	2.84	7.923	9.4
Finland[a]	$19.04	2.88	16.232	1550.0
Sweden[a]	$41.63	0.41	25.400	2284.0
Western Europe[a]	$56.62	1.00	55.618	3995.0
Japan[a]	$162.37	0.95	16.099	1904.0
New Zealand[b]	$72.44	1.00	10.466	9.5

a--supply is a function of both prices and the level of growing stock.
b--upward sloping supply with AAC constraint.

Table 2. Parameters for Important Processing Regions in the CGTM: 1993

Regions	Price Elasticity	Price $US/m3 $1980	Product Quantity Mill m3 1993	Installed Capacity Mill m3 1992	Manuf. Costs US$/m3 $1980	Recovery Factor m3 log per m3 product
U.S. PNW	0.32	$188.85	11.710	16.052	$186.69	2.088
Eastside U.S. West	0.55	$290.50	3.759	6.536	$207.55	2.625
Interior U.S. West	0.45	$176.13	10.626	14.172	$163.31	2.363
U.S. South	0.19	$153.65	23.322	28.875	$122.67	2.777
U.S. North	0.34	$136.78	2.749	3.675	$123.53	2.932
Coastal B.C.	0.19	$197.85	6.432	8.100	$150.72	2.384
Interior B.C.	0.24	$173.31	20.866	23.090	$109.81	2.656
Eastern Canada	0.58	$201.50	12.287	16.461	$92.17	2.775
Chile	1.06	$180.41	2.660	3.551	$111.11	1.800
Finland	0.61	$145.73	8.300	9.762	$87.03	2.065
Sweden	0.25	$146.04	12.544	13.494	$133.37	1.996
Western Europe	0.10	$163.56	31.510	41.158	$141.19	1.650
Japan	0.11	$275.95	23.301	23.999	$289.42	1.400
Korea	0.37	$308.21	2.704	3.312	$222.46	1.400
New Zealand	0.28	$214.10	2.684	2.860	$208.14	2.147

Adjustments in capacity are a function of historical profitability. That is, capacity is fixed for the period of production but can adjust in subsequent periods depending on previous profits and capacity utilization targets. Given that markets produce fluctuations around a long-term average in capacity utilization, investments and capacity expansion occur with above-trend capacity utilization and high profits. Investments and capacity expansion, spurred by higher profits, will then lower capacity utilization toward the target level in future periods and vice versa. For example, if log costs increase, everything else constant, and with a specified capacity utilization target, such as 85 percent of total capacity, total profits would decrease. If mills are operating above their utilization target of 85 percent, the lower profits will reduce output towards their utilization target without reducing capacity in the next period. If mills were operating below the target capacity utilization, higher log costs would reduce capacity in the next period to reach the utilization target of 85 percent. Lower log costs may either expand output if mills are operating below utilization capacity and expand capacity if mills are operating above utilization capacity. The rate of capacity change in CGTM is restricted to the range of historical operation.

Future levels of product production for other regions not listed in Table 2 are projected using information on the region's projected capacity. Regions under this second specification of product supply do not respond to changes in prices. Examples of these regions include China and the former Soviet Union.

Demand for Solidwood Products. The CGTM employs two demand specifications. One specifies consumption as a function of prices and is used to model softwood lumber demand in the U.S., Canada, Japan, Korea, Chile, New Zealand, the CGTM-defined European regions as well as major hardwood consuming regions of the world. The second approach utilizes projections of consumption that are unresponsive to price changes. Again, China and the former Soviet Union are examples of this second application. Projections of demand end-use factors, economic and population growth are used to shift demand from period to period.

The Trade Component. The CGTM includes over 400 trade flows in its current specification. Trade volumes observed in 1993 are utilized to calibrate current global trade patterns. Most trade flows are endogenous in the model, i.e. price levels and transfer costs can affect the amount of trade activity. Trade flows can also be projected and utilized as input assumption in CGTM if one chooses to do so under alternative policy analyses.

Model Dynamics. The trade model solves market equilibria on a year by year basis. It incorporates dynamic behavior by linking each period with models of timber supply dynamics, processing capacity dynamics and projections of end-use factors in the consumption of solidwood products. Changes in regional supply or demand result in dynamic adjustments toward the long-term capacity utilization target.

The timber supply dynamics are captured in the CGTM by changes in merchantable inventory caused by timber removals and growth in each region. Several inventory models have been linked with the CGTM to describe the development of the merchantable inventory in each region including ATLAS (Mills and Kincaid 1992) and SERTS (Pacheco, Abt and

Cubbage 1996). Both models provided detailed inventory descriptions and information on how the structure of the inventory in a region changes as each region meets its harvest requirements.

Since updating procedures for processing capacity have already been discussed, they will not be discussed further. Input/output processing coefficients are also updated to reflect greater efficiency in wood use, changes in raw material size and the emergence of new technologies, but they are not considered to be price sensitive.

Prices are determined period by period with no anticipation of future price levels. In effect, however, investment and capacity expansion respond to profits--a proxy for cash flows. Historical prices adjusted for inflation have been cyclical and sometimes volatile but with few instances of any significant long-term trend. Short-term price volatility in projections could be induced by cyclical demand indicators but such simulations have not been the focus of prior research.

The CGTM Data Requirements. The CGTM represents a large global data base on forest products sectors. Attempts are currently underway to make the data set more easily available to those interested in its richness for further analyses. Three data types are required to operate the CGTM. The first type consists of information on model definitions including regions, products, their number and types, the start year for the data and the start and end years for the analysis. In CGTM there are 43 timber supply regions and 33 product demand regions. Products which are consumed in CGTM are softwood and hardwood lumber and plywood. Products produced by CGTM are softwood and hardwood sawlogs, pulpwood, lumber and plywood. Sawlogs and pulpwood are indirectly consumed through the derived demand for these inputs from product demand. In addition, CGTM defines two additional products, pulp and reconstituted panels, whose production levels are projected to account for the consumption of residual chips produced in lumber and plywood manufacturing and pulpwood harvests.

The second type of data is historical data used to determine model parameters. Key parameters in the model are elasticity estimates for log supply, processing supply and product demand. Other parameters include input/output coefficient and trade cost estimates. Inventory growth, acreage changes, capacity adjustment coefficients are additional parameters specified in the model using historical data.

The third type requires the observed level of production, price, consumption, and trade that corresponds to 1993--the start year. These data requirements are extensive and discussed in more detail below.

Demand equation parameters include the price elasticity and constant term for the calibration year. Updating the constant term for the demand equation is performed using percentage shifts of the demand curve for each product consumed based on projections of end-use activity indicators such as wood housing starts. When end-use activity indicators are not available, shifts in the demand curves are based on population and economic activity.

Product information is contained in five product data files. Historical, current and projections of either production and consumption levels for those regions that are not price sensitive are contained in one file. A second product file contains yearly projections of pulp and reconstituted panel production levels. Production parameters are contained in two additional files. The production parameters include supply parameters--constant and slope coefficients--capacity adjustment coefficients, the manufacturing margin--the constant portion of manufacturing costs--the capacity utilization target and the year in which the manufacturing margin target is achieved. Historical and current data on processing capacity and manufacturing margin for each product consumed is also contained in the file. The final product file contains the input/output coefficients for products and how they change over time.

The CGTM contains four timber data files. The production information describes past sawlog and pulpwood log levels, current year production levels, and projected levels for those regions which do not have a price sensitive supply function. Supply equation parameters are contained in a second timber data file. It includes stumpage and harvests and delivery supply parameters for regions describe by price sensitive supply functions. The type of supply function discussed above is specified in a third timber data file. Additional data on timber supply behavior such as projections of disposable personal income are also contained in the file. The fourth timber data file describes the dynamic behavior of timber supply. It contains information on inventory levels, forested areas, growth per area and miscellaneous, non-timber harvests. An additional file allows CGTM to be linked directly with either SERTS or ATLAS.

Information on bilateral trade flows, whether they are fixed over time, updating fixed trade flows and bilateral transfer costs are contained in three trade data files. Bilateral transfer costs are also updated in another trade data file. Optimal tariff rates can be calculated by use of still another trade data file.

Price information is used to both estimate price behavior and to calibrate the model to the start year conditions. Log prices, and their component costs--stumpage fees and harvest and delivery costs--are utilized in the model to develop supply behavior parameters. Product prices and their component costs and revenues--manufacturing costs, wood raw material costs, chip revenues--are utilized to develop supply behavior parameters. The CGTM also contains an exchange rate file that allows the user to perform sensitivity analysis to fluctuating exchange rate regimes.

Model Output and Discussion

The model produces information useful for assessment of policies, their alternatives and uncertain future conditions facing the forest sector, such as climatic change when linked to ecological models. Projections of consumption, production, trade and price levels for solidwood products and wood raw material inputs are determined by the model. The model also calculates the changes in inventory and processing capacity, the price-cost ratio of products and stumpage prices for timber. Consumer's and producer's surplus measures are also determined as well as revenues associated with projected prices and production outlooks. The information produced by the model may be used to derive meaningful policy measures such as job impacts, loss of revenues by stage of processing and region, and environmental measures. Examples of the measures can be found in Perez-Garcia (1993, 1995) and Perez-Garcia, Lippke and Baker (1996).

Preliminary results of the 1993 data update for the CGTM suggests continued upward price pressure for North American and Pacific Rim softwood lumber markets. Asian markets are directly tied to North American softwood lumber markets showing a similar price trend due to their dependency on North American imports. With the shortfall of timber in PNW markets, U.S. softwood lumber producers are facing rising wood costs and a steady growth in demand. As a result, softwood lumber consumers in U.S., and Asian markets as well, should see continued upward price pressure for softwood lumber products.

Figure 3 illustrates historical and projected price paths in real 1993 dollars per thousand board feet for five softwood lumber markets. The figure demonstrates how prices in the Japanese and North American markets move together. Note that Japan is the higher-priced market, followed by the U.S. west coast, the U.S. South and Canada.

Figure 3 also illustrates a notable departure of European softwood lumber prices from those observed in North American. Softwood lumber prices for Finland are illustrated in the figure for comparison purposes. Softwood lumber prices in Finland and other European markets (not shown in the figure) decline in the second half of this decade and begin to rise afterwards. From the result and historical data, it appears that the real price of softwood lumber will continue to remain flat in European markets throughout the next decade. A rise in the price of lumber appears as the Scandinavian markets continue to supply Asian markets with wood raw materials and lumber products over time. In effect the cost associated with Scandinavian supply is not low enough to successfully service the Asian region in large quantities until Asian prices are increased further by shortages in North American markets.

Log prices for the same markets show similar trends with a few notable exceptions. As illustrated in Figure 4 there persists upward price pressure in U.S. and Japanese log markets. The higher log prices pushes lumber prices upwards, as previously discussed. One notable departure is the lack of upward price movement in the Interior B.C. log market. Without log exports, the Interior region isolates itself from higher log prices observed in the U.S. (Perez-Garcia 1996a, 1992). Lumber exports to the U.S. markets however sell at the higher lumber price due to U.S. log scarcity. As a result, the price/cost ratio for lumber mills in Canada improves throughout the projection period while mills located in the U.S. become less competitive. Supply reductions in Canada could of course alter the relative log price spread.

Figure 4 also illustrates a log price increase for the U.S. South. One may conclude that the U.S. South and PNW log markets are linked through direct trade activity. This is not the case however. There appears to be log scarcity in the U.S. South as well. A model of southern timber inventories linked to the CGTM suggests timber scarcity in several regions within the South and a shift in harvests among states in the South (Perez-Garcia and Abt 1996). Figure 5 reproduces output from the CGTM-SERTS model at the inventory analysis unit level on removals in the South for 2010. The figure illustrates the reduction in removals in the central regions and the movement northward of greater removals. The result indicates a redistribution of South-wide harvests.

The above preliminary results are the outcome of recent data updates to the CGTM data base. Previous analyses with the CGTM have provided input into a wide variety of assessments. Economic impacts of climatic change on the global forest sector were measured with CGTM (Perez-Garcia et al., 1996). Impacts of U.S. carbon mitigation strategies on U.S. and global carbon accounts were also recently analyzed (Perez-Garcia in review). The CGTM was used to study impacts of timber supply shortages on land-use allocation (Perez-Garcia 1995). Trade policies in the U.S. (Perez-Garcia, Lippke and Baker 1996) and Canada (Perez-Garcia 1996a, 1992) were also analyzed. The model has been used to simulate the development of tropical hardwood markets. In 1992, the model was utilized in separate studies funded by Jaakko Poyry through the World Bank and the London Environmental Economics Centre through ITTO. The first study examined effective trade policies on tropical deforestation in Southeast Asia (World Bank 1992). The second study utilized the model to examine impacts of supply constraints and trade policies on global tropical forests (Perez-Garcia and Lippke 1992). The CGTM was also utilized to analyze market distortions and their impacts on the forest sector in Latin America, a region primarily possessing tropical hardwood resources for USAID (Perez-Garcia 1994). This brief summary of work with the CGTM illustrates the flexibility of the model to provide input into a variety of assessment processes.

A Broad Historical Perspective on the Use of Models

After a model has been constructed and is available for assessment support, the review process is still critical. It requires linking the modeler, policy maker and others interested in the development of the forest sector. The linkage of modeler and user in an assessment process has been shown to lead to continuous improvement in the quality of models and analyses over time. The paper presents several examples below.

Macro Econometric Models and Economic Outlook Conferences. Macro economic modeling and assessment processes have been around for three decades. For those of us who have been active participants in that process[2] there are important historical lessons to be gained from those activities. Observations at some 100 economic outlook conferences support the conclusion that soliciting participants for "burning" questions to be answered is one of the most significant phases during a conference and an important input to the success of assessment processes. Conferences that start by going around the table and asking each participant to state in 30 seconds the burning questions they would like answers to were judged to be far better by users as they were more likely to get answers to their questions. Was it sector competitiveness impacts such as who gains and who loses and why; was it a policy issue or distributional impacts on who pays; or whether structural change issues are

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[2] Bruce Lippke was President of Wharton Econometric Forecasting ('83-'87) and joined the original Wharton/user group as the 15th member company in 1968.

cause or effect? Even if a model had an answer, it was not the only possible answer and the response of different participants added valuable dimensions to the assessment process.

Participation in economic outlook conferences also leads to the remark that, more often than not, the questions are about assumptions and not the modeling approach. The importance of asking the conference participants to state their questions lies in the observation that, frequently, the question, and not the model, was the driving force that added insight. The model was only a support tool, and frequently deficient in providing a complete answer.

Models, by themselves, are not as important as the process of asking and attempting to provide answers to burning questions. Models do help frame the answer and maintain consistency since they organize massive amounts of information, help sort impacts and provide coherence of important relationships. Models furnish largely an accounting perspective.

A good process involves competent modelers but also requires a balanced group of dedicated users. Those users that are full time analysts and live by the results of their analysis (and projections) are generally knowledgeable enough to ask the often dirty questions such as: how come, what about this, why not fix that? Experienced users are essential to the improve the assessment process. The structural relationships embedded in the model reflect hypothesis by authors and the scientific community which may be impossible to validate. Questioning the hypothesis is healthy and generates progress.

A conference involving modelers but serving users provides a "user peer" review not a "modeler peer" review with priority focused on what improvements are needed to better address the burning questions of the users. The result is higher caliber modelers, models, and users. This open user-review process worked well for the economic forecasting services in early history.

Agricultural Sector Models and the Commodity Policy Process. A nearly identical process was developed for agricultural commodities by the Food and Agriculture Policy Research Institute (FAPRI) at the University of Missouri, Iowa State University and other collaborators. FAPRI responds to policy analysis requests of the agricultural commodities sector; needs that are fairly similar to the forest sector. It is funded largely by Congress with supplemental contributions from competitive research grants. The FAPRI models are a collection of satellite models that use inputs from the macro econometric models (initially the Wharton Econometric models). The FAPRI review process was modeled directly from macro economic outlook conferences. Pre-meeting baseline projections were presented. Then, assumptions and guidance for changes as well as policy alternatives of interest were reviewed at an initial conference. Policy alternatives were distributed prior to a second review meeting to provide feedback on needed changes and priorities for improvement. This process has been ongoing since the early 1980s. The quality of the discussion, the availability of competent modelers and the capability of the models improved substantially in the early years.

Commercial Economic Forecasting Services. Most economic forecasting services were spawned out of these early activities. They have models that can provide an analysis of alternatives but in recent times they largely serve a mass market for profit-making strategies involving larger audiences of less critical users. As a result their conferences involve little of the questions and review process that is important to model improvement and the education process associated with alternative policy impacts.

Role of the PC. There appears to be a new PC paradigm at work. Knowledgeable user groups each have their own model, go through the same user peer review conference process on issues, but exercise their own judgments on their own models. The critical difference is that their models are never opened for full review. There are several economic forecasting clubs represented by top companies still operating in this mode (e.g. NBEIC and CBE).

Forest Sector Modeling. The forest sector has never advanced very far on any of the above historical scales, particularly from the perspective of conducting conference settings that permit questioning and direction of modeling efforts. There are a handful of academic models, Resources Information Systems Inc. and a few other consultants that provide outlooks but they include very little open review and their contribution to policy analyses of the day are limited. The Forest Service Assessment process has not followed the open conference review process nor could it be expected to provide such a catalytic role given its changing mission. The FAPRI process for the agricultural sector was deliberately moved out of the Department of Agriculture at its inception to provide consistency in the face of changing agricultural politics.

The research attempt to develop a global trade model in the early 1980s had some of the open conference review characteristics. The International Institute for Applied Systems Analysis (IIASA) brought together scientists with a few users to rebuild an international data set and construct a model of global forest products production, consumption and trade. IIASA, followed by CINTRAFOR, hosted several forest sector modeling conferences. From the first to the last in 1991, there was movement from the theoretical modeler perspective to more interest by users, but none of these conferences would be considered an organized process for developing a baseline and alternative scenarios for review. Their focus was on the models and not on the assessment processes.

Placing Forest Sector Models within the Perspective of the Users

Improving the process through open conference formats will also require improving models and methods to answers the user's burning questions and providing a larger set of measures of alternative impacts. How to make forest sector models answer questions asked by users will take greater model detail and linkages to produce these measures. It involves greater regional detail, environmental measure linkages, social benefit assessments and greater product modeling. None of the models reviewed at this conference--TAMM/ATLAS, CGTM, TSM and NAPAP--have had the financial and technical support and review that the macro economic or FAPRI efforts receive. This is a non-trivial concern since there is plenty of complexity that needs to be characterized by models to provide answers to many wood fiber supply and demand questions users are asking.

Environmental Questions Raised by Users: The Importance of Environmental Linkages. The forest sector assessment has become far more focused on environmental policy than other U.S. economic sector assessments. This has raised questions by model users on environmental matters that are contentious and difficult to answer. The nature of environmental amenities provided by forests compounds the modeling problem. The public demand for environmental amenities are not bought and sold in a market place but, rather, have been provided for by highly volatile, government-induced supply constraints that have affected both public and private forest land management. The need to conduct the analysis in an open conference format to reduce the contentious nature of the issues and produce relevant measures of policy impacts is apparent.

The high cost of environmental regulations and unpredictability of policy changes have had enormous financial impacts and raises questions whether alternative management schemes exist that can reduce costs and maintain environmental amenities. The forest sector should be justified in spending more time and effort on how to serve changing environmental demands and answer these questions. If the consumer demands for environmental services were being serviced by markets you can feel assured that suppliers would be dedicating enormously greater resources to determine how best to serve those demands. But since they are being served by government, with negative compensation to landowners, the tendency has been to do as little as possible. The costs to industry have been high and the justification to be able to better serve these demands can be made. Success will almost certainly require environmental linkages to sector models.

The environmental debate is contentious and raises the complexity of analyses. The question requires high quality assessments that produce a larger set of alternatives and track many more outputs, including many of the non-market environmental amenities. Since there is no consensus on the publics values of environmental amenities, the tough tradeoffs will still be political, but understanding alternative policy impacts on markets and environmental amenities can frame answers to the question.

More model linkages can be important in providing a larger set of alternatives and measures as well. Decision support models, operating at a more micro level, provide a number of environmental measures through useful links to forest sector models. The support models can be consistent at regional levels, operating directly as a satellite model to a global forest sector model, or they could operate on a smaller land base than the region and link to a more detailed single region model that is in turn connected to a global model. The set of models linked to one another provides consistency in analyses of many global competitiveness issues. This analytical system also produces a credible set of environmental measures to describe changes in regional environmental amenities which also can be aggregated to the global levels.

To understand the added complexity of an assessment process which considers environmental questions consider the following measures which are not presently carried by existing forest sector models. Stand structure mix can be an important environmental measure. Biodiversity classifications, such as late seral and old growth functionality, multiple and single species habitat indices, forest floor functions and ecosystem productivity for non-timber outputs are associated with stand structure mix (Carey et al. 1996). When these measures are quantified over a projection period and compared to the past they provide important biological indicators of environmental performance linked to policy alternatives. Similarly, carbon storage on the forest floor and in products can be linked to forest sector models using some of the detail in micro models to characterize the impact of raw material supply alternatives. Product storage of carbon also requires an analysis of the impact of fossil intensive substitute products. The analysis can be provided by product substitution models as extensions to the products included in forest sector models. A recently formed research consortium has as its objective the updating and extension of the work done by the Committee on Renewable Resources and Industrial Materials (CORRIM). This effort expects to provide more precise estimates of fossil fuel and environmental impacts over the next few years (Bethel and Bowyer 1995).

The list of important environmental amenities is growing. Efforts to quantify their effects locally have expanded. However, if these support systems are not linked to forest sector models it is almost certain that the tradeoff of improving the environment in one's backyard while exporting the impact (pollution) as well as the economic costs and benefits to other regions will be ignored with perhaps counterproductive impacts on the environment.

Social Benefits. Environmental policies raise interesting social questions, which add further complexity to the assessment process. Every environmental regulation that constrains the maximum economic performance of the forest sector produces social costs or benefits. Environmental policies can be described both in terms of degrees of improvement or restoration, measured with environmental measures, and the cost of producing them. Their production costs is not necessarily their true social value, however. Assessing social values requires additional measures.

For normal cost benefit analysis it is important to show who benefits in order to justify and allocate costs, if the market place is not the allocator. Policy alternatives that seek to change forest management practices may involve forestry investments which impact local employment, regional and federal tax receipts--social value measures. Social value measures of local and regional employment and tax receipts may be important for any compensation scheme that is designed to motivate the forest sector to produce more non-market values or to compensate property owners for any takings. Regional satellite models, those that provide more detailed supply information for major supply regions, can be linked to a global model, such as the SERTS and ATLAS linkage with the CGTM in order to provide the detail necessary to answer questions raised for a local constituency.

The full range of social, environmental and economic measures, from the local level to the global level has importance if environmental and social value measures are significant to the forest sector's license to operate. The modeling framework requires linkages from the global model to satellite models with regional detail which in turn may be non-recursively linked to decision support models for the transformation of forest management treatments to environmental variables and local economic impacts. Once certain sensitivities are characterized in forest management decision support models that include environmental measures and local economic measures, the transformations can be made by simple spread sheet linkages to forest sector models.

The added complexity of producing a quality assessment process points to the need for improving existing methods to measure social and environmental attributes of alternative policies. Forest sector analysts frequently use relatively simple input/output models to determine local employment impacts. The use of the simple models can result in serious limitations for policy analysis.

Management alternatives resulting from policy change frequently involve substantial changes in capital stock such as timber. They may also require new technology adoption affecting processing costs for several stages of processing. From the policy perspective the jobs created from returns to capital or indirect purchases associated with a change in the production process are equally important. The location of jobs may not be equally important when distributional issues are dominant. That requires a direct linkage to regional models that endogenously track the uses of capital flows and indirect purchases. In practice the most important measures are employment, revenue, income and tax receipts. Valid estimates require the use of indirect multipliers developed for specific management alternatives to be linked to forest sector models.

Currently available input/output multipliers such as IMPLAN short change the benefits of most management alternatives, forest investments, and value-added processing activities that may be capital intensive. The results may be completely misleading on the social impacts. Linkages to models that characterize the benefits of investment, indirect activities and direct processing have been shown to produce tax receipt benefits and other social benefits that are larger and more acceptable to the public. Since the license to operate is at stake, it is important to begin to quantify impacts that have historically been left out for the sake of simplicity.

A Perspective on Insufficient Product Detail. If the important questions relate to competitiveness and who wins the battle for trade flows, current models have limitations. Consider the following question: Are products or resources substitutable? The classic analogy for modelers was the nutritional diet problem. What meals keep the caloric intake within bounds while reaching the minimum nutrients for five food groups (or even a longer list of nutrients).

For the pulp and paper sector, chips derived from different species and regions have different physical characteristics. Each pulp is different when made from a mix of chips or recycled materials and involve different processes. Assuming they are all equal substitutes to reach a balance between all demands and all supplies will not produce good insight on competitiveness and trade flows. A set of diet constraints for products, pulps and chips involving (1) strength, 2) opacity and (3) smoothness can go a long way to getting the right flow of chips passing through the right process to serve the right markets, yet remains fairly simple to implement. It provides a possible short cut to a very detailed analysis of alternative technologies and processes which also require projections on the rate of technological innovation.

The solid wood version of the pulping problem is different. There is a range of solid wood quality in every region, but each region still does not produce products useful in all applications. Species differences characterized by strength, machinability, straightness, drying properties and even appearance are important differences in many end uses. A diet formulation could teach us why hemlock is doing so poorly, where its future potential might be, and where minor species will have their greatest market penetration over time.

Without some diet formulation the model's efforts to balance supply and demand will understate the cost of getting the right resources to the market users and have some flow problems as well. While the complete specification of trade routes has been more important in the development of models to date, more attention to physical characteristics will likely be important in the future. If environmental amenities and social benefits are important objectives there may not be any good substitutes for more detail in modeling approaches.

A More Complete Assessment Process

Given the dominance of environmental and social issues impacting forest policy a much more complete assessment process seems to be needed. The above discussion suggests that more detail on environmental amenities and regional economic and social impacts could be developed. FAPRI characterizes the impact on the small farm in each region. The same could be done for the small timber producer or processor. Both more measurements and alternatives than provided in the current Forest Service Assessment are needed. Table 3 illustrates the potential scope of a larger set of alternatives and measures than currently included in forest sector assessments. The area marked I in Table 3 indicates current assessment conditions. Adding new impact measures to current alternatives is presented by area II. Future needs of impact measures are signaled in area III. Area IV in Table 3 illustrates in full range of additional analyses required to include new measures and a greater set of alternatives. And, of course, for the results to be useful and establish any credibility the open review process will have to be perfected.

The first critical review is the baseline condition for policy assessments, whether it be constructed with the CGTM or another forest sector model. Briefly stated, the assessment process begins with the projection of baseline conditions that simulate the future with no change or specifically-stated assumptions. The baseline condition provides a reference case to study alternative policy requests. Ideally, the baseline projections should by made available to a broad set of experts including modelers and practitioners to identify weaknesses in the model structure and assumptions, and to discuss them in an initial conference setting. Questions to be answered by the assessment process should be solicited during this stage. The review comments should be incorporated into the assessment process through model structure changes and revision of assumptions to produce a revised baseline condition. Once a baseline has been established, the assessment team, which includes policy analysts and other stakeholders, identifies alternative policies and assumptions of importance for additional evaluation in order to respond to user questions, assumption uncertainties and policy alternatives.

Following the ranking of policy requests, alternative simulations with comparisons to the baseline are developed and made available to the review group. The review comments on alternatives are analyzed during a second conference opened to a broad audience of interested parties in the activities of the forest sector. A review panel identifies priorities for research and monitors the progress of continuous improvement of the analytical structure and review processes between annual baseline projections and assessment of alternatives. Under such a process, there should develop a better understanding and a broad-based support for policies and their implementation.

Table 3. An expanded information matrix to improve forest sector policy assessments.

	RPA Alternatives				Other Alternatives		
Impact Measures	RPA Baseline	RPA Alternative 1	. . .	RPA Alternative 13	Foreign Supply Shifts	Management Alternatives for Biodiversity	Others selected by public policy participants
Harvest, Inventory, Production, Consumption, Imports, Prices		**I**					
Other requirements: Trade balance, Tax receipts/ Timber revenues, Employment, Environmental measures such as biodiversity, stand structure balance, regional and global carbon balances		**II**				**IV**	
Future Needs: Special forest products, Recreation, Specific non-timber values...		**III**					

Figure 1 is available from the authors.

Figure 2 is available from the authors.

Figure 3 is available from the authors.

Figure 4 is available from the authors.

Figure 5 is available from the authors.

REFERENCES

Bethel, James and James Bowyer. 1996. Committee on Renewable Resources For Industrial Materials: A Look back and Consideration of the Future. *Mimeo*. Seattle: University of Washington, College of Forest Resources.

Cardellichio, Peter A., Yeo Chang Youn, Darius M. Adams, Rin Won Joo, and John T. Chmelik. 1989. A Preliminary Analysis of Timber and Timber Products Production, Consumption, Trade and Prices in the Pacific Rim Until 2000. *CINTRAFOR Working Paper* No. 22. Seattle: University of Washington, College of Forest Resources.

Cardellichio, Peter A.; Yeo Chang Youn, Clark S. Binkley, Jeffrey R. Vincent, and Darius M. Adams. 1988. An Economic Analysis of Timber Supply Around the Globe. *CINTRAFOR Working Paper* No. 18. Seattle: University of Washington, College of Forest Resources.

Carey, Andrew B., Catherine Elliot, Bruce R. Lippke, John Sessions, Charles J. Chambers, Chadwick D. Oliver, Jerry F. Franklin and Martin G. Raphael. 1996. Washington Forest Landscape Management Project: A Pragmatic, Ecological Approach to Small-Landscape Management. *Washington State Department of Natural Resources* Report No. 2. Olympia, WA: Washington State Department of Natural Resources.

Kallio, Markku, Dennis P. Dystra, Clark S. Binkley, eds. 1987. *The Global Forest Sector: An Analytical Perspective*. New York: John Wiley & Sons.

Mills, John R. and Jonna C. Kincaid. 1992. The Aggregate Timberland Assessment System--ATLAS: A Comprehensive Timber Projection Model. *General Technical Report* PNW-GTR-281. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Pacheco, Gerardo, Robert C. Abt and Fred W. Cubbage. 1996. Southwide Timber Supply Projection Assessment. in *Southern Forest Economics Workshop Proceedings*. Gatlinburg, TN.

Perez-Garcia, John M. In review. Global Carbon Fluxes Associated with U.S. National Policies. *Adaptation and Mitigation Strategies for Global Change.*

Perez-Garcia, John M. 1996a. Log Export Restriction Impacts on Log Prices in British Columbia. *Mimeo.* Seattle: University of Washington, College of Forest Resources.

Perez-Garcia, John M. 1996b. Meeting the Needs of Policy Makers: Experiences with a Global Forest Sector Model in the Policy Arena. In *Proceedings of Project Group P.6.11 Foresea Meetings at the 20th IUFRO World Congress, Tampere, Finland,* compiled by Lars Lonnstedt, Richard Haynes and Judith Mikowski. Seattle: University of Washington, College of Forest Resources.

Perez-Garcia, John M. 1995. Global Forest Land Use Consequences of North American Timber Land Withdrawals. *Journal of Forestry* 93(7):35-38.

Perez-Garcia, John M. 1994. Trade Potential from Latin American Timber Producers to Support Sustainable Management of Tropical Forests. In *Government Policy Reform for Forestry Conservation and Development in Latin America Workshop* edited by Silvo DeFranco, Anuro Contreras, Ronnie de Camino and Hernan Cortes. Washington D.C.: United States Agency for International Development.

Perez-Garcia, John M. 1993. Global Forestry Linkages: Understanding the Impacts of Reducing the Supplies from North America. *CINTRAFOR Working Paper* No. 43. Seattle: University of Washington, College of Forest Resources.

Perez-Garcia, John M. 1992. Canadian Log Trade Between Coastal and Interior B.C. and the U.S. Pacific Northwest and Rocky Mountain Regions. *Mimeo.* Seattle: University of Washington, College of Forest Resources.

Perez- Garcia, John and Robert Abt. 1996. SERTS-CGTM Model Linkage. *Mimeo.* Seattle: University of Washington, College of Forest Resources.

Perez-Garcia, John M. and Bruce R. Lippke. 1992. The Timber Trade and Tropical Forests: Modeling the Impacts of Supply Constraints, Trade Constraints and Trade Liberalization. *London Economics Centre* DP 93-03. London, UK: International Institute for Environment and Development.

Perez-Garcia, John M., Bruce R. Lippke and Janet Baker. 1996. Who Wins and Who Loses: Trade Barriers in the Pacific Northwest Forest Sector *Contemporary Economic Policy*. In press.

Perez-Garcia, John M., Linda A. Joyce, Clark S. Binkley and A. D. McGuire. 1996 Economic Impacts of Climatic Change on the Global Forest Sector: An Integrated Ecological/Economic Assessment. *Environmental Science and Technology*. In press.

Samuelson, Paul A. 1952. Spatial Price Equilibrium and Linear Programming. *American Economic Review*. 42:283-303.

World Bank. 1993. Tropical Hardwood Marketing Strategies for Southeast Asia. *Agriculture and Natural Resources Division/FINNIDA.* Washington D.C.: World Bank/FINNIDA

6. Timber Supply Model 96: A Brief Overview

Roger A Sedjo and Kenneth S. Lyon[1]

This paper presents a brief overview of the "Timber Supply Model 1996," which is an update of our earlier Timber Supply Model (TSM), which was fully developed in our book, *The Adequacy Of Global Timber Supply* by Sedjo and Lyon (1990), published by Resources for the Future. The updated version, called Timber Supply Model 1996 (TSM96)[2], builds on the original TSM, which used an economic market supply/demand approach to project an intertemporal time path of the world's price and output level of industrial wood.

BACKGROUND

The original timber supply model was designed to provide a number of improvements over earlier timber projections models. The objectives included the development of a model that:

1. was a long-term global model, which included all of the major wood-producing regions of the world;
2. focused on the supply side;
3. used a more sophisticated modeling approach than previously - the next generation - and thus used an optimal control approach;
4. minimized required "tweaks" an ad hoc constraints that commonly and, in our opinion, are used excessively in some timber projection models;
5. avoided model "blow-ups" and thus the need for ad hoc "model control reality changes" which are often used in very long-term models;
6. was dynamic in that forest investments were endogenous; and
7. is tied to forest and age class, thus can drawdown, and bare-ground forestry can be addressed in the same model.

The model has been used for policy analysis in a number of applications. These include a) an assessment of the effects of tax reform on timber supply (Sedjo, Radcliffe and Lyon 1986); b) an assessment of the effects on timber supply of the set-asides in the National Forests in the Pacific Northwest (Sedjo, Wiseman, Brooks and Lyon 1994); c) the use of the Timber Supply Model 96 in a study of the global paper cycle (Sedjo and Lyon 1996); and d) an

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[2] The complete version of this model appears as "Timber Supply Model 96: A Global Supply Model with a Pulpwood Component," by R. A. Sedjo and K. S. Lyon, RFF Discussion Paper 96-15.

assessment of the role of human adaptation in ameliorating the impact of climate change on global timber markets (Sohngen, Sedjo, Mendelsohn and Lyon 1996).

A major feature of the updated TSM96 is that industrial wood has been subdivided into two different wood types -- pulpwood and solidwood. The supplies of these two commodities are not independent but rather they can be viewed as joint products in production. Timber harvests may involve harvest for solidwood (e.g., sawlogs and peeler logs), for pulpwood (generally smaller logs that are used to produce pulp from which paper is made) or both. However, even when harvests involve only solidwood, the processing of logs into solidwood products (lumber and plywood) generates substantial wood residues, which are typically used as pulpwood.

As did the original TSM, the demand side of TSM96 is specified only very crudely. Additionally, TSM96 provides projections of the time path of the equilibrium output levels of the several regions into which the world has been subdivided. The purpose of TSM96 is to function as a tool to assist in the task of assessing the condition and the adequacy of the long-term world timber supply. TSM96 is a useful vehicle for systematizing and formalizing the factors that affect long-term industrial wood supply as well as examining the nature of the forces and the interrelationships within and among supply regions. In addition, the projections can identify questionable implications of the assumptions of the model and/or assumptions of the specific conditions associated with the projections.

AN OVERVIEW OF THE MODEL

As noted, the TSM96 subdivides the industrial wood-supplying regions into their pulpwood and solidwood components. This subdivision allows for an analysis of both the pulpwood and solidwood components of industrial wood supply. However, because harvesting the timber resource generates a joint product, the pulpwood and solidwood markets are not independent but rather are highly interrelated. Thus a proper analysis of either component requires that it be examined as part of the whole system.

The TSM96 uses information about species, age and log size in the various forests to determine the mix between solidwood and pulpwood, thereby providing separate but interrelated projections of pulpwood and solidwood supply. Furthermore, the solidwood-pulpwood mix of the resources of a specific forest is also allowed to vary through a range, as a function of the relative solidwood and pulpwood price.[3]

A working hypothesis of this study is that, in the aggregate, timber production in the real world is experiencing a transition from the draw down of existing old growth stands to the utilization of second-growth and plantation-grown industrial wood. This transition is at different stages in various regions of the globe. A basic question that the model is designed to

[3] This feature reflects the existence of some ability by producers to adjust the mix of solidwood and pulpwood inputs.

address is that of determining the economically optimal transition from an old-growth forest to a regulated steady-state forest in a global setting.[4] This approach is in conflict with the common "growth/drain" approach to modeling forest harvest since the long-term steady state stock of timber is changing. Because the usual growth-drain approach has no provision for the age distribution of the inventory, harvests are invariant to the age composition of the forest. While such approaches are useful when applied to even-aged regulated forests, such an approach can lead to serious errors when applied to a non-even-aged situation, since there is no mechanism for a transition from an old-growth to an even-aged regulated forest.

The TSM96 utilizes a control theory approach that introduces "initial conditions" and "laws of motion" for the forest system. "Control" variables are introduced to monitor and describe the changing "state" or condition of the forest. The initial conditions refer to conditions that obtain initially, such as the forest inventory by location, age group and land class. Since the initial conditions include old growth and various other non-regulated timber stands, the approach requires "laws-of-motion" rules that govern the system over time, that can address an initial stock that includes large volumes of old growth.

In the control theory approach, the changing age and volume conditions of the forest are constantly monitored and updated so that management decisions explicitly recognize the changing state of the forest. In this approach the laws-of-motion have young trees becoming older; and as older trees are harvested, either natural regeneration occurs on the site or investments in regeneration are made. Any investments, in turn, influence the rate of growth of the forest. The control variables, or choice variables, give the area harvested by age group and land class for each year. This, in turn, determines the rotation age by land class. Also control variables determine the investment in regeneration and the magnitude of regeneration input each year by land class.

An optimization procedure calculates the values of the control and state variables in the steady state. A solution algorithm then solves for the optimal values of the control variables in the transition between the initial conditions and the conditions of the steady state. The optimal control variable values generate an evolution of the state variables from their initial values to their steady-state values that identify the economically optimal time path of price and harvest between the initial conditions and the terminal steady state. The economically optimal time path is the one that maximizes the sum of consumer and producer surpluses in the transition between the initial conditions and the steady state.

Uses of Models

The ability of models to examine the implications of alternative assumptions and situations is one of their major strengths. A formal model allows the user to examine possible

[4] Foresters are fond of the regulated or steady-state forest in which there is (a) an equal area of forest land for each age class; (b) a fixed rotation age; and (c) an age class for each year to rotation. Under this condition each year's harvest will be the same and steady-state production will be achieved.

futures under various assumptions regarding relationships and events. Since the assumptions must be explicit, the model forces the analyst to define precisely the assumptions and to confront the implications of the assumptions. Fundamental deficiencies or logical inconsistencies in a model's structure and/or underlying assumptions, are reflected in the form of implausible projections. These types of results force the analyst to reconsider the structure and assumptions of both the model and the analyst's thinking.

For example, an important implication coming out of TSM96 is that it demonstrates that if pulpwood demand grows sufficiently more rapidly than the growth of overall industrial wood demand, a logical implication is that there must be an absolute decline in the production and consumption of solidwood, as pulpwood demand bids raw wood away from solidwood uses. This finding reveals the interrelationship of demand for pulpwood and demand for industrial wood. Since they draw in part from the same resource basket, they are not wholly independent. However, some analysts make the mistake of trying to assess the global pulpwood market without recognizing its relationship with total wood supply.

Factors Affecting Harvest Levels

In the TSM harvest levels can be affected by adjustments of six types:

1. the rate of draw down of old-growth inventories;
2. the number of forested land classes utilized for harvest;
3. the rotation length;
4. the level of regeneration inputs, which influence future harvest levels;
5. the rate of technological change in timber growing; and
6. the rate at which industrial plantations are added to the world's forest-producing regions.

The first three of these factors relate to the rate at which existing forests are harvested and are determined within the model (endogenously). They are affected by the current and future prices, as well as the interest rate. These can be viewed as short- or medium-term effects. The last three factors relate to the rate at which new sources of wood are made available or used more efficiently.

The fourth factor, investments in regeneration, is determined endogenously in the model. This activity influences future harvest levels. The fifth factor is dependent on the rate at which technological progress is incorporated into the forest's yield function and thereby effects timber growth. Its effect on timber growth enters the system via the regeneration component in the supply model. The sixth factor is the rate at which new industrial plantations are established. In the timber supply model the base case assumed that 200,000 ha of new plantation be established annually, beginning in year one for 30 years. This assumption is revised in TSM96. Finally, technological change can also enter TSM96 via the demand side by reducing the rate of increased demand for the raw wood resource.[5]

The Regions

The TSM96 subdivides the world into eight industrial wood supply regions, seven of which are formally modeled and called "responsive regions."[6] The "rest of the world" is lumped together as the eighth region and referred to as the "nonresponsive region." The harvests of the nonresponsive region are viewed as autonomous and determined independently of the usual economic considerations. This characterization is clearly only approximate in that some areas within the "nonresponsive" region do respond to market incentives, while some ownerships in the responsive region may not be fully responsive. The nonresponsive region includes (a) the former centrally planned economies, some of which have not yet developed efficient working markets for industrial wood, due in part to unresolved issues of land ownership and tenure, and (b) countries in of Europe that claim to have a tradition of harvest rotations that are longer than financially optimum. The characterization of this aggregate region as nonresponsive is probably an adequate overall approximation.

As in the earlier TSM, the seven responsive regions of TSM96 are further subdivided into a total of 22 timber land classes, each of which corresponds to a unique geographic area. The specific regions are:

Responsive Regions

Emerging Region[7] (1 land class)
US Pacific Northwest (4 land classes)
Canada, west (2 land classes)
Canada, east (4 land classes)
US South (8 land classes)

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[5] A host of technological innovations are wood saving and wood extending in that they allow intermediate and final products to be produced utilizing less wood, or lower quality wood, than previously. Examples include wood-saving pulping techniques and new types of engineered wood, such as oriented strand board (OSB). The effect of wood-saving technology is to reduce the wood requirements of various intermediate and final products using wood thereby lowering the rate of outward shift in the demand curve for industrial wood for a given rate of increase in the demand for the final product.

[6] The industrial wood sectors of the seven "responsive regions" are treated as being driven by market forces under competitive conditions. Although this is not completely correct, it is probably a good first approximation. Even where a large portion of the market is served by public forests, as was the case in the US before the 1990s and still, to a lesser extent, is the case today, the results can be viewed as approximating the market since the large private sector responds to price signals generated in part by the harvest levels of the public sector. Thus, the market Timber Supply Model can be applied.

[7] The Emerging Region is a composite consisting of a number of regions that are producing industrial wood from intensively managed exotic species tree plantations. These include countries such as Brazil, Chile, Indonesia, New Zealand, South Africa and Spain. Although the species, growth rates and rotations vary somewhat across regions, all these plantations have relatively rapid growth and short rotations.

Nordic Region (2 land classes)
Asia-Pacific (1 land class)

Nonresponsive Region
Rest of the World

TSM96 incorporates physical and biological elements to provide what economists might call an underlying biological production function. Each of the 22 land classes in the model incorporates physical and biological information appropriate to the area and develops a production function. This includes information on land-class quality, location, accessibility, and area; growth and yield functions by dominant species and land class; existing inventories and their age distribution; suitability of timber for sawlogs or pulping;[8] and silvicultural responses to investment inputs. The amount of investment in forest regeneration and management is determined endogenously.[9] In some situations a land class may not be harvested since there is no mature timber or because the stumpage price does not justify harvesting this land class, given the harvest and transport costs and the alternative wood sources available.[10]

Technological Change

Technological change in tree growth is introduced into the model through genetic improvement that is imparted to improve growing stock introduced through artificial regeneration. When new high-yield seedlings are planted to regenerate the forest after harvesting, the yield function of the forest coming from that year's regeneration cohort is shifted upward, reflecting the superior growth of genetically improved stock. The increased yield associated with that age class is captured at harvest.[11] Since naturally regenerated forests do not incorporate genetic improvement, the yield function is shifted only for artificially regenerated forests.

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[8] Suitability is determined largely by average log size (width) with large logs having a greater fraction of their total volume going to solidwood.

[9] See appendix N of *The Long-Term Adequacy of World Timber Supply* (1990).

[10] This feature means that the timber base is allowed to expand and contract depending upon the endogenously determined price.

[11] We assume that technology is progressing at an initial rate of 0.5 percent annually decreasing linearly to zero in year 50. The rate is embodied in the current year's yield function and introduced through the regeneration input. If a forest is wholly naturally regenerated, no technology is introduced. If there is $500 of regeneration per ha, the entire 0.5 percent is captured by that year's age class. Regeneration between zero and $500 is prorated proportionally. See chapter 6 and appendix L of *The Long-Term Adequacy of World Timber Supply* (1990).

Costs and Processing

Also, each land class has a unique set of costs including establishment, growing, harvesting, transport to a pulp mill and international transport costs. The industrial wood product is assumed to be processed in a local pulp mill and transported to the world market. Since the focus of this analysis is the resource, the mill costs are assumed to be identical across regions. The costs of transporting the processed product to the world market, which in part determine the timber's delivered value to the mill and the stumpage value, depend upon the region's location vis-à-vis the major world market. The world market price is the net price (fob) the pulpmill mill receives for the processed product. The world market is treated as consisting of three submarkets -- eastern North American, western and central Europe, and East Asia. Prices among these markets could differ, but not by more than transport costs, since arbitrage is assumed to limit the price differentials.

The level of output of the nonresponsive region is viewed as independent of market conditions. This aggregate region is assumed to continue its production over the 50-year period with the growth of annual output based upon historic trends. Its production is assumed initially to be expanding at 0.5 percent annually, falling linearly to zero at the end of the 50-year period. In the period 1985-1995, total world industrial wood production is divided roughly equally between the seven responsive regions and the nonresponsive region.

Demand

On the demand side, total world industrial wood demand first interacts with the known nonresponsive-region supply to generate an excess or derived demand curve for the industrial wood of the responsive region. In the TSM96 base case, the total world industrial wood-demand function is initially assumed to be shifting out at 1.0 percent annually,[12] linearly declining to zero growth in year 50.[13] This, in turn, generates an initial rate of expansion of about 1.5 percent annually for the excess demand curve that is applied to the responsive region. The excess demand curve is then related to the supply conditions (production and cost functions) of the 22 land classes of the responsive regions to generate the individual and aggregate supply curve for the responsive regions.

Pulpwood demand is added to the model as a subset of industrial wood demand. Implicitly, the solidwood demand function is the residual of the difference between the industrial wood demand function less the pulpwood demand function.[14] Based on recent

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[12] The rate of growth of world demand for industrial wood from 1970 to 1991 reported by the FAO was 1.0 percent. Also, no attempt is made in this model to forecast the business cycle and the projections should be interpreted as long-term trends.

[13] For tractability, the trends in the model converge to zero in year 50. Therefore the more useful projections occur in the early part of the period, roughly the first three decades.

[14] The implication of this structure is that, for any given rate of growth of total industrial wood demand, the more rapid the growth rate of pulpwood demand, the less rapid the growth of solidwood demand. A result of

output levels, an initial pulpwood demand growth of 2.25 percent.[15] In all cases the growth of the demand function is linearly reduced to zero by the end of the period. Under these conditions, over the period, the pulpwood share of industrial wood demand is allowed to grow from about 35 percent in 1995 to about 60 percent in 2045. This changing share reflects the anticipated long-term increase of pulpwood in total industrial wood demand.

Since the pulpwood demand function is a component of the total industrial wood demand function, the more rapid growth of the pulpwood demand function implies a reduced demand function growth rate for solidwood. This implication shows up strongly as slow and/or negative solidwood growth in many of our projections.

Supply

The TSM96 views pulpwood supply as coming from two sources. These are: (a) timber harvests which are undertaken explicitly to generate pulpwood and (b) as by-products of industrial solidwood production in the form of sawmill residues. The timber resources of each of the 22 land classes are allocated between solidwood and pulpwood. The initial division is based on the nature of the forest, e.g., typical log size, species, usual rotation age. In principle, all solidwood can be converted to pulpwood, but not all pulpwood can be converted to solidwood. For each land class an initial solidwood/pulpwood mix is given based on the nature of the timber in a land class. The actual proportions are allowed to vary within a range on either side of the initial proportions depending upon the relative price of solidwood and pulpwood.[16]

With these modifications the TSM96 now has additional initial conditions. In addition to land area for each land class, inventory age and volume by age, and yield function by land class, it also has as part of the initial conditions the mix between pulpwood and solidwood, by land class, including provision for mill residues becoming pulpwood. Also, included is a substitution function whereby the mix between pulpwood and solidwood can change within some limits as a function of the relative prices of pulpwood and solidwood.

The Model Solution

The TSM96 is solved given the known initial conditions, which now include both initial total industrial wood demand and pulpwood demand levels, and the rates of change of these

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this formulation is that for a sufficiently rapidly growing pulpwood demand, solidwood demand would need to be declining. This is perhaps not as unlikely a real world event as it may seem. For example, during the period 1900-1985 total industrial wood demand growth in the US was only 0.81 percent annually.

[15] Worldwide demand for pulpwood grew at an annual rate of 2.53 percent between 1964 and 1985. However, for the subperiod 1970-85, the worldwide growth rate was only 1.4 percent. The FAO world pulpwood growth reported for the most recent period, 1980-1991, was 1.8 percent annually.

[16] From the initial sawnwood/pulpwood proportion, the amount of solidwood can increase a maximum of 5 percent. However, pulpwood can increase to consume the entire log.

demand schedules over the total period. The model is then solved for the steady state[17] solution of both outputs by land class and price. Next, one of the set of feasible time paths, e.g., that which traces the path from the initial conditions to the steady state, is identified. Finally, the optimal time path, which maximizes the sum of producers' and consumers' surplus, is identified from among the feasible paths.

In TSM96, pulpwood production is constrained to be equal or to be less than industrial wood production for each region. Solidwood production for each region is calculated as the difference between total industrial wood production and pulpwood production.

BASE CASE

The base-case presented in the TSM96 is an extension of the base case of the TSM as it appeared in our 1990 book, *The Long-Term Adequacy Of Global Timber Supply*. The base-case outcome is viewed by the authors as the most likely outcome, and it is against this case that the various scenarios are compared.

Assumptions

The assumptions used in the TSM96 for the base-case forecast are as follows:

1. World demand schedule[18] for industrial wood initially increases at an annual rate of 1.0 percent, with growth falling linearly in successive years to zero after fifty years.
2. World demand schedule for pulpwood initially increases at an annual rate of 2.25 percent, with growth falling linearly in successive years to zero after fifty years.
3. The production of the nonresponsive region increases at a rate of 0.5 percent annually, falling linearly to zero after fifty years.
4. Biotechnological change is assumed to shift the yield functions upward to a maximum of 0.5 percent annually, falling linearly to zero after fifty years. Technological change is introduced via investments in regeneration. The rate for any specific land class is a function of the amount of regeneration investment varying between a maximum of 0.5 percent for regeneration investments of $500 per ha or more, falling to no technological change for zero investment in regeneration.

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[17] The steady-state solution is that equilibrium to which the global industrial system adjusts after which it provides a continuous given output over time.

[18] Being a market model where the price and quantities are determined by changes on both the supply and demand sides, the changes in production and consumption are generally different than the posited "changes in demand." Throughout this analysis the changes in demand refer to the changes or shifts in the demand function or schedule. The actual change in consumption and production will depend upon the price effects as well and the demand schedule shifts and will, in general, be a somewhat different percentage change than is the shift in the demand function.

5. New forest plantations are established in the emerging region at a annual level of 600,000 ha, falling linearly to zero at year 50.
6. The dollar exchange rate is assumed to remain at the current level throughout the period of analysis.[19]

A Global Overview of the Base Case

Overall global pulpwood production (figure 1) increases from about 700 million cubic meters in 1995 to about 1.325 billion in 2045.[20] Thus, there is almost a doubling of the production of pulpwood over the 50-year period. This magnitude of increase does appear to be reasonable over a five-decade period in the context of the expanding production from newly developed plantations, wood-saving technological change that is occurring in pulping,[21] the increase in tree yields due to technology, and the worldwide increase in the use of recycled paper as a substitute for virgin fiber.

Additional insights into the nature of the base case and indeed the TSM96 can be gained by viewing pulpwood production as a part of the larger global industrial wood production. Figure 2 presents the total world industrial wood base case production by the eight regions for the 50-year period 1995-2045. Over that period total industrial wood production increases from about 1.7 billion cubic meters to 2.3 billion cubic meters, an increase of about 35 percent over a five-decade period; while, as noted in figure 1, total pulpwood production essentially doubles over that period. This large shift in the composition of industrial wood production away from solidwood to pulpwood is necessary to accommodate the more rapidly rising demand for pulpwood.

The implication of the above is that, worldwide, total solidwood production must decline to allow such a large shift in the composition of production without even larger increases in total output. This, in fact, is projected on figure 3 as total world solidwood production falls from almost 1.1 billion cubic meters in 1995 to about 980 million in 2045.

Finally, figure 4 shows the real price trends of pulpwood and solidwood over the 50-year period. Pulpwood price shows a fairly substantial increase throughout the first one-third of the period, a more modest increase over the second third, and a slight decline during the last third. Solidwood prices are almost the inverse of pulpwood, declining over the first third of

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[19] For a discussion of exchange rates used see *The Long Term Adequacy of World Timber Supply*, pages 204 and 205.

[20] This increase is generated from both the responsive and nonresponsive regions. The responsive region increases come as the result of increases in technology, management and new plantations, as well as the addition of increased harvests from the marginal land classes that, in the TSM96, are induced into production by higher prices. The output from the nonresponsive region increases on the basis of historical trend and may well involve inclusion of the harvests from additional forest lands.

[21] Such as thermomechanical, chemi-thermomechanical and groundwood pulping techniques.

the decade, increasing slightly over the next third and increasing in the last third of the decade. Over the whole of the 50-year period, overall price increases are rather modest being about 30 percent for pulpwood and only about 8 percent for solidwood. The rise in pulpwood prices in the early period reflects the rapid rate at which pulpwood demand is expanding relative to solidwood. Thus, the pulpwood price must increase to attract wood from solidwood to pulpwood uses.[22]

SCENARIOS

In this section we undertake a number of scenarios that explore the implications of hypothesized changes in the conditions applicable to the industrial wood industry. These include:

1. Decreasing Demand
2. High Demand (based on FAO forecasts)
3. Very High Demand
4. Integrated Supply Constraints with Base Case Demand
5. Integrated Supply Constraints with Low Demand
6. Very High Demand with High Plantation Establishment

The above scenarios show that very large differences in output and prices are associated with large differences in the rate of demand schedule growth and with large differences in the potential to produce and expand available supply. A summary of some aspects of the base case and various scenarios appears in Table 1.

SUMMARY AND CONCLUSIONS

The TSM96 provides projections of the time path of the equilibrium output levels for the world and for the several regions into which the world has been subdivided. A major new feature of TSM96 over the earlier timber supply model is that industrial wood, treated as homogeneous in the earlier study, has be subdivided into two difference wood types -- pulpwood and solidwood. The supply of these two commodities is viewed as joint products in production.

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[22] In the various scenarios examined only the base case and the integrated supply constrained have the very large difference between the rate of growth of pulpwood demand and that of total wood demand. This difference implies that solidwood demand is growing very slowly, if at all. In this case the price of pulpwood rapidly approaches that of solidwood as, through the early part of the period, the pulpwood market must bid wood away from solidwood market.

Table 1. Summary: Production and Prices for the Base Case and Scenarios

Scenario	Production Year 50 (Bn m3)		Prices ($/m3)	
	Pulpwood	Total Industrial	Pulpwood over 50 years	Solidwood over 50 years
Base Case	1325	2.3	31 - 40	52 - 57
Decreasing demand	0.570	0.930	38 - 18	55 - 44
High demand (FAO forecasts)	1.375	2.6	40 - 80	60 - 135
Very high demand	2.2	2.9	60 - 310	80 - 310
Integrated supply with decreasing demand	0.43	1.25	45 - 35	58 - 58
Integrated supply with base-case demand	1.0	1.65	60 - 80	77 - 87
High demand with high plantation establishment	4.3	6.9	40-53	60 - 80

Figure 1 World Pulpwood: Base Case

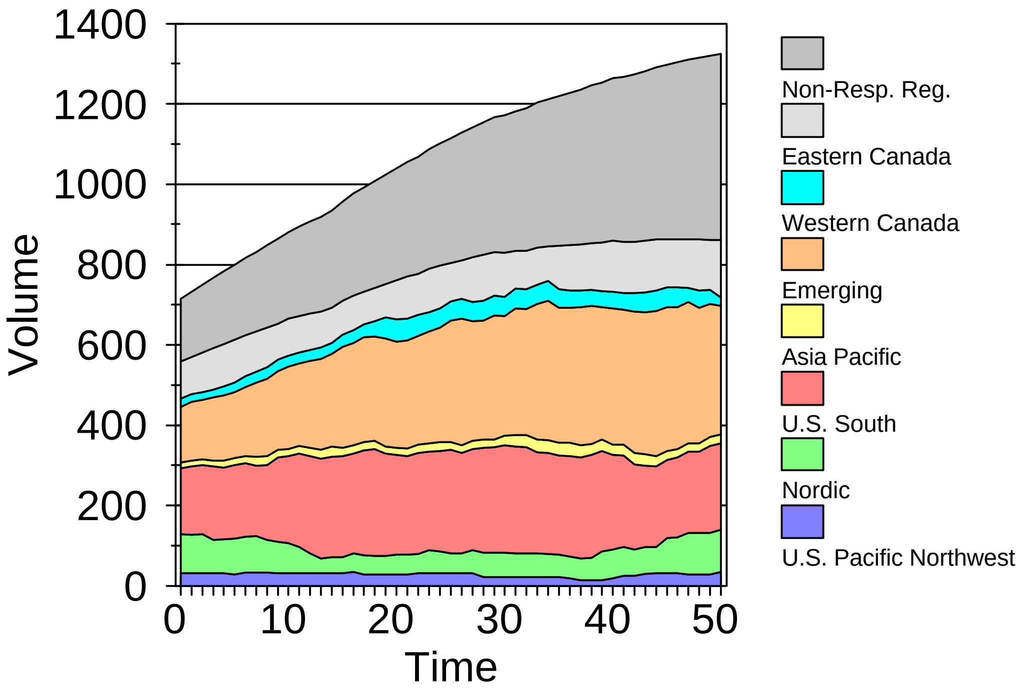


Figure 2 World Industrial Wood: Base Case

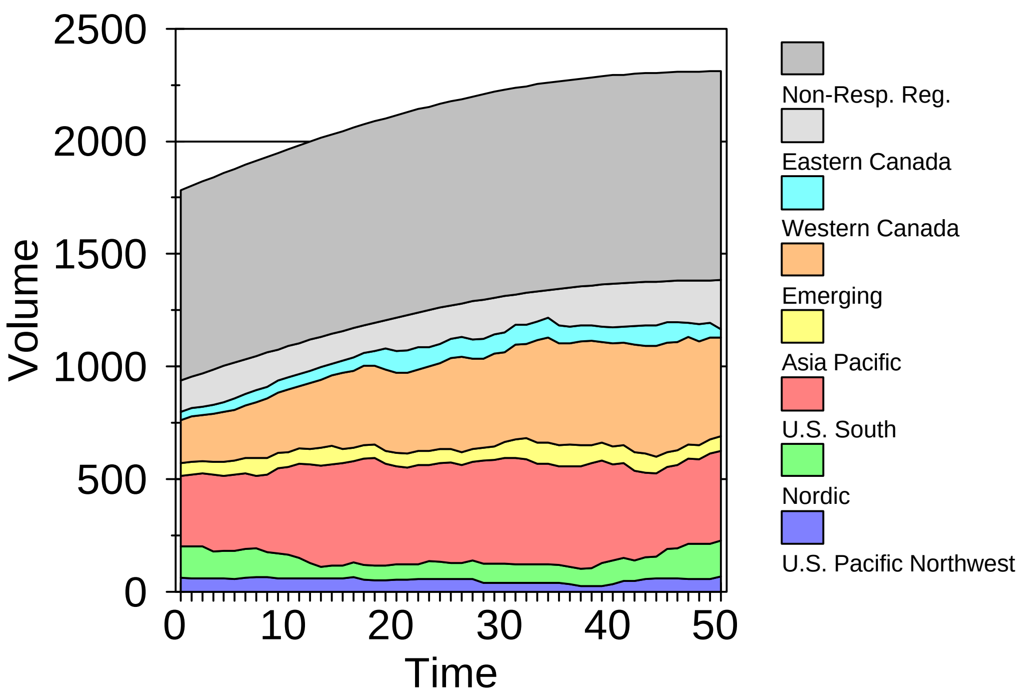
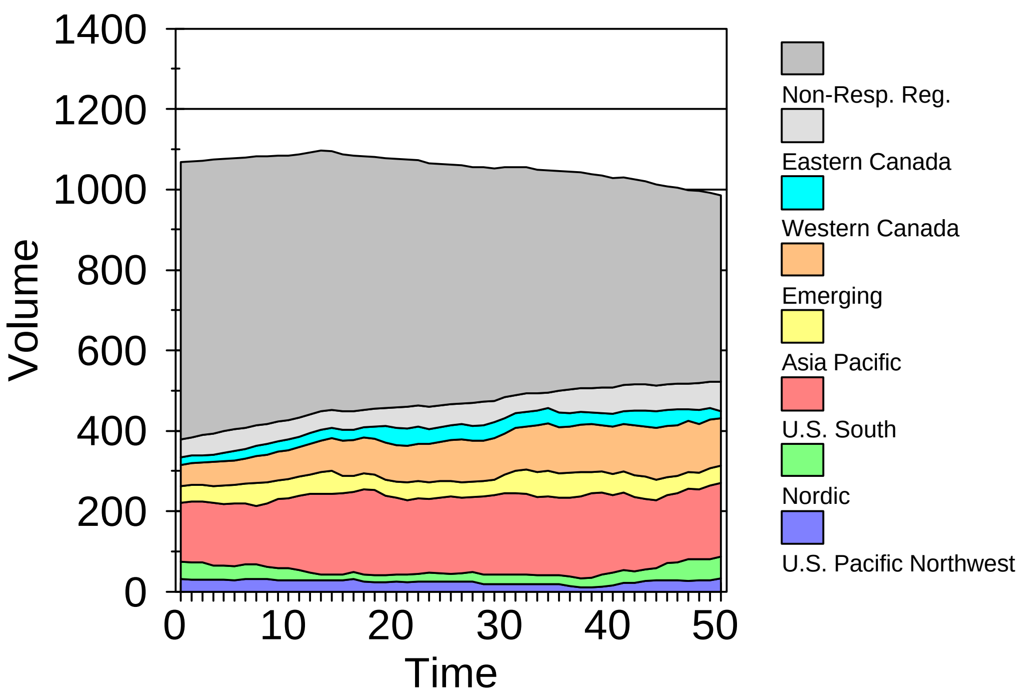


Figure 3 World Solidwood: Base Case



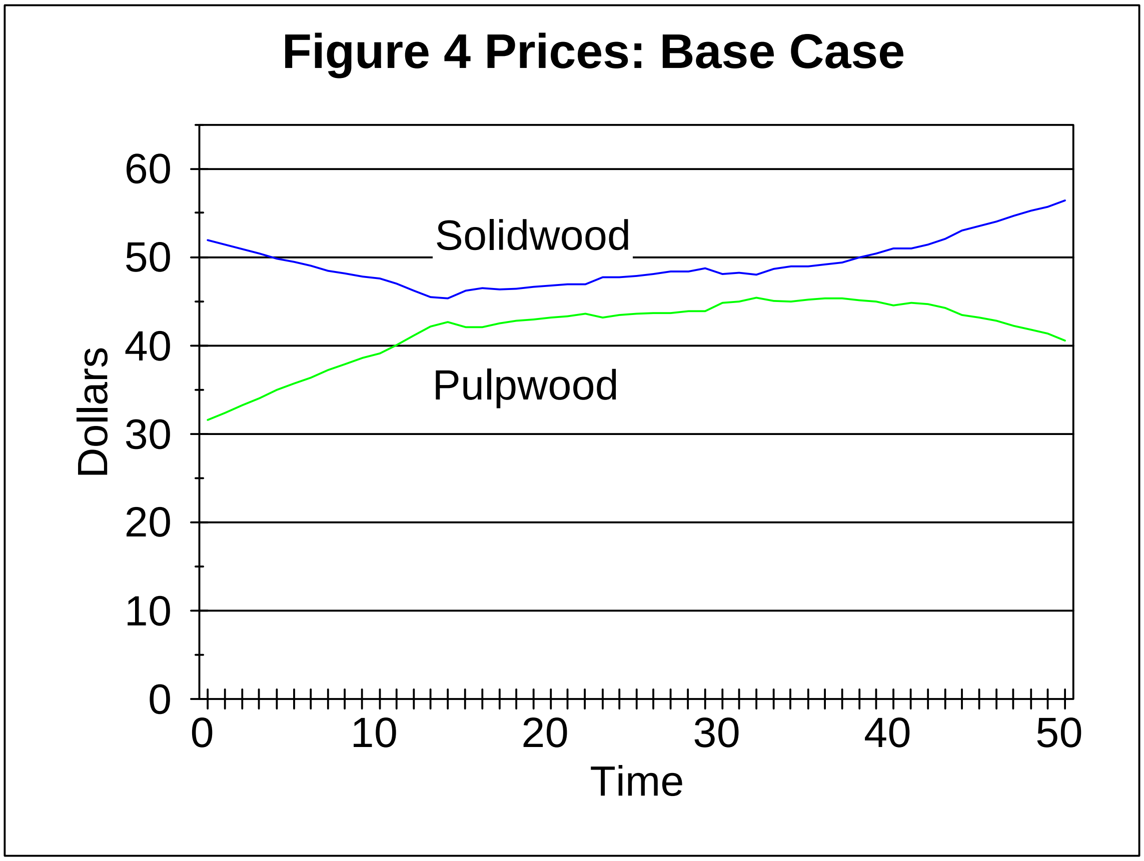


Figure 4 Prices: Base Case
Solidwood
Pulpwood
Dollars
0
10
20
30
40
50
60
Time
0
10
20
30
40
50

REFERENCES

IIED. 1996. *Towards a Sustainable Paper Cycle*. Prepared for the World Business Council for Sustainable Development by the International Institute for Environmental and Development. London: IIED.

Sedjo, R. A. 1995. The Potential of High-Yield Plantation Forestry for Meeting Timber Needs: Recent Performance and Future Performance. RFF Discussion Paper 95-80. Washington, DC: Resources for the Future.

Sedjo, R. A. and K. S. Lyon. 1990. *The Long-Term Adequacy of World Timber Supply*. Washington, DC: Resources for the Future.

Sedjo, R. A. and K. S. Lyon. 1996. Timber Supply Model 96. RFF Discussion Paper 96-15. Washington, DC: Resources for the Future.

Sedjo, R. A. S. J. Radcliffe and K. S. Lyon. 1986. Tax Reform and Timber Supply. RFF Policy Brief. Washington, DC: Resources for the Future, June

Sedjo, R. A. A. C. Wiseman, D. Brooks and K. S. Lyon. 1994. Effects on Timber Supply of the Set-Asides in the National Forests in the PNW. RFF Discussion paper ENR 94-25. Washington, DC: Resources for the Future.

Sohngen, B. R. A. Sedjo, R. Mendelsohn and K. S. Lyon. 1996. The Role of Human Adaptation in Amelioring the Impact of Climate Change on Global Timber Markets. RFF Discussion Paper ENR 96-8. Washington, DC: Resources for the Future.

7A. Comments and Thoughts: One User's View of Fiber Supply Market Models

Paul C. Van Deusen[1]

We have discussed a number of wood fiber market models, with emphasis on TAMM, CINTRAFOR, TSM96, and NAPP. Fiber supply models implement systems of equations and solution procedures that are based on economic assumptions about how markets will respond to policy changes. The policy maker hopes to gain insight into the effects of a proposed policy change by simulating it. Clearly, model predictions will be imperfect, and my role with NCASI would likely be to help our member companies assess the uncertainty of predictions and evaluate underlying assumptions. In practice, a fiber market model's predictive accuracy can only be assessed by looking at past performance, or by making comparisons to other models. If model A has consistently outperformed model B in the past, we would tend to prefer Model A's future predictions.

I have been implicitly talking about generic econometric models, which by my definition means quantitative models that formally implement economic assumptions to simulate the wood fiber market using equations. It is also possible to make predictions based on expert opinion. A recent example of this approach (Greene and Siegel 1994) looks at expected impacts of state and local regulatory enactments. If an expert opinion model could be shown to produce predictions that are comparable or better than an econometric model, then it should be used. However, I am biased toward the econometric approach. I believe that econometric models will produce the most detailed information, and also provide an opportunity to locate specific assumptions that need to be changed. It may not be clear what to change if expert opinion is wrong.

How many wood fiber market models are needed? A simplistic view of an econometric fiber market model is that of a black box that accepts certain exogenous inputs and gives back internally produced (endogenous) outputs. But 2 models that take the same inputs and give similar output variables may be internally quite different. I think competition (among modelers) is good, and I would like to have access to more than one fiber supply model in order to perform my simulation with competing models. Ideally, these models would be publicly accessible so that a user could simulate alternative policy scenarios by deviating the inputs away from a set of default values and observing the change in output. It would be difficult for the modelers to make their products user friendly enough for this situation to occur, but it seems like a worthy goal. However, I suspect economists will like the idea of competing models better than policy makers. Multiple models give economists full employment, but the policy maker

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gets potentially conflicting simulation results. Regardless, I would encourage the policy maker to look to more than one model before making major policy decisions.

Now I'll belabor the idea of having more than one model to do the same thing, and give justification for having more than one black box. In practice, it's very difficult for an outsider to fully understand what's taking place inside of a complex fiber market model. Even models that seem to be based on the same economic theory can implement the theory differently by using different equations or different algorithms to attain a spatial equilibrium. Legitimate models could also implement different economic theories. For example, demand and supply might be modeled using disequilibrium theory under the assumption that wood fiber markets can't clear over short time periods. Fortunately, the law of supply and demand will limit the proliferation of models. Therefore, the policy maker won't be totally overwhelmed, but some economists may have to seek employment elsewhere.

My discussion about competing models is related to the concept of sensitivity analysis and evaluating the uncertainty of a projection. Here are some of the items that contribute to the variance of the projection: uncertainty in the economic theory, uncertainty in the equation forms and solution procedures to implement the theory, and uncertainty in the exogenous variables. Exogenous variables like timber supply from National Forests and the imposition of state level regulations are difficult to project. These uncertainties can be evaluated in a limited way by changing the assumed level of an exogenous variable and looking at its effect conditional on all of the other assumptions. This gives some insight into the conditional variance of the projection with respect to a single exogenous variable. Some sensitivity analysis is typically done, but it would be valuable to go further to remind the policy maker that the confidence interval around a projection widens exponentially with time. This exponential effect is partly due to the fact that projections are strongly influenced by prevailing short-run conditions.

Now I'm trying to generate some work for biometricians. Fiber supply projections are very deterministic. It's conceptually easy, but computationally demanding to vary multiple inputs simultaneously to look at their joint impact on the projection. However, if more of this were being done I might be somewhat less prone to favor multiple modeling efforts. I think there is a need to consider developing fiber supply simulation methods that are more stochastic and would better convey the inherent uncertainty in a projection to policy makers. It might be possible to do this with a combination of computational brute force and judicious application of Monte Carlo or Bayesian simulation techniques. This is an area that is seeing rapid development in the field of statistics and econometrics as well. By failing to do this, there is a risk that too much confidence will be placed on fiber supply projections and bad policy decisions will be made.

My final comment has to do with inventory information. Regardless of the model being used, USDA Forest Service inventory and analysis data (FIA) will provide the basis for the current inventory. National level projections must use FIA data from many states, and an additional level of uncertainty is added to projections if these data are incompatible and out of date. FIA is currently evaluating some annual forest inventory system pilot projects, which would make the data current each year. If an annual system were implemented nationwide, it would reduce the uncertainty of the inventory projection component of fiber supply models. Under the current FIA system, there are states that go 15 or more years between inventories, which means that considerable modeling and error is incurred just to get to time zero. Fiber supply projections would be improved by annual forest inventory systems.

In summary, I think the econometric approach is the best way to make wood fiber market projections. However, the best methodology is sufficiently uncertain and complex to justify more than one or two major, independent modeling projects. I don't think enough effort goes into sensitivity analysis and toward exposing and evaluating the uncertainty associated with a projection. Finally, FIA data should be as current as possible in all states to reduce this source of uncertainty at time zero.

LITERATURE CITED

Greene, J. L., and W. C. Siegel. 1994. "The Status and Impact of State and Local Regulation on Private Timber Supply." General Technical Report RM-255. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

7B. Comments and Thoughts: Timber Supply Modeling: Promises, Problems, Proposals

Frederick Cubbage[1]

Timber supplies are important in providing industrial wood and fuelwood; planning and developing manufacturing capability; and protecting the environment. Two broadly contrasting themes about timber supplies may be characterized as Malthusian (pessimistic) or technocratic (optimistic). Increasing population and a fixed land base drive Malthusian fears of a timber shortage and high prices. Market efficacy, technology, and substitutes drive optimistic views of timber supply.

World, national, and regional timber supply models have projected very different results regarding timber supply. Better information about how these models work, what assumptions they use, or even better models might help clarify the many discrepancies.

Defining timber supply is one key to our view of the timber situation and prospects. Supply of course indicates the quantity of timber that is sold by a willing buyer to a willing seller at a given price for a unique product at a given location and time. Note that location (timber still is only moderately transportable) and quality (wood fiber is not perfectly substitutable in the short run) are crucial in determining supply. Given these caveats, what would be helpful for users of timber supply models?

First, let me note a couple of projection results to illustrate the importance of understanding what timber supply models are doing. I examined the past Forest Service projection of timber supply published in the RPA and timber trends studies (Table 1 and Table 2). In general, they show that there were modest but not wild differences in the projections of southern roundwood supplies (harvests), depending on the year of the forecast. The forecast of the southern timber inventories, however, varied considerably from one projection to the next. A second example is a comparison between the current RPA projections and the RFF TSM96 model. RPA generally suggests increasing sawtimber prices and decreasing pulpwood prices for most regions of the U.S. TSM96 projected exactly the opposite for world timber prices over the next 15 years. Discrepancies such as these need to at least be better explained, and perhaps better modeled.

Desirable timber supply models must of course be theoretically sound. They should employ the best economic theory and empirical evidence available given the limited market data and funding we have to build models. Timber market models are not new, but many of the econometric or mathematical approaches developed now can improve model estimation and reliability.

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[1] Professor and Head, Department of Forestry, North Carolina State University.

Table 1. Forecasts of Southern Roundwood Supplies from Five Different National Assessments of Timber Markets

			Softwood Supplies by Year		
Year of forecast	1990	2000	2010	2020	2030
		--------Billion Cubic Feet--------			
1974	5.22	5.77	-	5.79	-
1982	4.89	5.39	5.77	6.05	6.23
1988	5.41	5.82	6.15	6.57	6.59
1990	5.13	5.99	6.33	6.97	7.54
1995	5.28	6.27	6.39	7.08	7.89
			Hardwood Supplies by Year		
Year of forecast	1990	2000	2010	2020	2030
		--------Billion Cubic Feet--------			
1974	3.01	3.33	-	3.42	-
1982	2.73	3.47	4.12	4.77	5.21
1988	3.35	3.71	3.99	4.18	4.08
1990	2.93	3.93	4.91	5.21	5.41
1995	2.91	3.78	4.33	4.55	4.50

Sources: USDA Forest Service (1974, 1982, 1988), Haynes (1990), and Haynes et al. (1995)

Table 2. Forecasts of Southern Timber Inventories from Five Different National Assessments of Timber Markets

			Softwood Inventory by Year		
Year of forecast	1990	2000	2010	2020	2030
		--------Billion Cubic Feet--------			
1974	98.0	100.3	-	99.4	-
1982	119.7	134.7	145.4	152.5	156.1
1988	96.7	91.5	92.8	96.8	100.9
1990	103.8	100.9	108.4	116.8	118.3
1993	102.9	99.4	106.3	115.3	119.1
			Hardwood Inventory by Year		
Year of forecast	1990	2000	2010	2020	2030
		--------Billion Cubic Feet--------			
1974	90.4	91.1	-	89.6	-
1982	130.6	142.8	146.8	144.0	135.5
1988	125.4	128.3	122.7	114.2	105.8
1990	134.2	134.4	124.1	109.8	97.3
1993	147.7	151.6	151.0	143.0	133.9

Sources: USDA Forest Service (1974, 1982, 1988), Haynes (1990), and Haynes et al. (1995)

A good timber supply model should be as simple as possible and still capture fundamental economic and biological behavior. It should be understandable, replicable, usable by knowledgeable experts, and well documented. Terms in the model (i.e., roundwood supplies, removals, harvests) should be defined. The inputs used and assumptions made should be widely accepted and clearly described. Means of spatial aggregation should be reasonable, balancing national and local needs. The objectives of the relevant model, policy analysis, local wood supply, sectoral details, need to be clear.

Timber supply models should be described well to be useful. The model structure should be specified, as well as input data and sources. The version of the model being used and the data of the model "run" should be footnoted, with any unique features from prior efforts explained. The assumptions made in running timber supply models and whether they are trivial, widely accepted, or strong needs discussion. Unique model features, merits, a quirks need explanation.

The output from models should be listed in tables and discussed in text. Figures help lay persons but data helps detailed users. Any interventions make by the modelers to develop the base or other runs need to be explained. Notable inputs or outputs need to be highlighted or explained, and the sensitivity of the models to changes in assumptions or data examined. Linkages and driving forces with other models need explication.

The roles of technological change, timber substitution, quality or product differences, non-timber substitution, and structural change should be assessed by model runs and in model publications. To the extent possible, modelers should identify and separate (1) the biological bases for model outcomes; (2) the market factors and responses driving model outcomes; (3) the mathematical structures and model assumption driving outcomes; (4) the technological change or trade factor influencing outcomes; and (5) the differences in outcomes by location or for different products or quality or time periods (supply determinants).

Applications of timber supply models should include the above information for the base case and assumptions, for likely scenarios, for common regions, and for common ownership types. Within the limits of the model and the data, they should break regions down. They should help identify wood supply trends and the impacts of government interventions. They should the models sensitivity to crucial assumptions, to common input changes, and to mathematical relationship changes. When possible, they should provide some estimates of the probabilities of outcomes or their confidence intervals. Estimates of timber "availability" would be useful.

Output from models also should be analyzed and discussed, not just restated. Timber supply projections should be compared with the base data and linear projections to see if they are reasonable. They should be compared to prior forecasts with the same model or by the same agency, or other model results. Discrepancies should be noted, discussed, and explained. The caveats, problems, or limits of the model or its findings should be clearly noted and discussed, and suggestions made for model improvements.

Once the model structure, inputs, outputs, and limits have been described well, then detailed summaries of the implications should be made. What do the results of the projections imply? Will timber be scarce (expensive)? In what region, for what product, when? How much land area is projected or required? What impacts can intensive management, trade, or substitutes have? What is the role for firms or government? What will happen to timber harvests, inventories, and prices by product and ownership class? Such questions are of course the bottom line of timber supply modeling. One should develop models well, describe them clearly, and validate them as best possible. Then the results and recommendations that come from their application become truly useful for public and private analysis and decision making.

7C. Comments and Thoughts:

Presentation of Steven Winnett, U.S. EPA User Panel
Workshop on Wood Fiber Market Models
October 3-4, 1996

The EPA's Office of Economy and Environment (formerly, Office of Policy Analysis) has used the models discussed at this workshop for several years in policy analysis. The Office's Climate Change staff has focused on developing policies to reduce greenhouse gas emissions and increase carbon sequestration. Over the past seven years, we have examined the U.S. forest and agriculture sectors for their capabilities to increase carbon sequestration, and as a source of bioenergy feedstocks for offsetting the use of fossil fuels.

Working with both the Forest Service's Northeast and Northwest staff, we have developed and run scenarios of climate change mitigation policies. Using the TAMM/ATLAS model linked with Peter Ince's NAPAP model, Richard Birdsey's forest carbon model FORCARB, the Row/Phelps model HARVCARB which simulates the fate of harvested wood products, and the EPA's own forest carbon model, we have examined a number of policies to change utilization rates for recycled fiber, increase afforestation on marginal crop and pasture land, change harvest levels (in both directions) on National Forest lands, and use forests for biomass fuels. We have also examined combinations of these policies, as it is unlikely they would either exist or be implemented singly. In addition, we have worked with CINTRAFOR to link these TAMM/ATLAS runs with their Global Trade Model, examining how these domestic policies would affect international markets, and how carbon sequestration would be affected globally.

The results of these analyses were used in the development of the Administration's Climate Change Action Plan, and in subsequent policy discussions about forest sector carbon sequestration. The results of these linked analyses are reported in two documents, one by USFS on the economic results and one by EPA documenting the whole project, which are available from my office. In addition, three CINTRAFOR documents are available (papers 43 and 50, and a paper by John Perez-Garcia) on the CGTM analyses resulting from this project. These documents have been circulated widely both nationally and internationally.

While these linkages have not always been easy to develop and maintain, they have grown easier over the years with greater experience and use. The modelers had to become familiar with each others' approaches, and had to work out many bugs. Certainly, we would have preferred a single model capable of doing everything we wanted. Lacking such a model, we have tried to be as creative as possible, working with a number of experts and asking them to be creative with their models and with other modelers. These efforts have been productive and have allowed us to conduct analyses which would not have been possible any other way.

In the course of our work with USFS and CINTRAFOR, we found that while the models fulfilled many of our analytical requirements, certain functions were not available that we needed. Until recently, CGTM did not have the ability to examine carbon dynamics, which are important to our office. This has now been realized, at least for the softwood sector. TAMM, as we have discussed, is not at its best when it must model activities that are outside of the range of events that have been historically observed, and that are part of its data history. Tree planting at a large scale has always been a very attractive policy option in addressing climate change, because of its reliable carbon sequestration and the other environmental benefits which accrue from planting.

We ran a number of scenarios of large-scale afforestation on agricultural land, and when these simulated activities were at a scale larger than previously observed, TAMM's results were predictably implausible. In addition, we were unable to model the effect of such activities on the agricultural sector because we had no dynamic way of connecting the two sectors together to examine how the competition for the land base affected markets. Our needs pointed to a model that did not yet exist, so we funded Darius Adams (Oregon State University), Bruce McCarl (Texas A&M University), Ralph Alig (USFS), and Mac Callaway (Hagler Bailly) to build us a dynamic model of the joined forest and agriculture sectors. The result is the Forest and Agriculture Sector Optimization Model (FASOM), to which several previous speakers have referred. It is a regionally disaggregated model of the U.S. log market which optimizes the sum of consumer and producer welfare in both sectors over a time period up to 100 years, at 10 year steps, in which the sectors compete for the land base.

The model incorporates a number of features that Joshua Bishop discussed in his talk early in the workshop. In addition to its explicit treatment of interactions across land use sectors, it is an optimal control model which has perfect foresight of the future, and adjusts the domestic forest inventory through harvesting and changing management intensity and species types to meet demands for fiber across the entire projection period. It also allows substitution between hardwoods and softwoods, and downward substitution of sawtimber for pulpwood, and pulpwood for firewood. It also includes a carbon sector which considers carbon in the forest, in products, and in disposal pools.

We recently documented the forest sector of the FASOM model in the journal *Forest Science*, and we have copies available for anyone who is interested. The documentation of the agriculture sector of the model was published several years ago in Bruce McCarl's papers on his Agriculture Sector Model (ASM). The land-use interactions part of the model is being documented in a paper for the *American Journal of Agricultural Economics*, now in revision. I have copies of this paper available, also. EPA has two reports, which I would be happy to make available, in which we describe FASOM in detail, and present the results of a set of base line and alternative scenarios of forest policies.

As users of models for policy making purposes, we need to have the models which have a good reputation in the professional community and which are well-documented. As it is important to know how the models differ or are similar, we, too, would like to see more work where the models are compared across similar scenarios. We would also like to see more cooperative use of the models where they are used to describe the outer bounds of the range of possible solutions for similar policies. We think this is particularly valuable when in the models, as in the case of TAMM and FASOM, themselves represent extreme cases of behavior in the sector (perfect markets and perfect foresight versus the observed imperfect market behavior). We have copies available of an EPA report which compares the performance of FASOM and TAMM on similar scenarios. We also have available a paper which describes our work on incorporating into FASOM's perfect market behavior some of the types of market imperfections, in this case constraints to capital and land supply, which are a part of TAMM.

At this point, it doesn't seem that any one model has the ultimate right answer, and the "true" solution probably lies somewhere in a range between or around the models' solution. Each model presents a valuable facet of the problem and we feel there is value in comparing the results and discussing what each models' result has to say about the sectoral interactions. Unless we have a situation where the models' results present a range which is too wide to say anything useful about possible sectoral outcomes, we think that this approach will be workable in cases excepting where a decision maker or an administrative process must have a single answer. In such situations, we have used an average of the range of results. In the case of forest soil carbon dynamics, where there is a basic scientific debate over the nature of these interactions, EPA and USFS have used a single estimate which is the average of two modeling approaches which span the scientific understanding. Simultaneously, we are working together at resolving the issue.

We are also concerned that model inputs and assumptions be as consistent as possible across models, so that the work we do within the Administration and within the modeling community is comparable. Currently, USDA is the only department not using the macroeconomic projections endorsed by the Council of Economic Advisers (CEA). As members of the Administration, and users of USDA models, we are concerned that since our modeling results do not incorporate these economic assumptions, we will be at a disadvantage in interagency activities. In the coming months, we will be working with members of the modeling community to derive macroeconomic assumptions for the forest sector consistent with CEA's projections. We will run NAPAP and TAMM scenarios with these assumptions so that our FASOM work, and any other work we do with USFS's models, will be consistent with the CEA projections. We will be happy to make these data available to anyone who wants them.

We have been interested for several years in examining how certain forest management alternatives would affect the incidence, and impacts, of catastrophic fire and other destructive events. Especially in light of the potential for changes in climate, which could cause warming and drying in various regions, we would like to have the ability to estimate how changes in climate might interact with management alternatives to either exacerbate or relieve various forest health problems. This work would not only support development of the type of environmental indicators that were discussed at the workshop, but it would also support forest impacts work vis a vis climate change, and forest health, fire and related management issues.

Our plans for the immediate future include building the intermediate product markets into the FASOM model. This will free us from needing to run NAPAP and TAMM to set up FASOM's demand projections, and allow us to more fully estimate downstream economic effects. We are also working on estimating substitution between wood products and non-wood substitutes. Although we have environmental indicators in the agriculture sector of the FASOM model, we have such abilities on the forest sector side. We are investigating building some of these indicators into the forest model, and we would welcome the suggestions of any of our colleagues. We look forward to reporting the results of our efforts to you at a future meeting of this group.

7D. Comments and Thoughts: Comments at Workshop on Fiber Market Models

Michael Carliner[1]

The home building industry, unlike the forest products industry, is not capital intensive and does not require long-term commitments comparable to those involved in forestry or even comparable to the medium-term commitments made by forest products manufacturers when they invest in new mill capacity. As far as home builders' business planning is concerned, only relatively short-term forecasts of lumber supplies and prices are significant.

The primary interest of home builders in long-term fiber models is in connection with policy analysis, particularly to the extent that long-term model solutions influence policy decisions affecting short-term lumber supplies and prices.

Over the longer term, builders can respond to changes in softwood lumber supplies and prices by switching to alternative materials or changing home designs to use less lumber. With little capital investment beyond saws and nail guns to tie them to wood framing, the only factors limiting substitution are education and, to a limited extent, constraints related to building codes. In specifying demand for lumber from home building in fiber models, a lagged adjustment process extending over a few years should be incorporated to account for substitution and conservation, and the demand curve should be non-linear, with a much higher elasticity once thresholds are reached where steel and other alternatives become competitive.

With little relevant historical experience in the price range where substitution is likely, as well as significant technological and institutional changes, the modeling of demand may be more realistically based on engineering calculations than on econometrics.

Overall demand for housing is probably not very responsive to changes in lumber prices or wood fiber supply. The number of new units will be dictated more by demographics and macroeconomic variables. The average size of new units could be a bit more sensitive, but with the wholesale value of framing lumber representing only about 5 percent of the cost of a new home, the effect of a change in lumber prices on sizes of homes is not likely to be significant.

Efforts to develop forecasting or simulation models of the fiber market will not be rewarded if there are no data on timber supply, growth or harvests, or on fiber utilization. Particularly for the increasingly-dominant private timber supply, information is too sparse and unreliable to justify highly-elaborate models, and the development of improved data should be the first order of business in any initiative to improve models.

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[1] National Association of Home Builders, Washington, DC.

As everyone who has developed models should realize and concede, there is generally more art than science involved. Indeed, where model-building efforts have tended to exclude changes in structure or assumptions based on judgment, the result has generally been a less accurate representation of reality and less accurate forecasts.

The objective of creating models that are user-friendly is likely to produce a mis-allocation of resources. The experience with other models, including commercial macroeconomic forecasting models, has generally been that few potential outside users have actually produced their own simulations, despite major investments in software to allow such independent use. It's not clear that outside users could really use complex models sensibly even if they tried.

A more worthwhile objective is to make the models as transparent as possible, with documentation that include specific details rather than simply abstract statements of philosophy. One aspect of such transparency that could be facilitated by this meeting and the participants here is to produce forecasts using a common set of assumptions and to calculate the effects of specified changes in assumptions. Since each model has a different list of exogenous variables, doing so would not be simple or straight-forward. Similar exercises have been valuable for comparing models in other sectors and models of the overall economy, however, and the effort should be made to reconcile the differences among fiber models.

One of the common pitfalls in model building is excessive disaggregation. The development of satellite models to calculate detailed implications of an overall result may be useful, but the aggregate result is unlikely to be improved by creating a maze of disaggregation simultaneous equations.

The inclusion of environmental measures is vital if the models are going to play a meaningful role in policy analysis. On the other hand, it is not clear that there is a quantifiable direct feedback from environmental changes due to timber harvests back to fiber supply within the range of likely scenarios. Thus, models of environmental impacts may formally be satellite models rather than internal to the fiber market models.

7E. Comments and Thoughts:

Fiber Supply Modeling -- Advancing the Art (and Science): Workshop Discussions as captured by Alberto Goetzl

The purpose of the workshop was to reflect on the state of the art in forest sector economic modeling. Forest sector models are used principally in two ways. First, models assess the economic implications of public policy alternatives and, hence, play a critical role in public-policy decision making. And second, models are used in the private sector to assess investment opportunities and to develop strategic production and marketing plans. This workshop brought together the developers of the major forest sector models used primarily in the former context -- i.e. for public policy analysis -- with the objective of determining where the strengths and weaknesses of various models lie, and assessing what improvements might be made in modeling processes generally to provide more reliable results for users whether public policy decision-makers or private sector analysts. These objectives were largely met by the workshop.

As chairman of the workshop, Henson Moore conveyed the perspective of the forest industry in the context of his own personal experience in the energy sector. In the energy sector, models provide useful to resolve some of the confusion and concerns raised by different policy alternatives. The goal should be the same in the forestry sector, but all too frequently there is little consensus on implications of various policy options.

Barbara Weber of the Forest Service noted that, unlike in the past when domestic concerns drove forest sector analysis, global issues are increasingly necessitating the need to assess sustainability implications in the forest sector. The development of national criteria and indicators as part of the Montreal Process and Santiago Declaration underscore the need to better measure socio-economic inputs and outputs in the forest sector.

During the initial session, several speakers described their experiences with sector modeling. Based on a presentation by John Weyant of Stanford University, parallels might be drawn between the evolution of modeling in the energy sector and what is developing in forestry. He described how the various energy interests have used the Energy Forum at Stanford University to evaluate the results from different modeling efforts in order to assess the range of possible outcomes for a given a question.

Josh Bishop of the International Institute for Environment and Development (IIED) related his experience in using models to examine different aspects of the forest and paper sector. Specifically, he described using the GTM at University of Washington for a study of tropical timber trade and, later, RFF's TSM for a multi-faceted study of the global paper cycle. By using the GTM, IIED was able to conclude that imposition of import constraints on tropical forest trade would likely be detrimental to tropical forests. He noted that the GTM enabled detailed analysis of bi-lateral trade flows. However, the model has certain rules and limits that are not easily understood and appear arbitrary. The TSM has the advantage of being able to distinguish pulpwood component of roundwood supply. By using the TSM in its recent analysis, and after running several different scenarios, IIED concluded that world fiber supply would ultimately keep up with demand but with some tightening. In some ways, the results were highly predictable, but the model was able to show which factors mattered the most. For example, the model clearly showed the role that price plays in responses to supply needs. The experience in conducting the paper study pointed to desirable refinements in the modeling capability. He noted that the TSM fails to account for competition among land uses except exogenously and there is no link with other land use models such as agriculture. He also emphasized the need to incorporate more non-fiber inputs and outputs in analyses using sector models. It is no longer simply price, production and capacity which drives public policy decisions. Most models currently being used also suffer from two other deficiencies: they do not consider substitution among products and they generally necessitate ad hoc adjustments to produce plausible results.

The subsequent session allowed the developers of the most prominent forest sector models to describe their work. The models which were featured included TAMM, NAPP, GTM, and TSM. Each presentation was followed by a discussion led by a reviewer. Bob Abt discussed the TAMM model. He noted that among the strengths of TAMM are its flexible structure for linking different sub models and its ability to provide regional, inventory and market detail. The fact that TAMM represents a stable modeling philosophy and team that has remained consistent for over 16 years may be its most valuable contribution. However, from a purely modeling perspective, TAMM has a number of drawbacks. It relies on short-term econometric relationships to drive long term forecasts. It incorporates numerous exogenous inputs, including global trade flows and land use changes. Many variables are thus handled in an ad hoc fashion (based on the expert opinion of the model developers). Derived demand is not price sensitive so substitution capability is weak. While TAMM enables flexible linkages, many of them are inconsistent. It also has a softwood solid wood focus. A basic problem for TAMM, as well as all other national models, is the lack of annual harvest and inventory data. These data are interpolated from periodic forest surveys. Others commented that TAMM is, in large part, a function of the experience and expertise of Darius Adams and Richard Haynes. Much of the modeling is long-term and inconsistent with the typically 1 to 5 years market and planning horizon of the private sector. As with other models, TAMM is difficult to learn and is not user-friendly.

John Perez-Garcia described the University of Washington's GTM as structured with 33 product demand regions and 43 timber supply regions. Log prices, elasticities, production and inventory control variables are tracked for each region. The model uses a very large database and one of the challenges is in keeping the database up-to-date. Joe Elling of the Weyerhaeuser Company summarized his review by noting the model's emphasis on trade flows, one of the distinct features of the GTM. However, product type characteristics could be better developed and, like most models, non-linear relationships are difficult to deal with.

Ken Lyon and Roger Sedjo presented a description of the RFF Timber Supply Model (TSM). David Brooks noted a number of strengths of the TSM, including its clear and focused specification and its ability to address supply on a global scale. However, a fundamental assumption in the TSM is that supply responses stem entirely from rational expectations. This vastly simplifies questions being asked. Most of the world does not operate rationally, nor are public lands managed under rationale expectations. He and others noted that TSM includes few demand side inputs, nor does it allow disaggregation of hardwood and softwood, or tropical and temperate species. Also noted was the fact that fiber from plantations is a key component in the model, but assumptions about plantations are exogenous to it.

The North American Pulp & Paper Model (NAPP) was the subject of Peter Ince's presentation to the workshop. NAPP differs from other models in that it is a technology driven demand side model. Peter Cardelicchio praised the information base used by the model and its sophistication but pondered about its complexity. He noted its limited international component and reliance on numerous assumptions.

Brent Sohngen of Ohio State University then provided an over-arching comparison of forest sector models, noting their respective theoretical bases and assessing their respective published results over time.

On the second day of the workshop, Rod Young of RISI explained the approach taken by his firm which focuses on short-term projections. Assumptions about changes in public policy are integrated into the process. RISI is in the process of developing a world fiber model. Following his presentation, a diverse panel of users offered insight in what was useful and what was lacking in the various forest sector models. Workshop participants were then led through a discussion on needs and capabilities. The following general themes about modeling approaches emerged:

- While data and methods are important, the process through which models are developed, applied and evaluated is equally as critical. Modelers should get together periodically to compare results from a common set of analytical questions. The Energy Policy Forum at Stanford is a working example of a process that enables an on-going dialogue on modeling efforts and results.

- Models being used for public policy purposes should be well-documented. The fact that most models also rely on the experience and expertise of the modeler should be recognized. Judgments based experience and expertise are necessary for a model to produced reasonable results.

- The next generation of sector models should be more user-friendly.

- A comprehensive sector model should incorporate an international trade and fiber flow component.

- An appropriate balance between sophistication and simplicity should be sought. The workings and results of simpler models are easier to communicate and more easily understood by decision-makers. However, most tasks require detailed analysis.

- Questions that models are designed to analyze should be clearly articulated. Different models are designed to answer different sets of questions. Better linkages between models that are available would be beneficial.

- While modeling is part art as well as science, public policy decisions should, to the extent possible, be founded on science and not politics. Models have a role to play by bringing science to bear in public policy decisions. Models should be able to quantify and contrast different approaches to achieving policy objectives.
- There should be a "buy-in" by the broader community of stakeholders. They should help define the questions to be addressed by using one or more models. To date, most of the models in the forest sector are centered around changes in stumpage values. However, innovative ways of measuring non-timber outputs are necessary. Demand inputs should not be solely fiber requirements, nor should outputs revolve only around supply and cost impacts. Outputs from forest sector modeling should address a "basket of benefits," including measures of sustainability and biodiversity.
- Models should incorporate the effects of new or expected changes in technology in analyzing alternative scenarios. Some models now do that to varying degrees.

Appendix A

Workshop on Wood Fiber Market Models to Assist in the Development of a National Fiber Supply Strategy for the 21st Century

October 3-4, 1996

Kimball Conference Center
1400 16th Street, NW
Washington, DC 20036

Sponsored by:

American Forest & Paper Association
USDA - Forest Service
Resources for the Future

Agenda

Day 1: October 3, 1996

Chairman: Henson Moore, AF&PA

Moderator: Richard Storat, AF&PA

8:00 Continental Breakfast

8:30 Welcome: Paul Portney, RFF; Henson Moore, AF&PA; Barbara Weber, USFS

8:40 Overview -- The Need for Better Fiber Supply Policy Models: Henson Moore, AF&PA

9:00 Modeling Experience in the Energy Area: John Weyant, Energy Policy Forum, Stanford University

9:30 What is Required for a Useful Fiber Supply Model: Joshua Bishop, International Institute for Environment and Development, London, UK.

The Panel of Modelers:

10:00 The TAMM: David Brooks, USDA Forest Service for Richard Haynes, USFS; and Darius Adams, Oregon State University

10:30 Discussant: Robert Abt, North Carolina State University

10:45 General Discussion of the TAMM

11:00 The CINTRAFOR Model: Bruce Lippke and John Perez-Garcia, University of Washington

11:30 Discussant: Joe Elling, Weyerhaeuser Co.

11:45 General Discussion of CINTRAFOR Model

12:00 Luncheon

1:30 TSM96: Roger Sedjo, RFF; Kenneth Lyon, Utah State University

2:00 Discussant: David Brooks, USFS

2:15 General Discussion of TSM96

2:30 Pulp and Paper Model (NAPP): Peter Ince, Forest Products Laboratory

3:00 Discussant: Peter Cardellichio, Asia Forest Products

3:15 General Discussion of NAPP

3:30 An Overview of the Models: Brent Sohngen, Ohio State University

4:00 - 5:00 Some thoughts on the models: Comments and Discussion:

Clark Binkley, University of British Columbia

Luis Constantino, World Bank

Steve Lovett, AF&PA

Day 2: October 4, 1996

Moderator: Steve Lovett. AF&PA

8:30 Continental Breakfast

9:00 Some Thoughts on the User Perspective: Rod Young, RISI

9:30 A User's View.

The Panel of Users:

Michael Carliner, NAH

Fred Cubbage, NCS

Jon Goldstein, OPA, Department of Interior

John Heissenbuttel, AF&PA

William Lange, USFS

Richard Pierson, Weyerhaeuser

Paul Van Deusen, NCASI

Steve Winnett, EPA

10:45 Where do we go from here? Mike Lesnick, facilitator, Keystone Center

12:15 Closing Thoughts: W. Henson Moore, AF&PA

12:30 Luncheon and Adjourn

Appendix B

Workshop on Wood Fiber Market Models to Assist in the Development of a National Fiber Supply Strategy for the 21st Century

October 3-4, 1996

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