

**Projecting Impacts of Global Climate Change on the U.S. Forest and Agriculture
Sectors and Carbon Budgets**

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ABSTRACT

A multiperiod, regional, mathematical programming economic model is used to evaluate the potential economic impacts of global climatic change scenarios on the U.S. forest and agricultural sectors, including impacts on carbon budgets. Four scenarios for the biological response of forests to climate change are based on combinations of global circulation and ecological process models, reflected by changes in forest growth rates. These scenarios are simulated in the forest and agricultural sector model and results are summarized to characterize broad impacts of climate change on the sectors. We find that less cropland is projected to be converted to forests, forest inventories generally increase, and that aggregate economic impacts (across all consumers and producers in the sector) are relatively small. Producers income is most at risk, and impacts of global climate change on the two sectors vary over the 100-year projection period. The forest sector is found to have adjustment mechanisms that mitigate climate change impacts, including interregional migration of production, substitution in consumption, and altered stand management.

Projecting Impacts of Global Climate Change on the U.S. Forest and Agriculture Sectors and Carbon Budgets

INTRODUCTION

Global climate change induced by anthropogenic release of greenhouse gases, mainly CO₂, is perceived by some as one of the greatest environmental challenges the world faces today. The specter of possible deleterious effects of climate change on agricultural and forest productivity has been raised. A significant amount of international discussion on how to reduce and mitigate the greenhouse gases released into the atmosphere by industrial emissions and land management practices involves sequestration of CO₂ in the biomass of forests as one of the options. If global climate change can modify the growth and geographic distribution of U.S. forests, the biological effects of climate change *on* forests also need to be considered along with the effects of forest-sector based adaptation actions on climate change. The present study investigates the simultaneous potential economic impacts within the forest and agricultural sectors due to alterations in forest growth arising under different global climate change scenarios,¹ including producer and consumer welfare, prices, and land-use changes.

We employ a dynamic model of the U.S. forest and agriculture sectors (FASOM as described in Adams et al. (1996, 1997) and Alig et al. (1998)) that simulates

¹This analysis is part of the ongoing National Climate Change Assessment by the U.S. government and cooperators. The national assessment is examining impacts of possible climate change by sector and region of the United States (e.g., U.S. Forest Sector Team (2000)).

agricultural and timber market behavior and resource management responses in both sectors. Given the considerable uncertainty about the biological impact of global change on forests (e.g., Mendolson and Sohngen 1998), we examine four scenarios based on combinations of projections from global circulation and ecological process models. The following sections of this paper describe problem background, prior studies, methods employed to estimate the impacts on forestry and agriculture, and then results and discussion.

FOREST RESOURCE AND PRODUCT MARKET IMPACTS OF CLIMATE CHANGE

Shifts in global climatic conditions would affect crop and tree growing conditions, but the nature of the altered climate could vary substantially by region. The ecological and economic importance of forests varies across the nation, as do growing conditions and the importance of agriculture. For example, in the southern United States, much of the forest is managed for pulpwood and lumber production, while recreational use is more important in midwestern forests in a region dominated by agriculture. Further, because climate change is global in nature and a considerable portion of U.S. softwood timber consumption is produced in Canada (30% of softwoods), the implications of climate change for harvest in Canada must also be recognized.

In addition to ecological and economic considerations, forests and soils may be important sinks of atmospheric carbon dioxide. Impacts on agriculture and forests arise from increases in atmospheric CO₂ concentration, change in temperature regimes, and variations in patterns of rainfall over the year. Such shifts could alter basic physiological

processes in crops, trees, and soils, influencing growth and the yield of commercial products over time. The actual time pattern of change will be complex, owing to lags between atmospheric changes, climate effects, and biological responses. Economic impacts resulting from growth changes will be further delayed due to the length of forestry rotations, generally involving two or more decades.² Thus, an examination of the effects of climate change on agriculture and forests needs to consider forest rotation decisions as well as lags between the onset of climate change and resulting biological impacts. These dynamic aspects of climate-induced changes in yields need to be addressed with a model that recognizes the temporal characteristics of both product markets and the agriculture and forest resources.

Climate change may alter the quantities of agricultural and forest products harvested in a substantial fashion. This will necessitate some resource management changes and may stimulate social and economic processes of adaptation. Differential impacts of climate change on the two sectors could lead to land use shifts as one possible adaptation strategy. For example, if climate-influenced growth impacts result in relatively higher agricultural productivity per hectare, some hectares may be converted from forests to agricultural use. In regions where climatic effects reduce growth, smaller volumes will be available for harvest in both existing forest stands and in those replanted after harvest in the future. The reverse would be true in regions experiencing increased growth. Such changes would alter the supply of products to national and international markets, changing the prices of forest products and the economic well-

²A forest rotation or age is the length of time that trees are grown from natural regeneration or planting to final harvest.

being of both consumers and producers of these products. Consumers, in turn, will shift their patterns of consumption between forest and non-forest products. Producers will change both the types of management they practice (planting, thinning, and other cultural treatments) and the ages at which they harvest trees in various ways, depending on the nature of the owner (private or public).

The difference between climate change effects on existing trees and trees planted in the future bears further emphasis. Existing trees will be affected only in their incremental growth from the current period to harvest age as climate change occurs. Trees planted in the future will grow entirely in an environment with altered climate. Thus, growth rate responses must differ for existing and future trees. For existing trees, current volume will remain unchanged³ but future incremental growth may vary. For new trees, the entire future time path of volume growth and product yield may be altered. Landowner options to shift land uses also brings in temporal differences between the forest and agriculture sectors with respect to lead time required to respond and shift production. With agricultural rotations typically of one to several years, that provides more flexibility relative to forestry. This affects the likely mix of afforestation, reforestation, and deforestation under different global climate change scenarios for forest industry and nonindustrial private owners that tend to have notably different land management objectives (Alig et al. 1990).

PAST STUDIES OF THE TERRESTRIAL EFFECTS OF CLIMATE CHANGE

³Forest fire risk may increase in some areas according to some studies (e.g., Sohngen and Haynes 1999).

Several studies have explored climate change implications for the agricultural sector (e.g. Adams et al. 1990, 1999; Kane et al. 1992; or others as reviewed in Adams et al. 1998 and Lewandrowski and Schimmelpfennig 1999). In forestry, longer rotation lengths complicate development of data on biological responses to global warming (Sohngen and Alig 2000). Comprehensive long term experiments have not been completed on how trees behave when exposed to alternative climates or CO₂ levels, nor can analyses of existing forests be used with confidence because CO₂ levels associated with future climate change have not been observed. Also little is known about how experimental results on individual trees generalize to stand, forest, and regional levels.

Investigators have simulated climate effects on the distribution and productivity of forests using three different types of models.

Biogeochemistry models which simulate the gain, loss and internal cycling of carbon, nutrients, and water. With these models, the impact of changes in temperature, precipitation, soil moisture, atmospheric carbon dioxide, and other climate-related factors can be examined for their influence on such processes as ecosystem productivity and carbon storage.

Biogeographic models which examine the influence of climate on the geographic distribution of plant species or plant types such as trees, grasses, and shrubs.

Dynamic global vegetation models which integrate biogeochemical processes with dynamic changes in vegetation composition and distribution.

****** this does not fit**

An earlier analysis using biogeochemistry models and four climate scenarios (different from those in the national climate change assessment) showed increased net primary productivity at the continental scale (VEMAP members 1995) (this is not in the bibliography). Carbon storage results varied with the assumed sensitivity to changes in water availability.

Experimental and simulation evidence indicates that forest productivity increases with the fertilizing effect of atmospheric carbon dioxide (needs a reference). Across a wide range of scenarios, it is likely that modest warming could result in carbon storage gains in most forest ecosystems in the conterminous United States(Why???). Yet, under some warming scenarios, it is possible that drought-induced losses of carbon would occur in certain forests, notably in the Southeast and the Northwest (U.S. Forest Sector Team 2000)(this is not in the bibliography). The extent of these potential gains and losses of carbon will be affected by changing land-use patterns, such as the conversion of forests to other uses, and the reversion of other lands to forests.

Economics studies have examined potential impacts of climate change on the forest sector. van Kooten and Arthur (1989) concluded that the overall implications of climate change for economic welfare may be negative for Canada.⁴ Later van Kooten

⁴Economic welfare refers to the combination of producer profits and consumer well-being measured in monetary terms which results from the interaction of supply and demand in a market. Forces that shift demand and supply influence the overall level of welfare in the market and the distribution of welfare between producers and consumers.

(1990) examined 5% and 7.5% increases in Canadian harvests together with positive and negative changes of similar magnitudes for U.S. harvests concluding that consumers in both countries would benefit, but that producers would lose. He also concluded that the overall Canadian impact would be positive only if U.S. harvests declined. Perez-Garcia et al. (1997) assumed that climate change would stimulate increased net primary production and examined climate change effects on the world forest economy using a model that did not change land management patterns. They found increased timber supplies, falling timber prices, and rising consumption. Also major timber producers such as Canada realized a positive, but small, economic gain, while the United States benefitted under all scenarios examined.

Sohngen and Mendelsohn (1998) linked a dynamic model of U.S. timber markets with a large-scale biogeographic model. This application provided more information on the dynamic adjustment of markets and resources than the Perez-Garcia et al. (1997) study, although it also assumed a doubling of CO₂ to an equilibrium level that leads to steady-state biogeographical results. Similar to Perez-Garcia et al. (1997), Sohngen and Mendelsohn found that climate change expanded long run timber supply under all scenarios. Economic welfare effects were relatively small. The analysis suggests that human actions in markets can mitigate, and even reverse, resource production shifts induced by climate change (Sohngen et al. 1998).

Rather than drawing directly on growth change estimates derived from ecological models, Burton et al. (1994, 1998) considered hypothetical cases of extreme biological response, representing probable bounds on the range of forest response to stresses induced by global change. Their study used the FASOM model to look at three

scenarios of change in growth induced by global climate change: a 50% increase in decadal growth rates on timberland in both the U.S. North and South; a 50% decrease in both regions; and a 50% increase in the North and a 50% decrease in the South. Simulation results indicated that producers' impacts exceed those on consumers and that Southern producers are affected more than producers in other regions.

McCarl et al. (2000) expanded the approach of Burton et al. (1994) to develop a set of *response functions* predicting climate change implications across a broad range of possible forest growth effects. Results using the FASOM model indicated that aggregate sectoral welfare effects (consumers' savings plus producers' profits) are relatively limited even under extreme scenarios. There are more marked economic welfare shifts between producers and consumers. Yield increases induced by climate change were found to benefit consumers but not producers, while yield decreases have the opposite effect. The forest sector was also found to have adaptive adjustment characteristics, including regional (e.g., northerly) migration of production, substitution in consumption between wood and non-wood products and between sawtimber and pulpwood, and the ability to alter the intensity of forest management (rotation age and timber management regime) among owners and regions.

METHODS

Base Model for Simulating Forest Climate Change Effects

The FASOM (Forest and Agricultural Sector Optimization Model) model, as documented in Adams et al. (1996, 1997) and Alig et al. (1998)(**this is not in the bibliography**), was employed to derive projections of agriculture and forest sector production, prices, and welfare given a climate change scenario. FASOM is a dynamic optimization model of forest and agricultural markets. The FASOM model finds the market equilibrium for each period in a multiperiod time horizon, using nonlinear mathematical programming methods that maximize a measure of economic welfare in the two sectors. FASOM constructs an intertemporally optimal production/consumption pattern and associated prices for a 100-year projection. In the case of forestry, FASOM depicts the volume removed, area harvested, and forest management investment decisions for industrial and nonindustrial private forests, together with the consumption of timber products and market prices in the U.S. forest sector by major forest region. Products comprise fuelwood, sawtimber, and pulpwood for both softwood and hardwood species. Hectares harvested from public lands and the import supply of timber from Canada are assumed to be determined by forces outside the present analysis and are taken as exogenous input, although these volumes are likely to be affected by climate change.

The biological effects of climate change, as described by Joyce et al. (2000), are introduced in the analysis by modifying timber yields in FASOM(**shouldnt there be a reference to the data in the national assessment here**). The FASOM yields (volumes per unit area) vary by the age of the forest and an array of conditions that reflect the quality of the growing site. Let the total volume per unit area in a forest stand at the end

of year 1 be Y_1 , Y_2 in year 2, and Y_t in year t , and suppose we anticipate a *increase* in the growth rate of δ (for $0 \leq \delta \leq 1$) induced by climate change. Total volume in period 1 would be adjusted upward by δ . In all subsequent periods the volume at the end of the period would be the volume at the beginning of the period times one plus the *altered* growth rate. The altered growth rate is the original growth rate in the yield table, $(Y_t - Y_{t-1})/Y_{t-1}$, times one plus δ . A similar approach was used to treat existing stands. However, for a stand of trees that is $t-1$ years old at the beginning of the analysis, only the formula for a stand at age t is employed, treating Y_{t-1} as a constant and leaving the initial volume unchanged (McCarl et al. 2000)(**this is not in bibliography**).

Modifications were also made in public cut and Canadian import supply to reflect the impacts of climate change. Volumes from these sources were adjusted by the average percent change in harvest observed in comparable regions on private lands in the United States. To reduce the scope of the problem, we differentiate between growth changes in only two broad regions within the United States, North and South, for softwood and hardwood species.⁵ Because timber production is limited in the regions outside the southern and northern regions as here defined, we assume that the growth change in these other areas is the average of the changes in the North and South.

Timber Growth Scenario Projections and Results

⁵The North region includes the Pacific Northwest, Rocky Mountains, Lake States, Corn Belt, and Northeast. The South comprises the South East and South Central regions. The specific regional definitions are in Adams et al. (1996) and Adams et al (1997).

To investigate the outcomes under climate change scenarios, we simulate a base case (BASE) developed as a baseline for comparison. The BASE assumptions for the forest sector derive from the USDA Forest Service's 1993 Resources Planning Act Assessment Update (Haynes et al. 1995). Agriculture sector assumptions are discussed by Chang et al. (1992) and McCarl et al. (1993). Essentially all U.S. farm programs are eliminated in the BASE case, reflecting the Freedom to Farm legislation of the 1995 U.S. Farm Bill. By assumption, conversions of forests to urban and developed uses do not vary between the Base case and the four scenarios and are primarily driven by the projected addition of more than 200 million people in the United States over the next 100 years (Alig et al. 1999).

The four climate change scenarios are drawn from a national climate change assessment (U.S. Forest Sector Team 2000). The scenarios represent combinations of climate projections from two global circulation meteorological models (Canadian and Hadley) which in turn are fed into two ecological process models (Century and Terrestrial Ecosystem Model) to generate net primary productivity estimates⁶: 1) Canadian-Century; 2) Canadian-TEM, 3) Hadley-Century, and 4) Hadley-TEM. The analyses used an equilibrium climate scenario based on the transient Canadian and transient Hadley scenarios (U.S. Forest Sector Team 2000). The baseline scenario was the average climate for the 1961-1990 period, and the "climate change" scenario was the average of the projected climate for 2070 to 2100. Results from the global circulation and ecological models provided inputs into the FASOM model to evaluate the

⁶Citations for models

range of possible projected changes in forest land area, timber markets, and related consumer/producer impacts associated with climate change.

Examination of **the ecological model results? -- i am lost** suggest that forests will experience slight to moderate (5 to 30 percent) increases in forest productivity across the climate change scenarios (**how about a table and reference to the irland paper**). Although most of the climate scenarios suggest a generally more productive environment, certain regions may experience significant reductions (>20 percent) in forest productivity, especially if other stresses such as ozone impacts are included in the analysis. Compared to the Hadley scenario, the Canadian scenario is much warmer and generally drier, with some current forest area projected to have a drought-induced loss of carbon. In the national climate assessment, three biogeochemistry models (TEM, Century, and Biome-BGC) and one dynamic global vegetation model (MC1) showed increases in total live vegetation carbon storage under the Hadley scenario. Under the Canadian scenario, the biogeochemistry models all project increases in live vegetation carbon for all ecosystems (U.S. Forest Sector Team 2000). Results for live vegetation in all ecosystems and for live and dead vegetation in both forest and all ecosystems parallel these results.

Measures of the economic impacts include the net present value of economic welfare accruing to producers, consumers, foreign interests, and the total market (for example, see McCarl et al. 2000). The producers here are the private owners of forests in all regions of the United States who harvest timber for commercial products. Their economic welfare is measured by their profits in the sale of timber beyond their costs of

growing the trees and of foregone interest involved in waiting until they are mature. Consumers comprise all users of harvested timber (for housing, manufacturing, shipping, paper and board, etc.). Their welfare or benefit from the market transaction is measured as the difference between their expenditures if forced to pay the highest price they would be willing to pay to still consume timber and their actual payments at the equilibrium market price. This difference represents a “savings” or “surplus” to consumers. Foreign interests are exporters (suppliers) of timber to, and importers (consumers) of timber from, the United States. Their welfare arising from this trade is measured in essentially the same way as for domestic producers and consumers. The total market welfare is the sum of gains and losses realized by all the market participants (plus adjustments for receipts by public timber sellers and the costs of transporting timber from sources to users).

Sectoral Level RESULTS

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Economic Welfare

Economic analyses for several different climate scenarios indicate that an overall increase in forest productivity in the United States is likely to increase long-term timber inventory (figure 1), subject to other external forces. With more potential forest inventory, timber harvests in most scenarios rise over the next 100 years (figure 2), lowering timber prices (figure 3), and reducing costs of wood and paper products to

consumers and returns to owners of timberland. Total economic welfare is higher than the base case for all the climate change scenarios (Table 1).

The net effect on the economic welfare of participants in both timber and agricultural markets was projected to increase between 0.4 to 0.7 percent above the BASE projections (Table 1). Land would likely shift between forestry and agricultural uses as these economic sectors adjust to climate-induced changes in production (Table 2). Although U.S. total forest production generally is projected to increase in these analyses, hardwood output is higher in all scenarios while softwood output increases only under scenarios with moderate warming (figure 2). The extent of these changes varies by region. It is possible that timber output will increase more in the South than in the North, and sawtimber volume will rise more than pulpwood.

Area Changes

The four climate change scenarios are projected to lead to less forest area than under the BASE case as less agricultural land is converted to forest (Table 2). Under the Base case, the projected net land exchange from agriculture to forests is about one million hectares over the next 100 years. With global warming scenarios, the FASOM model has less cropland converted to forests, while more pasture land than under the BASE case is converted to forests. Positive forest productivity impacts on the existing forest base due to global climate change lower future prospective returns to new forest hectares and lessen the economic attractiveness of afforestation on cropland.

Opportunity costs of land use differ compared to the Base case. The reverse case of

conversion of forests to agriculture use is impacted significantly less than the afforestation pathways (Table 2).

Carbon storage

Impacts of the global change scenarios on carbon storage in U.S. forests varies over the projection period. For the next 20 years, the range of percentage changes is +0.1 percent to -0.2 percent across the four scenarios, relative to BASE levels. Between 2020-2050, the range shifts to -1.0 to -1.7 percent. With harvest levels generally increasing (figure 2), the 2020-2050 reduction in carbon storage is due to reductions in carbon stored in forest ecosystems, relative to BASE levels. Beyond 2050, carbon storage relative to the BASE levels increases, as associated forest inventories by 2100 are higher under all scenarios relative to the BASE (figure 1).

DISCUSSION

Our results are generally consistent with findings in other studies. Relatively small impacts are consistent also with the fact that the existing variation in climate and yields across the United States as a whole far exceeds the likely variation caused by climate change. Research in the agricultural sector (Adams et al. 1990, 1998, 1999; Lewandrowski and Schimmelpfennig 1999) has reached similar conclusions, suggesting that production shifts across regions and between producers and consumers may act to contain the aggregate impacts. The possibility of "migration" of forest production to

other regions also has a parallel in most agricultural studies. In the forest sector, growth in northern forest output is encouraged by higher sawtimber prices and results in longer sawtimber rotation ages, with higher volumes at harvest. Adaptation is also seen as changing product mixes, with sawtimber use gaining at the expense of pulpwood production.

This does not mean that there would be no “distributional impacts,” that is, shifts in economic well-being or welfare among the various groups participating in the market. Indeed, as discussed by McCarl et al. (2000), shifts between consumers and producers may be substantial. In our results, consumers’ and producers’ welfare effects are uniformly opposing. Producers’ welfare sensitivity is roughly 10 times (in percentage terms) that of consumers’ welfare, which in turn is roughly five times in percentage terms that of total societal welfare. When yields are reduced, producers’ welfare shows gains while consumers’ welfare shows losses. When yields increase, the opposite occurs. This is not surprising given that the demand for forest products is fairly inelastic (insensitive to price). In such circumstances (as has been found in agricultural markets), small percentage increments in output lead to larger percentage reductions in prices, which lowers producers’ welfare (profits) but increases consumers’ welfare (they can consume more at a lower price). Climate change may portend some major dislocations for producers causing widespread structural adjustment, if it stimulates higher yields. These findings are also generally consistent with results from earlier studies to the extent that they are comparable. For example, van Kooten (1990) found that the impacts on producers from yield increases were likely to be negative, while consumers were likely to benefit.

The McCarl et al. (2000) study also provided a view of economic welfare impacts over time. Both consumers' and producers' impacts expand over time as the growth changes persist (recall the compounding effects of growth change on yields), resulting in variable patterns of change in the aggregate. However, further in the future, assumptions about changes in population, land use, trade in wood products, consumption of wood products, recreation patterns and human values become highly uncertain. For example, if human needs from forests increase over the next 100 years and imports are limited, the socio-economic impacts of climate change on forests would be greater than if needs are low or products can be imported from areas where climate may increase forest growth. Thus, assumptions about change in human needs in the United States and overseas, and about climate change effects in other parts of the world, are likely to have some effect on socio-economic impacts on the United States.

One general conclusion from this and earlier studies one is that timber and wood product markets will adjust and adapt to climate change in ways that act to limit economic effects. The FASOM model used in this study suggests several forms of adaptation may be used in the forest sector, including changes in: a) land use choice, b) timber management intensity; c) hardwood/softwood species mix, d) timber growth and harvesting patterns within and between regions, e) rotation ages, and f) consumers' use of wood versus other products (i.e., substitution of non-wood product in consumption based on relative price). Changes in climate and consequent impact on forests are likely to change market incentives to harvest and plant trees and shift land uses between agriculture and forestry. Adaptation to productivity increases induced by climate change could include less afforestation than under the base case, as

adjustments in agriculture and forestry land market equilibria are prompted by perceived higher present values of economic returns in one land use versus the other.

In addition to land markets, the timber growing and processing portions of the forest sector also have options for responding to market-based incentives from climate-induced changes. Here the forest sector may see interregional migration of production, substitution in consumption, and altered forest stand management. The latter instance could include changes in rotation length and intensity or level of investment in forest practices, such as types of site preparation and planting stock, fertilization, thinning, and salvage of dead or dying trees. In our results, timber output reductions in the South are generally matched by increases in northern production, suggesting the possibility of "migration" of production to the northern regions.

At a more detailed level, adaptation of human systems has proven to be an important factor in the assessment of climate change impacts. First, man's influences on landscapes across the United States is substantial, as humans have and will continue to modify the quality, amount, and spatial configuration of habitats. A number of natural community types now cover less than 2% of their pre-settlement ranges (Noss et al 1994). Forest changes caused by human use of forests could exceed those from climate change (Dale 1997). More broadly, the area involved in land use shifts can dwarf the land area involved in natural disturbances. For example, the area of harvested cropland went from 118 million hectares in 1964 to 140 million hectares in 1982, and then down to 119 million in 1987. Perhaps the largest cumulative natural disturbance, the total U.S. area burned in fires at 0.4 to 2.5 million hectares annually is much less than these land area shifts in and out of agriculture. Future human adaptation

is likely to include adjustments in fire detection and suppression if the threat of forest fires increases. A second aspect of human adaptation is the modification of production methods. Studies in agriculture suggest that shifts in crop varieties, crop mixes, and other factors may reduce climate change impacts by as much as fifty percent relative to estimates that ignore adaptation (Adams et al. 1999).

CONCLUSION

Projecting impacts of global climate change on the U.S. forest and agricultural sectors and carbon budgets helps to place in context prospective atmospheric issues, concerns about ecological change associated with climate change, and the importance of human actions in adaptation and mitigation. Based on the magnitude of changes in forest and agricultural yields from climate change estimated by ecological models, projection results point to relatively small aggregate economic impacts. At present, however, estimates of impacts of climate change on forest yields have a wide range of uncertainty (McCarl et al. 2000). As new findings on climatic effects arise, the scenarios of climate change from the national assessment (U.S. Forest Sector Team 2000) should be re-evaluated.

Results from the FASOM model indicate that although aggregate sectoral welfare effects (consumers' savings plus producers' profits) are relatively limited, there are marked economic welfare shifts between producers and consumers. The overall yield increases induced by climate change were found to benefit consumers but not producers. The forest sector was also found to have adaptive adjustment

characteristics, including land market adjustments, regional (in our example, northerly) migration of production, substitution in consumption between wood and non-wood products and between sawtimber and pulpwood, and the ability to alter the intensity of forest management (rotation age) among owners and regions. Such findings challenge modelers and policy analysts to be explicit regarding the size, location, and timing of various impacts, to consider the transition from current vegetation and forest stocks, and to gauge the trade-offs between near-term policy concerns and long-term ecological impacts. Feedbacks within the system—global circulation and climate, terrestrial ecology and forest growth, and human activities—warrant more attention in future work.

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Table 1: Impacts on economic welfare estimates from climate change scenarios, as percentage changes from the Base Case.
 (CS=Consumers' Surplus, PS=Producers' Surplus)

Measure	Hadley-TEM	Hadley-VEMAP	Canadian-TEM	Canadian-VEMAP
Domestic Forestry CS	+1.3	+0.9	+1.0	+0.5
Domestic Forestry PS	-7.1	-5.1	-5.5	-3.1
Domestic Ag. CS	+2.0	+2.0	+1.0	+1.0
Domestic Ag. PS	-15.9	-15.9	-7.6	-7.6
Total Welfare for Both Sectors	+0.7	+0.7	+0.4	+0.4

Table 2. Impacts on timberland area from climate change scenarios, as area difference (million hectares) from the Base Case.

Timberland Area	Hadley-TEM	Hadley-VEMAP	Canadian-TEM	Canadian-VEMAP
Forest to Crop	0.0	-0.1	0.0	-0.1
Forest to Pasture	-0.1	-0.1	-0.1	-0.1
Crop to Forest	-2.7	-2.7	-0.8	-0.7
Pasture to Forest	+0.2	+0.2	+0.3	+0.4
Net Ag. to Forest Transfers	-2.4	-2.1	-0.4	-0.2

Figure 1. Projected U.S. Total Timber Inventory by Scenario, 2000-2100.
(Million Cu. Ft.)

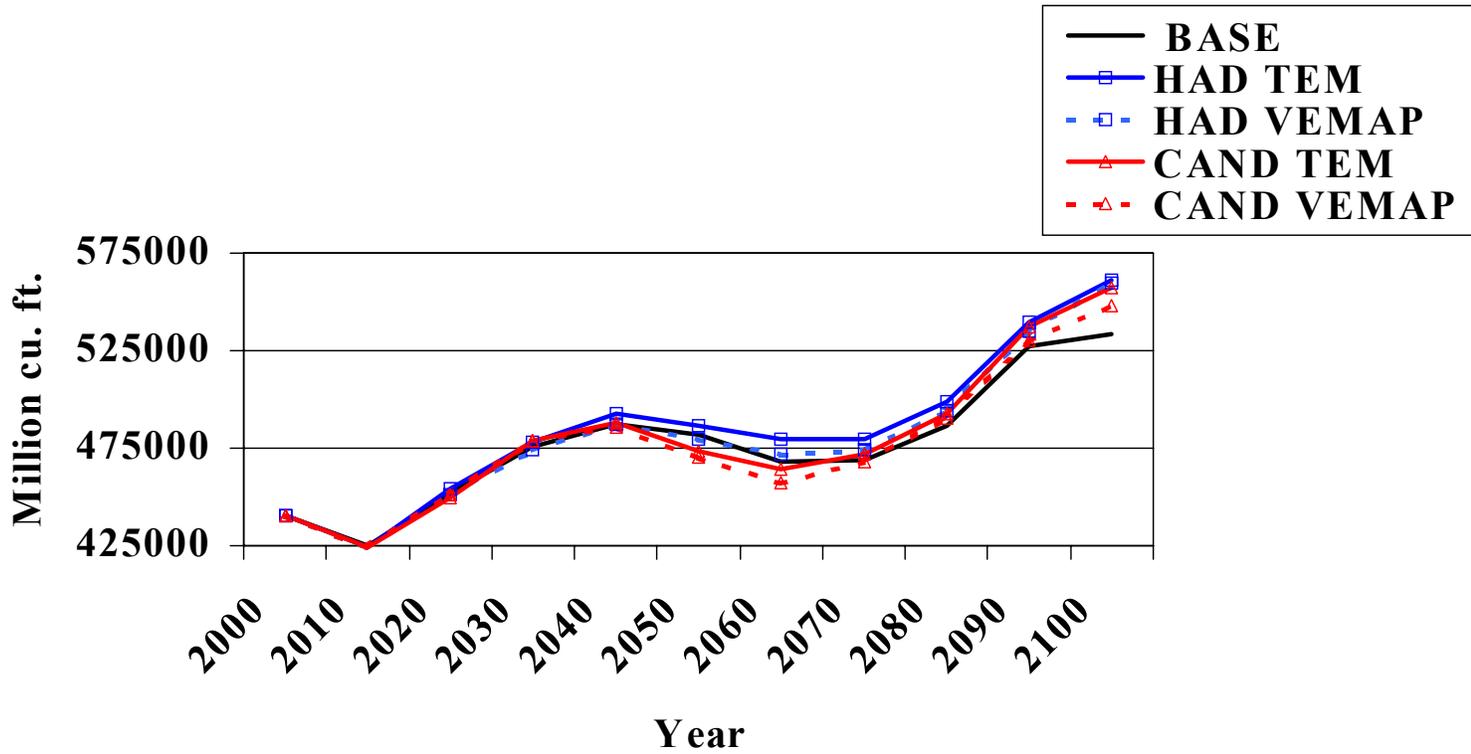


Figure 2. Projected changes in total harvest volumes over next 100 years, as percentage change from Base Case.

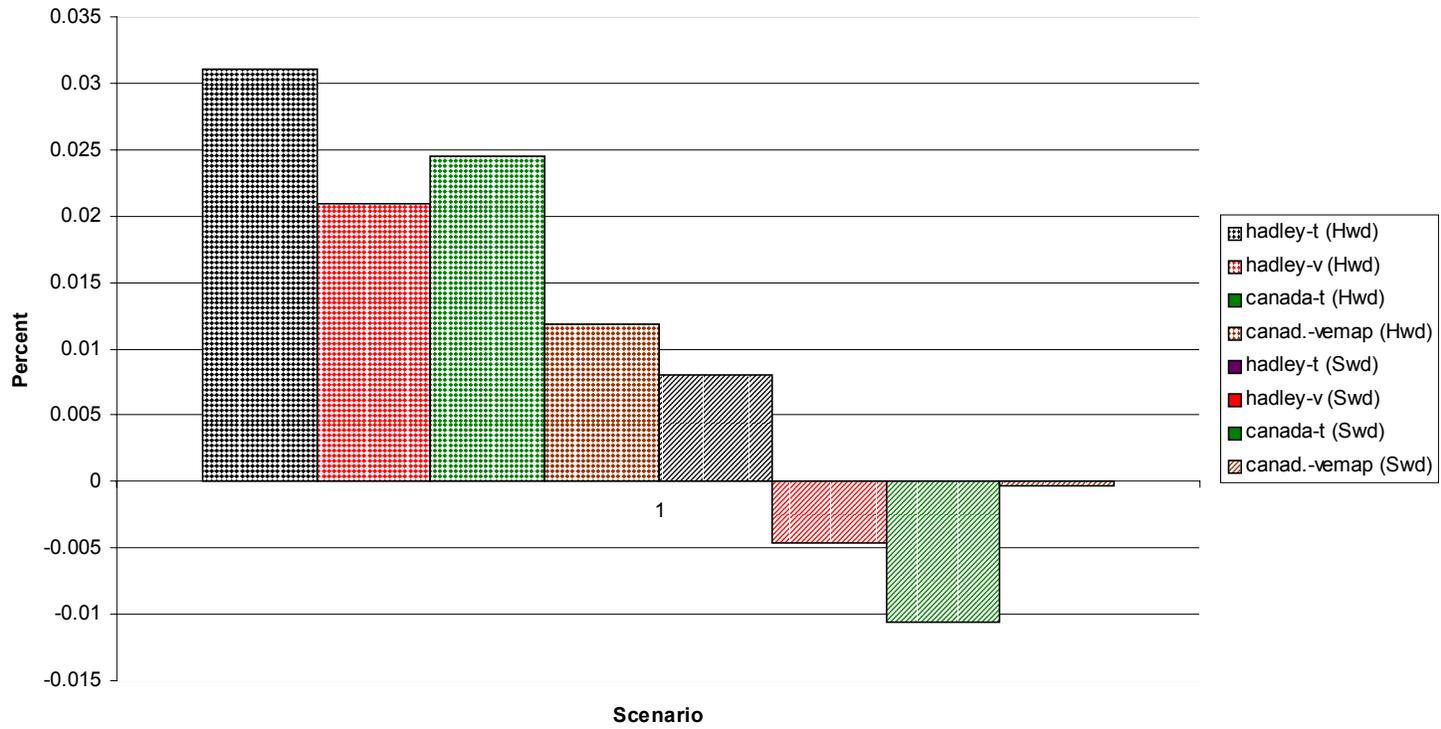


Figure 3. Projected U.S. average stumpage prices across scenarios

