Modeling Climate Change Impacts on the Forest Sector

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Introduction

The forest sector has had a relatively long history of applying sectorial models[1] to estimate the effects of atmospheric issues such as acid rain (see Haynes and Adams 1992; Haynes and Kaiser 1990), climate change (Callaway et al. 1994; Joyce et al. 1995; Mills and Haynes 1995; Alig et al. 1997; Perez-Garcia et al. 1997; Sohngen and Mendelsohn 1998), and the forestry impacts of reduced atmospheric ozone (Bently and Horst 1997). The models of the forest sector vary in scope and complexity but share a number of common features and databases. Three aspects in common among them stand out. First, the spatial equilibrium market framework first used by Haynes (1975) and expanded by Adams and Haynes (1980) has provided a structure and framework for many of these efforts. Second, the TAMM/ATLAS model (Adams and Haynes 1980; Mills and Kincaid 1992) itself has provided both relatively complete data sets and estimated relationships for economic processes that are robust and can be aggregated both in market levels and across spatial markets. The third aspect is the rich and unique forest inventory data sets that are available for the United States. This data set designed for assessing timberland conditions and trends provides an essential component to the development of aggregate timber resource models that are integral parts of most forest sector models. It allows for explicit treatments of changes in net growth, land use, and forest type changes.

The purpose of this chapter is to assess broadly our ability to model climate change impacts on the forest sector using two of the three forest sector models that are available in the public domain: the Timber Assessment Market Model (TAMM, Adams and Haynes 1980, 1996)/North America Pulp and Paper Model (NAPAP Ince 1994)/Aggregate Timberland Assessment System (ATLAS Mills and Kincaid 1992)[2] and Forest and Agriculture Sector Optimization Model (FASOM Adams et al. 1996a; Alig et al. 1997). A third model is the CINTRAFOR Global Trade Model (CGTM). It is the application of research started at the International Institute of Applied Systems Analysis (IIASA) and continuing work at the University of Washington (Kallio et al. 1987; Cardellichio et al. 1988, 1989). It has been used by researchers at the University of Washington to examine broad scale global climate change issues (Perez-Garcia et al. 1997).

In addition to the TAMM/ATLAS and FASOM applications that will be discussed in subsequent sections, some of the already listed references represent substantial efforts. For example, Joyce et al. (1995) for North America and Perez-Garcia et al. (1997) for the world examined the effects of climate change on the world's forest products economy using the terrestrial ecosystem model (Melillo et al. 1993) to link ecological change to actual vegetation. The general results show that as primary production increases, timber becomes more abundant, prices fall, and consumption increases. Major timber producers such as the United States and Canada received small positive economic gains from forestry changes. This work also indicates the differences among those particular climate scenarios tend to be small, except in southeast Asia and Oceania for hardwoods, and the northern regions for softwoods. Both studies show that production shifts and changes in trade patterns tend to dampen the effects of climate change in the forest sector. Several studies used variations of the TAMM/ATLAS model structure. For example, Callaway et al. (1994) showed that under a climate of doubled atmospheric carbon dioxide, harvests could be shifted over time, along with changes in tree planting investment, as part of the dynamic adjustment of markets and capital stocks. Haynes et al. (1994) focused on various mitigation strategies that are often suggested for using forests for carbon sequestration. Sohngen and Mendelsohn's (1998) model using a spatial equilibrium structure reduced from some of the relationships in TAMM/ATLAS, focused more on the dynamic adjustment pathway than these earlier studies. They found that markets will mitigate, and even reverse, CO_2 fluxes in contrast to natural response models. Finally, Burton et al. (1997) used a variant of FASOM to look at three scenarios of extreme growth-rate change induced by global climate change and found that impacts are felt more strongly by producers than consumers, and more by southern producers than producers in other regions.

Several unique gaps or opportunities are apparent from this array of applications of different approaches to forest sector modeling. First, most of these systems depend on forest inventory/resource models to provide exogenous variables in stumpage supply relations. These resource models are invariably based on actual (or current) forest vegetation types and extents that reflect exten-

[1] A forest sector model, in general, combines activities related to the use of wood: forest growth and harvest; the manufacture of pulp, paper, and solid wood products; and international trade and intermediate and final consumption of these products (Kallio et al. 1987).

[2] Hereafter called TAMM/ATLAS.

sive human modifications. Integrating economic and ecological models requires some means to relate actual vegetation to the projected changes in potential vegetation that result from process-based ecological models. Several of the applications above used the terrestrial ecosystem model (Melillio et al. 1993) as one such linking device. Second, most of the models described above have not addressed in detail the reallocation of land between forest and agricultural sectors if productivity is impacted by global climate change. Landowners continually consider shifts in land use between agricultural crops and forest, and shifts within forestland among different intensities of land management, some of which involve shifting from lower value to higher value tree species. In addition, there is the concern about land conversion to developed uses. A third set of opportunities involve consideration of the propensity for persistent change in the levels and types of human demands for various forest goods and services.

Comparison of Model Structures

The Timber Assessment Market Model (TAMM)

The TAMM system is one of the best known examples of what are termed forest sector models. Since its inception in the late 1970s, this system of models has undergone a number of extensions and revisions designed to improve the realism of its projections and the utility of its output to resource analysts and policy makers. Details about TAMM projections and underlying assumptions are described in detail in the 1989 USDA Forest Service RPA Timber Assessment (Haynes 1990) and 1993 RPA Timber Assessment Update (Haynes et al. 1995). TAMM is a bioeconomic model that provides an integrated structure for considering the behavior of regional prices, consumption, and production in both stumpage and solidwood product markets and incorporates a bilaterally linked model of timber resources and timber supply. In its current form it includes the North American Pulp and Paper Model (NAPAP) for paper products and ATLAS to model timber resources.

NAPAP (see Ince 1994) uses linear programming to solve for market equilibrium in spatially specific markets. It includes regional supply functions for pulpwood and recovered paper (recycling), and a detailed representation of production capacity and supply for all principal grades of market pulp, paper, and paperboard, in five North American production regions. The model also includes demand functions for all end products, with separate demand functions for U.S. domestic demand, Canadian domestic demand, and demand from various trading regions for export from the United States and Canada.

ATLAS (Mills and Kincaid 1992) is used as an inventory projection system and estimates of available timber inventory are used in the timber supply relations for each region and owner. ATLAS was developed to model timber inventories at subregional, regional, and national scales using timberland inventory data collected by the various USDA Forest Service Forest Inventory and Analysis Units (FIA). The data are stratified and aggregated by species group (forest type), site productivity, and expected management class. Growth and yield models are estimated representing a broad mix of conditions and management intentions. In each simulation period, inventory change is the result of growth, area change, and harvest. The area adjustment is derived from projections by area models (see Alig 1985; Alig et al. 1990).

Forest and Agriculture Sector Optimization Model (FASOM)

The Forest and Agriculture Sector Optimization Model (FASOM) was originally developed for the U.S. Environmental Protection Agency to estimate the market impacts of carbon sequestration options for both the agriculture and forest sectors (Alig et al. 1997). Unlike TAMM, FASOM is a price-endogenous quasi spatial multi-period equilibrium model. Its objective function maximizes the discounted economic welfare of producers' and consumers' surpluses in the U.S. agriculture and forest sectors over a finite time horizon. FASOM operates on a decadal time step, with projections made for 10 decades; however, policy analysis is limited to results for the 50 year period from 1990 to 2040. FASOM employs a single national demand region for forest products, which treats only the log market portion of the sector. The nine U.S. timber supply regions are similar to TAMM regions, except for combining the Northern and Southern Rocky Mountain regions and separating the "Corn Belt" and "Lake States" portions of the North Central region because of their agricultural importance. Private timberland in FASOM represents a reaggregation of the ATLAS model; the strata are differentiated by: 1) class of ownership (forest industry and nonindustrial); 2) forest type (four classes describing species composition, either softwoods or hardwoods, in the current and preceding rotation); 3) site productivity (three levels of potential for wood volume growth); 4) management intensity (four discrete timber management regimes); 5) suitability for transfer to or from agricultural use (four land suitability classes for crop or pasture plus a "forest only" class that cannot shift use); and 6) 10-year age class (ten).

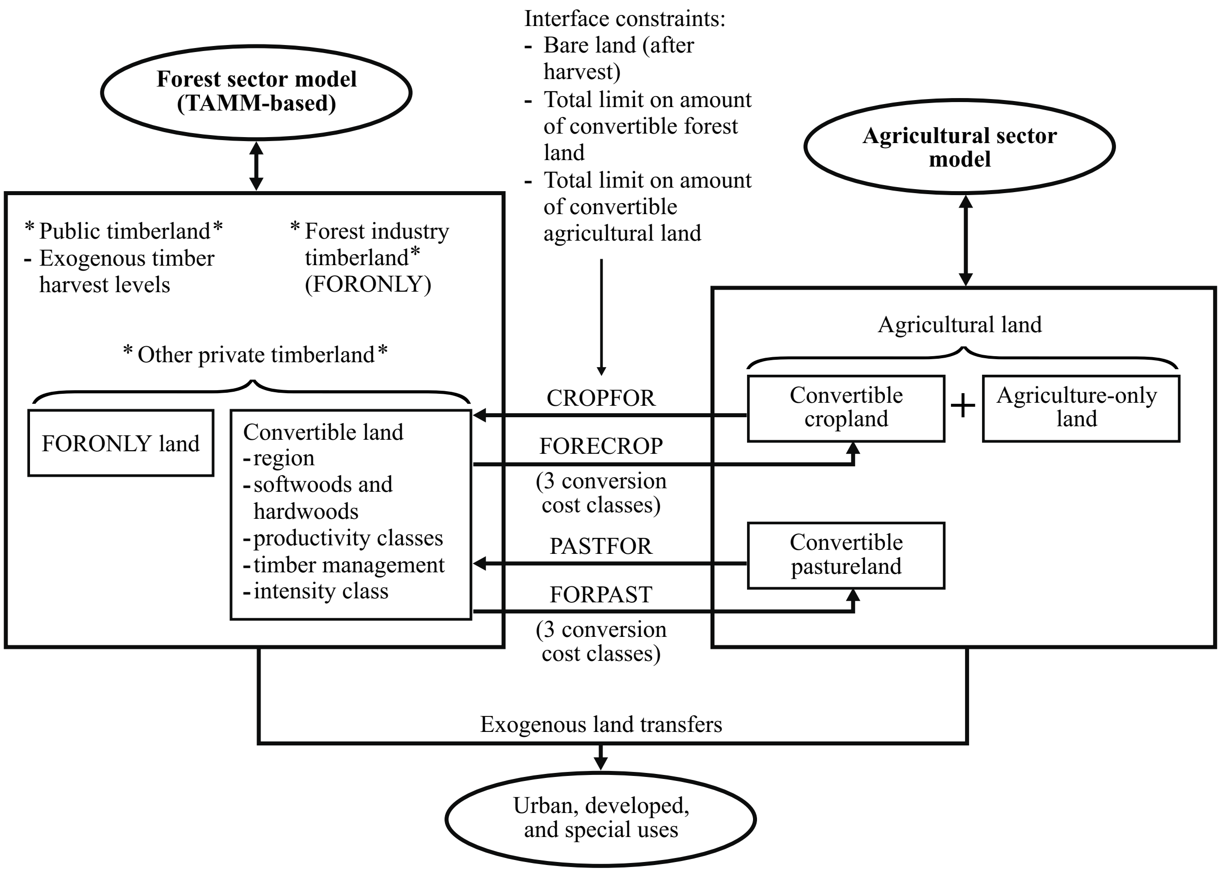

Figure 4.1—Linkage of forestry and agriculture sectors in FASOM.

Endogenous variables include: 1) timber harvests and log prices for nine U.S. regions, two species groups, and three classes of products (sawtimber, pulpwood, and fuelwood); 2) timber management investment activity for two private owner groups (forest industry and other private); 3) agricultural prices and production in 11 regions for 50 primary and 56 secondary commodities; and 4) the amounts of land used in, and transferred between, the two sectors. All exogenous forestry elements of the model are held constant after the fifth decade. The model values terminal inventories (at the end of the finite projection period) in both sectors assuming perpetual, steady state management following the terminal year of the explicit time horizon (Adams et al. 1996a).

The agriculture sector in FASOM is adapted from the Agricultural Sector Model (ASM)[3], aggregated to regions matching those in the forestry sector. ASM is a spatial price-endogenous agricultural sector model (Chang et al. 1992), with constant elasticity curves used to represent domestic consumption and export demands as well as input and import supplies. ASM was originally constructed as an essentially timeless, long-run equilibrium model. To link ASM with the decade cycles in FASOM and the forest sector, where market interventions may take several decades to play out, the model was converted to an annual format. Updating between decades was accomplished using projected growth rates in crop yields, domestic demand, exports, imports, and cropland availability.

One real strength of FASOM is the links between land inventories in the agricultural and forest sectors (fig. 4.1). Suitable land can move, at any time, between agricultural and forest uses, based on considerations of inter-temporal profitability and subject to the availability of resources and the specific provisions of particular policies.[4] The planning problem simulated in FASOM allows landowners to foresee the profitability consequences of all the pos-

[3] The Agricultural Sector Model (ASM) is described by McCarl, B. C.; Chang, J. Atwood; Nayda. W. in "The U.S. Agriculture Sector Model." On file with the Social and Economics Values Program, Forestry Sciences Laboratory, Pacific Northwest Station, 3200 S.W. Jefferson Way, Corvallis, OR 97331.

[4] Rising relative prices for urban and developed uses, at the top of the economic hierarchy of land use, prompt exogenous shifts of forest and agricultural land to urban/developed uses, by region each period, along with some timberland reclassified to reserved uses (Alig et al. 1990; Alig and Wear 1992).

Table 4.1—Component parts of contemporary forest sector models.

Model component	Type of variable	Process model/function
Product demand	Prices, macro economic variables	New product diffusion
Product supply	Costs, capacity levels	Capacity adjustment
Stumpage demand	Conversion factors	Materials balance relationships
Stumpage supply	Prices, inventory attributes	Resource projection system (ATLAS)
Land use changes	Land prices, land types	Area-change projection system

sible agricultural and forest uses of their land over time. Through the land type classes, hectares of nonindustrial private timberland that could be converted to cropland and pastureland and also agricultural land that could be shifted into forestry can be identified. Estimates of the area of convertible forestland are from USDA estimates of forestland with medium or high potential for conversion to crop or pasture use; area estimates for convertible agricultural land are drawn from Moulton and Richards' (1990) study of land suitable for tree planting.

TAMM and FASOM Comparison

The TAMM and FASOM models complement each other, and they are related in several important ways (Alig and Adams 1996). Both models contain representations for the various component parts of contemporary forest sector models (see table 4.1). As discussed in this chapter, these representations vary between the two models. Externally, the models have some common links, but internally the models offer different solution mechanisms. In brief, both models embody the four key components of timber supply modeling systems identified by Alig et al. (1984): land allocation, growth and yield projections, harvest flows, and forest management investment.

In terms of some of the model components illustrated in table 4.1 there are differences between TAMM and FASOM. TAMM deals relatively explicitly with the first four model components by treating land use changes as an exogenous process. FASOM focuses on the stumpage market (especially the last two components), relying on TAMM/ATLAS for product market detail that is collapsed to a set of derived demand relationships for logs aggregated at the national level. In the case of both models, the approach to estimating demand considers demographic and economic variables, including population growth, housing starts, household formation and size, and technology improvements—all of which are derived from other models and economic forecasts.

An important distinction is the solution algorithm used to simulate market behavior. The solution of TAMM represents a spatial equilibrium in the markets modeled for each year of the projection period. A spatial equilibrium model solves for equilibrium between price and quantity simultaneously in multiple spatially distinct markets at two different market levels. These solutions represent production, consumption, and price time paths that are estimates of outcomes of contemporaneous interactions in freely competitive markets. FASOM solves for equilibrium in the stumpage/log market recognizing spatially distinct timber supply regions. It differs from TAMM in that it also solves for the intertemporal equilibrium. That is, landowners make investment decisions guided by exact knowledge of future prices and harvest levels.

In terms of the resource situation, both TAMM and FASOM share the same base inventory and provide explicit treatment of actual vegetation attributes for 145 million hectares of U.S. private timberlands. Using actual types facilitates analyzing the combination of bio-physical, ecological, and socioeconomic forces that influence the amount of land allocated to major land uses and forest cover types in the United States.

In both models the timberland base is adjusted over time for the movement of land between forest (timber production) and non-forest (including, agricultural, urban, and reserved) uses. In TAMM, land allocation is exogenous, provided by models of land use changes that assume landowners are present value (quasi-rent) maximizers in allocating land to alternative uses (e.g., Alig 1985). Examples are usually cast in the context of two primary competing uses, but in most cases methods can be readily extended to multiple uses. Systems of equations describe the major land uses (Alig 1986). In FASOM this forestry-agriculture land use margin is endogenous. In both models, when timberland shifts to a non-forest use a portion of the timber volume is often harvested and counted in the current aggregate cut from the stratum. This reflects the process of land clearing or volume reduction associated with most land use changes in the private sector (Alig et al. 1990).

The investments are associated with various timber management practices. The yield regimes derived for the ATLAS model are used in both models. Some of these are empirically based (based in part on the regional FIA survey plots, Powell et al. 1993), while others are products of specific stand models. Assignment of areas to management intensity classes (MICs) are based on data derived from field measurements and judgments of USDA Forest Service inventory analysts and experts in industry and other groups. A MIC is defined by a combination of silvicultural activities including, but not limited to, improved regeneration, stocking control, commercial thinning, and fertilization. Land can shift among MICs over time to reflect changes in timber management investment. This investment is treated as exogenous in TAMM/ATLAS, where a schedule of management treatments is developed for all private lands considered in the ATLAS projection. This schedule is based on current expectations but is not sensitive to endogenous price changes or projected market elements (though it may be changed through considerations of model outcomes). In FASOM, the investment actions are part of the solution. The extent and timing of the MIC shifts represent an optimal solution based on the "perfect knowledge" of future markets.

Results

Both TAMM and FASOM have been used in the context of scenario planning to examine a wide range of alternative scenarios related to the role of forestry in climate change. In this section we describe generalized results for several of these scenarios. TAMM was used to examine the effect of increased atmospheric carbon dioxide on the timber situation in the United States and it has also been used to examine the use of various forest policies to mitigate global climate change, but that work is discussed elsewhere (see Chapter 8, and Haynes et al. 1994).

FASOM has been used to examine several alternative futures of increased forest carbon sequestration. The FASOM results about mitigation options are summarized in Chapter 8.

Climate Change and Forest Productivity—TAMM

TAMM/ATLAS has been run for scenarios where forest productivity was sensitive to climate change (for details see Joyce 1995). The nature of the prospective climate change was a doubling of atmospheric carbon dioxide by the year 2065. A biogeochemistry model (TEM) was used in conjunction with general circulation models (GCMs) to project changes in forest net primary productivity (NPP). A key assumption was that changes in annual NPP of potential vegetation were proportional to annual changes in the rate of projected forest growth. These changes were applied to the forest types in ATLAS, effectively linking a biogeochemistry model to a forest sector model.

Results from the baseline projections of the 1993 RPA Timber Assessment (Haynes et al. 1995) were compared with three scenarios depicting a maximum, mean, and minimum set of changes in NPP. With the exception of a negative impact on Southern hardwoods in the minimum projections, the change in NPP was positive for all forest types in all regions. In total, the projected increases in NPP far outweighed declines. This set of scenarios increased forest growth over all regions, which led to a 3 and 22 percent increase in inventory on private lands (13 to 112 billion cubic feet above the base). Where the RPA baseline projections showed declines, the climate change scenarios show increases.

One fundamental result from the TAMM/ATLAS simulations has been to show how increases in growth eventually impacts levels of harvest. Growth accumulates as inventory volume, leading to increases in the timber available for harvest; there is a market price response; and there is an increase in the harvest. But not only is this increase in harvest a lagged response, the magnitude of the increase indicates a relatively small consumer response to lower lumber prices. Demand for solidwood products is derived from consumption of houses, other types of buildings, and a wide range of consumer and industrial products. Demand for paper is primarily influenced by overall economic growth. In both cases downward changes in wood prices (or fiber in the case of paper) represent only a small proportion of total production costs. This is a significant result and it is consistent with work referenced earlier that studied the market impacts of acid rain and atmospheric ozone. These applications illustrated two important features of TAMM: first, the explicit temporal structure detailed the relatively long lag between changes in net growth and eventual changes in harvests and attendant economic impacts; and second, TAMM's explicit treatment of both stumpage and product markets allows for empirical estimation of producer and consumer surplus measures that follow the usual economic conventions (for both product and factor markets).

TAMM/ATLAS has also helped shape perceptions that with a change in available supplies of harvestable inventories, there is a shift of harvest both among and within regions as product production adjusts to take advantage of lower cost raw materials in some regions. Shifts occur between fiber types and between ownership classes. Under the TEM scenarios there is a higher overall supply of softwoods and lower prices. Harvest then shifts toward the industry ownership. In most regions, capacity increases and the harvest expands faster on industry land than it does on nonindustrial timberlands. In the Pacific Coast, the nonindustrial harvest declines under all three scenarios. Many of these changes are stimulated by changes in stumpage prices, which relative to softwood sawtimber stumpage prices in the RPA base projection (that follow an upward sloping path to 2040), these new projections show a leveling of prices by 2015 and then prices begin to decline and by 2040 drop below levels predicted for 1995.

This past work also showed the importance of trade, in that without a change in market demand or a change in Canadian inventories, domestic harvest replaces Canadian harvest. Imports of Canadian lumber decrease both in total volume and as a percent of the market. Cheaper U.S. raw material has both increased lumber consumption and made the Canadian lumber less competitive. Without explicitly modeling Canada's resource sector, it is difficult to say how a change in Canadian productivity would affect the level of U.S. imports.

Climate Change and Forest Productivity—FASOM

The FASOM framework has been used as a platform for investigating implications of increased forest carbon sequestration (Alig et al. 1997, 1998; Adams et al. 1999), constraints on available funds for forest investment by private owners (Alig et al. 1999; Adams et al. 1998), biomass analyses and natural resource policies (Alig et al. 1997). Investigating the sensitivity of FASOM projections to a range of different assumptions offers a unique perspective, particularly where policy makers are concerned with linkages between forestry and agriculture and with both economic and environmental consequences of different policy alternatives (e.g., information on future non-timber resource conditions, such as wildlife habitat, Alig et al. 1998).

The FASOM model was applied to examine the dimensions of economic impacts due to hypothetical biological responses to global climate change (Burton et al. 1995). This exploratory study considered eight possible scenarios for global climate change effects. They were designed as an attempt to dimension the potential impact of climate change. The first four climate/biological response scenarios evaluate the effects of across-the-board changes in tree growth rates, or yield, for each decade. The first scenario postulates an increase of 5 percent in tree growth rates everywhere in the United States. The second postulates an across-the-board decrease in growth rates of 5 percent. Two scenarios consider national growth rate changes of plus 10 percent and minus 10 percent.

In addition, two scenarios explore the different effects from increased warming at different latitudes in the United States. The warming, coupled with a slight decline in precipitation, may negatively impact timber yields in the southern United States. At the same time, yields in the northern United States may rise. Therefore, a pair of southern decline scenarios were constructed. One postulates a 5 percent decline in yield in the South, a 5 percent increase in the North, and no change in other regions. A second southern decline scenario explores the impact of a 10 percent decrease in the South, a 10-percent increase in the North, and no change in other regions. The baseline case is similar to that described by Haynes et al. (1995) for the 1993 RPA Assessment Update.

McCarl et al. (2000) have since developed response functions that represent a wide range of scenarios for the biological response of forests to climate change, ranging from small to large changes in forest growth rates. The response functions are used to characterize broad impacts of climate change on the forest sector. Aggregate impacts (across all consumers and producers in society) are relatively small but that producers income and future welfare 30–40 years in the future are most at risk.

The FASOM model projected characteristics of forest products production, price levels, timber management changes, land transfers, and economic welfare effects.[5] The results of the exploratory study indicate that market responses to climate change will vary by region. If yields increase nationally, the North can produce relatively more forest products. If yields decrease nationally, the South can produce relatively more. If yields in the South decrease, while they rise in the North, production of forest products is projected to shift away from the South. If stand establishment costs rise in the South, production may also shift away from the South.

Changes in timber producer and consumer prices under the climate change scenarios relative to the base scenario are fairly small in magnitude. When southern costs of timber production rise, timber price levels increase more substantially than in other scenarios.

The economic welfare impact of the global climate change scenarios is small—less than a 1 percent change from the base scenario across all eight hypothetical cases. In general, when yields rise, consumers gain. When yields fall or costs rise, producers gain. In FASOM any change in future conditions is optimally anticipated (from a net social welfare viewpoint) and investment is freely flexible to vary over time. A representation of "real world" behavior would doubtless be somewhat less adaptable, recognizing limitations of the decision maker. The structure of the present model has been modified to examine some of these questions of "stickiness" in product and capital markets (Alig et al. 1999; Adams et al. 1998), including limits on investment borrowing or capital budgets, increasing marginal costs of borrowing, and uncertainty regarding future market conditions. The FASOM results in the investments case are closer to those projected by the TAMM model for comparable scenarios. Use of both the TAMM and FASOM models reveals the differences between: 1) likely future paths for the forest sector if historical relationships between key variables continue; versus 2) production possibilities and optimal responses to external events (e.g., climate change) and policies. FASOM assumes perfect foresight and optimal adjust-

[5] *Global change mitigation analyses using the FASOM model are discussed in chapter 8 of this report.*

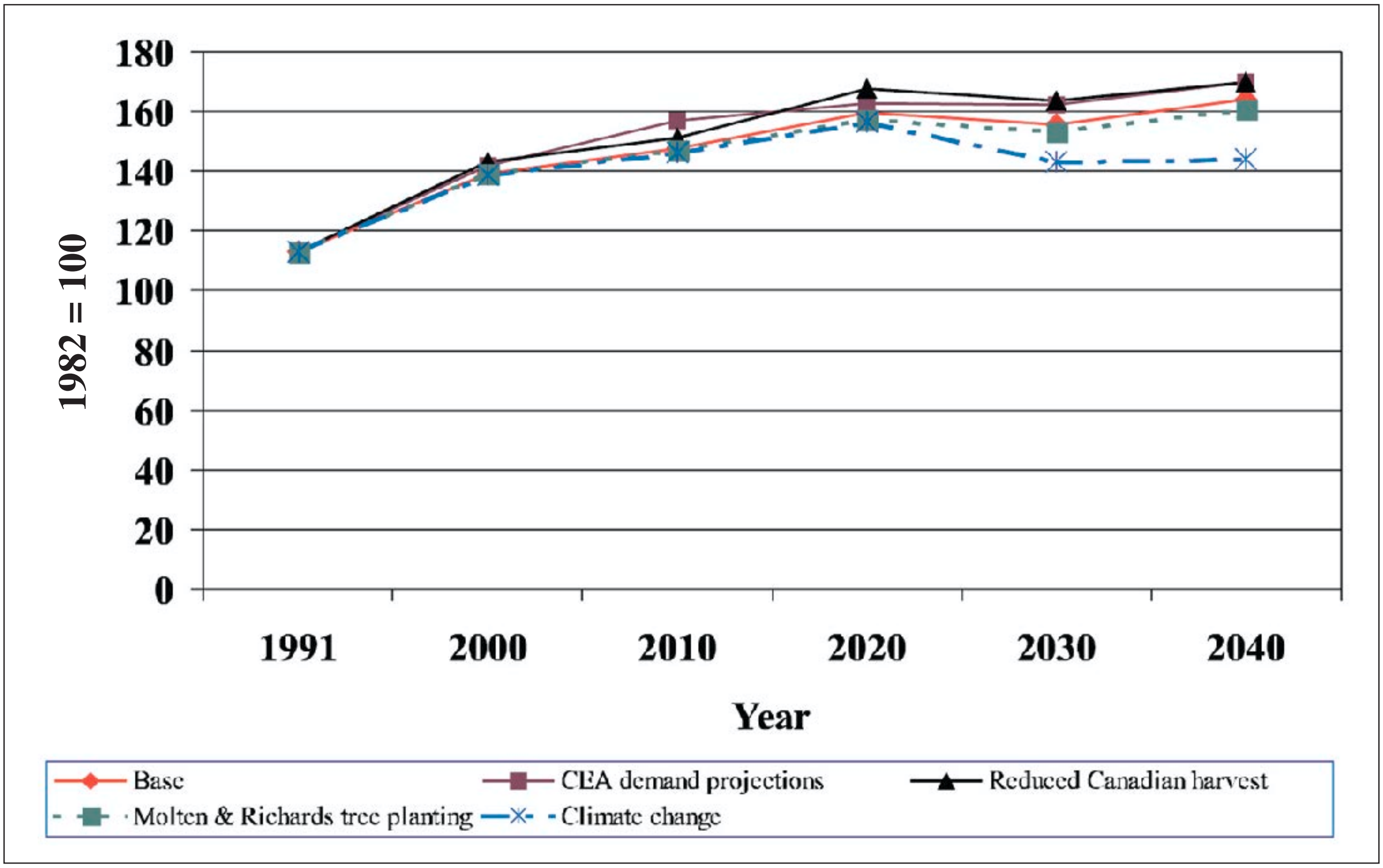

Figure 4.2—Softwood lumber price index under different views of the future including one prospective view of climate change. (The CEA projection represents the results from an alternative macro economic forecast developed by the Council of Economic Advisers in 1994.) Source: Haynes et al. 1995.

ments in the unfettered case. As such it shows a greater shift to pine plantations, and as timber prices fall, an increase in land moving from forest to agriculture and a decrease of investment in pine plantations.

With FASOM having all four key timber supply modeling elements as endogenous components, a different set of projected adjustments (both temporally and across regions) are possible than with TAMM. A range of adjustments is discussed in Chapter 8, where analyses of global change mitigation strategies using the FASOM model are reviewed.

Model Uncertainties

These two forest sector models are useful in developing a portfolio of possible impacts of human uses (in a commodity sense) on forests under climate change. Such factors are not normally considered with most climate change simulation models. They show how and the extent that climate-change influences on U.S. timberlands will be mitigated by market feedbacks between the natural resource base and the production and consumption of forest products. This helps place the issue in context. As shown in figure 4.2, the prospective impacts on the U.S. forest sector of one view of global climate change is overshadowed in the near term by other contemporary policy concerns such as habitat conservation strategies that involve reductions of timber harvest on federal timberlands in the west (e.g. Adams et al. 1996b). This raises questions about the timing of the often cited prospective catastrophic ecological declines associated with climate change and the accompanying specter of economic dislocation within the U.S. forest sector. This scenario needs to be examined in light of the extent and speed of changes induced by price signals from timber markets. That is, to what extent will the expectations of lower prices in the future associated with climate-change reduce land management actions taken in the next decade?

Like all views of the future, those discussed in this chapter are highly dependent on the underlying assumptions, including model form. An ideal system can vary with the policy analysis needs, but a truly ideal system is not possible because of limited resources and data gaps. Projections of timber markets require assumptions concerning future: 1) product demand, which is largely based on projected population and employment; 2) capacity, which is dependent on flexibility in location of production and profitability; and 3) available timber inventory, which is dependent on area in timberland, and minimum standards for tree size (age) by owner and fiber type. Challenges also arise related to the scale of the analysis. For example, the timber inventory modeling assumes a broad range of habitats and species can be aggregated into forest types across large regions. At this level the changes in inventory did not recognize the potential responses that might be associated with individuals in the system or how adaptive forest management regimes might affect those individuals. Assumptions are made in averaging over the range of variability in ecological relationships associated with temperature changes, rainfall patterns, nutrient cycling, and thresholds in growth or site carrying capacity related to the ability of ecosystems to adapt to change. Additionally, changing vegetation patterns are assumed not to influence climatic conditions.

Though these models accounted for harvest and importation of wood products from Canada, they did not account for climate induced changes in Canadian inventories. Melillo et al. (1993) found that the higher latitude forests experienced increases in productivity at least equal to those of the Northern United States. This result would likely lead to a possibly higher import level than previously considered.

Other assumptions need to address the context surrounding forest sector issues. For example, worldwide assessments of human influence should incorporate differences in likely use of forest resources. Specifically, developing countries tend to view forests as a source of food and fuel whereas in North America forests are viewed as a source of industrial wood products and a range of amenities.

Finally, U.S. product markets have grown 72 percent (1.4 percent per year) over the past four decades while at the same time forest resources have grown 28 percent. In the next five decades we expect slowing in the growth of consumption and in forest resources (Haynes et al. 1995). Prospective changes in prices signal changes in tastes, industry location, and incentives to landowners, all of which act to mitigate potential impacts of climate change. Two important concepts to consider when developing assessments of forests with respect to climate change are: 1) include effects of humans as the most adaptable component of the system; and 2) make clear distinctions between science and policy (or politics).

Ongoing Work

There have also been efforts to broaden the examination of the timber sector under climate change by linking TAMM with a biogeography model known as Mapped Atmosphere-Plant-Soil System (MAPSS; Neilson 1995). (See Chapter 2 for a more comprehensive description of biogeography models and MAPSS.) To date, we took a linkage approach opposite that used with TEM. The ATLAS timberland inventories were translated and then reaggregated into the physiognomic vegetation types projected by MAPSS. This allowed ATLAS to simulate simultaneous changes in cover type and forest productivity in terms of MAPSS.

Difficulties arose when we attempted to match the RPA base projection in terms of the physiognomic cover types. The MAPSS types were broader, including multiple forest types. The type transition and land area shifts already in the base projection had to be preserved so as not to lose the growth and harvest interaction at finer scales. Further difficulty arose when ATLAS could not match the hardwood and softwood aggregation required by TAMM. The new vegetation types cut across the traditional softwood and hardwood categories in which the forest types fit. Time and expertise have not been available to reprogram the TAMM/ATLAS model linkages. It is assumed that in all likelihood, large shifts in vegetation and productivity projected under some scenarios would require significant recalibration of the economic side of the model. The project remains a significant research challenge for the future.

Conclusions

Both TAMM and FASOM are affiliated models that share many common features and present similar views of the relationship between forests and atmospheric issues. Both help to place prospective atmospheric issues, concerns about ecological change associated with climate change, and concerns about the effectiveness of various mitigation measures in context. Both models challenge ecologists and policy analysts to be explicit in the size, location, and timing of various impacts and to consider the transition from current vegetation and to gauge the tradeoffs between near term policy concerns and long-term ecological impacts. While not explicitly addressed elsewhere, both models offer a common framework for integrating biophysical and social systems and for tracing how changes in typically biophysical attributes (growth, area of certain types, etc.) affect various measures of economic benefits and costs. In that role these models operate at the interface of science and policy where the emphasis is on how models themselves improve the information available for decision makers. That same information from the policy perspective helps shape perceptions about the effectiveness of various management actions.

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