THE IMPACT OF CLIMATE CHANGE ON GLOBAL TIMBER MARKETS

Brent Sohngen, Robert Mendelsohn, and Roger Sedjo[1]

ABSTRACT.—This paper assesses the economic impact of climate change on global timber markets. The results of a large scale ecological model are linked to an optimal control model of global timber markets. The results suggest that climate change may enhance global timber production and reduce prices. The results are driven by several important intertemporal adaptations. First, harvests increase over time as timber growth increases. Second, timberland management in emerging region plantations increases during the transition period to compensate for potential losses in the temperate zone. Third, harvests in some extensive regions increase during the transition to compensate for these losses.

INTRODUCTION

Global climate change is predicted to have broad and far-reaching consequences for ecosystems across the globe (Haxeltine and Prentice 1996, Neilson 1995, Melillo et al. 1993). As climate changes, water, nitrogen, and carbon cycles will shift, altering the underlying productivity of land. Climate change is predicted to have two critical effects on forested ecosystems: changes in ecosystem production in existing forests (Melillo et al. 1993), and changes in the structure of forested ecosystems (Haxeltine and Prentice 1996, Neilson 1995).

Much of the current ecological modeling has focused on predicting steady state changes in ecosystem distribution and production that result from doubled CO_2 climate change experiments (see, for example, VEMAP Members, 1995). Such steady state predictions suggest that large areas of land currently in forests will shift from one biome to another, including shifts from one forest type to another, and shifts from forest to non-forest. With these results, ecologists have suggested that existing forestlands will be stressed to the point of dieback during climate change, as areas that shift must adapt to new climatic conditions (King and Neilson 1992, Smith and Shugart 1993).

The question of forest adjustment during climate change, however, relies heavily on human adjustment and adaptation. Many forests across the globe are managed intensively for products such as lumber and paper. In particular, some of our most heavily managed forests exist in the temperate zone, where ecological models predict much of the stress will occur. In order to assess both the ecological and economic adjustment to a changing climate, it is critical to link ecological and economic models.

Several authors have considered the link between ecological and economic models in the context of climate change. The seminal piece, Binkley (1988), utilized a global timber market model, but considered only ecological adjustments in the boreal region. A more recent analysis by Perez-Garcia et al. (1997) examined the effect of changes in net primary productivity on global timber markets, without considering stock effects, such as a shift in species distribution.

Another analysis, Solomon et al. (1996), considered results of two ecological models (BIOME—Prentice et al. 1993 and IMAGE 2.0—Alcamo 1994), and economic predictions separately. With increasing human needs due to GDP and population growth, and potentially declining forest stocks, they predicted difficulties in timber market adjustment. Unfortunately, this exercise did not account for human adaptation and adjustment across both time and space during the transition from our current climate to an increased CO_2 climate.

[1] Sohngen is Assistant Professor, Department of Agricultural Economics, The Ohio State University, 2120 Fyffe Rd., Columbus, OH 43210; Mendelsohn is Professor, Yale School of Forestry and Environmental Studies, 360 Prospect St., New Haven, CT 06511; and Sedjo is Senior Fellow, Resources For the Future, 1616 P Street, NW, Washington, D.C. 20036.

In this paper, we present the results of an ecological-economic modeling effort which captures human adjustment in timber markets to climate change. Because ecological models predict only steady state changes, we begin with a set of steady state results for the BIOME3 model under current and doubled CO_2 climates (Haxeltine and Prentice 1996). These results are then linked with a dynamic model of climate change to develop transient predictions of ecosystem change. Such transient predictions are then introduced into a dynamic optimization model of global timber markets. The timber market model captures the human response to these changes, accounting for shifts in ecosystem distribution and production across the globe. The economic model is based on Sedjo and Lyon (1990) and Sohngen and Mendelsohn (1998).

ECOLOGICAL MODELS

The BIOME3 model is used to predict the steady state distribution of ecosystem types and net primary productivity (NPP) for .5°x.5° grid cells across the globe. Baseline and climate change results of the BIOME3 model are presented in Haxeltine and Prentice (1996) and Haxeltine (1997). This research represents a collaborative effort between the BIOME3 modeling group and the authors. Geographic Information Systems (GIS) techniques are used to compare baseline conditions to doubled CO_2 conditions in order to determine the proportion of each ecosystem type that converts to something else, the relative size of ecosystem types after climate change, and the percentage change in net primary productivity for specific ecosystem types (Table 1). The pathway of change (type to type) and separate regional results are also determined, but not shown in Table 1. Steady state ecological results used in this paper are based on two doubled CO_2 experiments: the Hamburg T-106 model (from Lennart Bengtsson, Max Planck Institute for Meteorology in Hamburg) and a run provided by Michael Schlesinger (University of Illinois).

Table 1.—Global results of the BIOME3 model with the Hamburg T-106 and the Schlesinger doubled CO_2 climate experiments

Forested Biome	Hamburg T-106			Schlesinger		
	Proportion Changing	Relative Size	NPP % Change	Proportion Changing	Relative Size	NPP % Change
Boreal Deciduous	0.65	0.62	180	0.30	2.45	143
Boreal Coniferous	0.31	1.08	12	0.42	1.36	7
Temp.-Boreal Mixed	0.36	1.41	12	0.74	0.53	1
Temp. Conifer	0.46	1.53	17	0.79	1.07	17
Temp. Deciduous	0.20	1.71	20	0.67	0.68	19
Temp. Broadleaf Evergreen	0.12	1.31	28	0.56	1.04	19
Tropical Seasonal	0.13	1.50	43	0.33	0.89	25
Tropical Rain	0.09	1.09	37	0.20	0.93	24
Tropical Deciduous	0.20	2.37	41	0.62	0.98	23
Total Forest	0.28	1.30	44	0.52	1.00	18

Dynamic scenarios of ecological change must be introduced in order to make these steady state results useful for economic analysis. For purposes of this study, climates are assumed to change linearly between now and 2060, as suggested by the Intergovernmental Panel on Climate Change (1996), and then stabilize. Dynamic ecosystem adjustments are assumed to occur proportionally to these linear adjustments in climate. Alternative pathways were considered in Sohngen (1996). Longer term adjustments changed the results only when the most valuable timber types were significantly affected by climate change.

Changes in the area of ecosystem types are predicted to occur along one of two pathways or scenarios. The first scenario involves stock dieback, followed by either natural or managed regeneration, depending on the management class. In terms of Table 1, this scenario predicts that the area of land included in the “shifting

proportion” column dies back during climate change. Dieback represents a rather dramatic impact of climate change on stocks, but it is one suggested by several ecological modelers (e.g., King and Neilson 1992, Shugart and Smith 1993). This scenario is named "dieback."

The second scenario entails only an impact on the regenerative capacity of timber stocks. As lands are predicted to become suitable for new timber species, the old types are able to continue growing where they currently exist, but they cannot regenerate. Thus, as these stocks are harvested, or as they die naturally, new types must migrate into the areas or be artificially regenerated in order for a new stand to be established. This transition implies that stocks which convert from one ecosystem type to another do so slowly, under the processes of competitive displacement. This scenario is named "regeneration."

In addition to changes in the area of ecosystems, changes in NPP imply changes in the growth functions of timber types. This paper assumes that timber yield functions change proportionally to the change in NPP predicted by BIOME3 for the given timber type. Furthermore, annual changes in NPP are assumed to occur proportionally to changes in climate. Note that only the future growth of timber stocks is affected by this change. Existing stocks of timber are given at the time when climate change begins affecting timber, and they are not affected by the changes in growth rates.

ECONOMIC MODEL

The economic model combines two earlier efforts: Sedjo and Lyon’s TSM model (1990) and Sohngen and Mendelsohn’s (1998) recently developed model of timber markets in the US. This economic model is described more thoroughly in Sohngen et al. (1997). In order to capture optimal economic adaptation to large scale ecological adjustment, the model utilizes a forward looking optimal control framework. As climate changes, foresters will respond to changing ecological conditions along a continuum of economic margins, shifting production from one region to the next as forest stocks respond to external stimulus.

Like the earlier two efforts, the objective of the timber market model is to maximize the net present value of net surplus in industrial wood markets. Timber is broken into age classes, which are followed through time. In addition, regeneration and management intensity are optimally chosen in each period when trees are planted. This model, however, incorporates several important improvements to the earlier models. First, it incorporates 46 different timber classes allocated into 5 broad management classes. Timber and management classes describe the location of important species across the globe, and they are linked to the ecosystem types described above. Second, the model endogenously determines harvests in both northern and tropical inaccessible regions, and it endogenously determines annual additions to tropical timber plantations. Thus, during climate change, the model will optimally adjust four margins: regular harvests, harvests in inaccessible lands, plantation establishment, and timberland management in regular types across the globe.

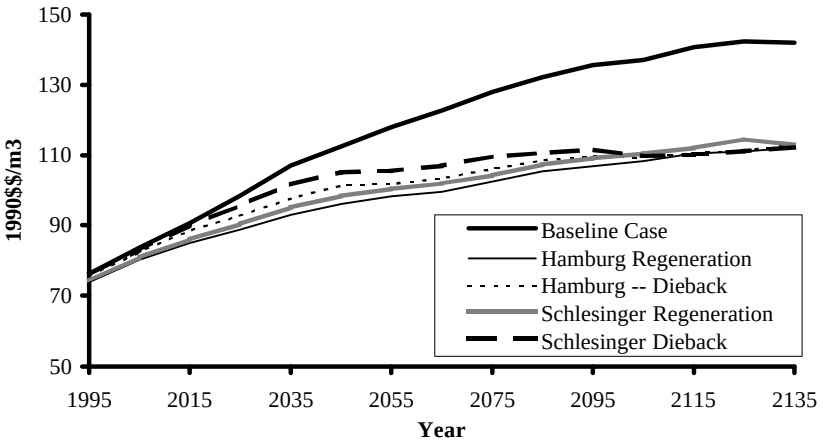


Figure 1.—Global price paths for the baseline and climate change scenarios.

EMPIRICAL RESULTS

In this section, we present the results of the ecological-economic model. Baseline harvest and management patterns are predicted first. Then, the ecological results from the BIOME3 model under two climate change scenarios are linked to the economic model. Shifts in harvest and management patterns are predicted and discussed relative to the baseline case.

While the BIOME3 model predicts substantial forest loss during climate change (the “shifting proportion” column of Table 1), economic adaptation and adjustment limit many of the economically harmful impacts of these changes. Figure 1, for example, shows predicted baseline and climate change prices. Global prices are lower than the baseline throughout the transition and into the long term. The long term results are driven by fairly large increases in timber growth predicted by BIOME3. Even though the model accounts for salvage from some regions, the dieback scenario predicts higher prices during the early periods because the value of salvage stocks is lower than the value of stocks that have been harvested from lands that do not experience dieback.

Potentially more important changes in regional harvests underlie these general results. Table 2 presents the change in timber harvests, averaged over both the dieback and regeneration scenarios for each of nine regions. Timber yields increase in all regions, except Oceania (Australia and New Zealand) for the Hamburg T-106 climate change scenario. In general, timber yields increase more in the developing regions than developed regions, leading to a greater overall response from those regions.

These changes, however, are not constant over time. North America, for example, experiences a decline in timber production during the first 50 years, when climate change causes substantial redistribution of existing biome and timber types. Although the Former Soviet Union (FSU) experiences similar ecological changes, dieback occurs largely in inaccessible regions. The FSU takes advantage of these changes to shift additional inaccessible land into more productive accessible types. This leads to substantial long term gains in timber production for that region.

Table 2.—Change in timber production relative to the baseline for nine regions of the globe for both doubled CO_2 climate experiments

	Hamburg T-106			Schlesinger		
	1990-2040	2040-2090	2090-2140	1990-2040	2040-2090	2090-2140
A. Developed						
North America	(0.02)	0.12	0.31	(0.02)	0.15	0.29
Europe	0.05	0.01	0.17	0.10	0.14	0.22
FSU	0.06	0.18	0.71	0.03	0.08	0.93
Oceania	(0.03)	(0.05)	(0.10)	0.12	0.33	0.36
B. Developing						
South America	0.19	0.47	0.50	0.10	0.22	0.20
China	0.11	0.29	0.31	0.10	0.27	0.27
India	0.22	0.55	0.58	0.14	0.30	0.29
Asia-Pacific	0.10	0.30	0.36	0.04	0.14	0.17
Africa	0.14	0.41	0.42	0.05	0.17	0.11
Total	0.06	0.21	0.31	0.05	0.18	0.29

Timberland management also shifts among regions as the underlying productivity of timberland and prices change over time. The combined impact of these adjustments leads to greater management intensity in the emerging region, but less in the temperate zone (Table 3). Large changes in biome distribution in the temperate zone reduce the incentive to manage in those regions, while the smaller changes in the subtropical regions allow management intensity to increase in emerging plantations. This adjustment has a substantial impact on global timber markets during climate change because plantations grow relatively quickly. Eucalyptus plantations, one of the most widely distributed, can be planted and grown to maturity for markets in 7-15 years, a time frame that allows several generations of eucalyptus to be planted and harvested when stocks are undergoing substantial changes in the temperate zone.

Table 3.—Average changes in management intensity of newly planted lands for the dieback and regeneration scenarios

	Regeneration		Dieback	
	Temperate	Emerging	Temperate	Emerging
A. Hamburg T-106				
1990 - 2020	0.86	1.03	0.86	1.09
2020 - 2050	0.91	1.06	0.96	1.12
2050 - 2080	0.96	1.05	0.97	1.09
2080 - 2110	0.91	1.05	0.94	1.05
2110 - 2140	0.84	1.01	0.80	1.03
B. Schlesinger				
1990 - 2020	0.84	1.00	0.82	1.08
2020 - 2050	0.92	1.00	0.93	1.08
2050 - 2080	0.83	0.98	1.05	1.02
2080 - 2110	0.92	0.94	0.92	0.95
2110 - 2140	1.09	0.89	0.88	0.94

Markets also shift the overall level of plantation establishment in the emerging region. The level of land available for forested plantations depends on current marginal land rental and plantation establishment costs relative to the discounted marginal benefits of adding new land today. Because plantations can enter and leave the global forestland base, the area of land in plantations increases initially relative to the baseline in both climate change scenarios and declines later in the model run (Table 4). Plantations are used in the earlier time periods to mitigate dieback in the temperate zone, but over the long term, the area of land in plantations does not expand because prices are lower and management intensity has increased.

Table 4.—Area of emerging region plantations for two climate change scenarios relative to the baseline

	Hamburg T-106		Schlesinger	
	Regeneration	Dieback	Regeneration	Dieback
2020	1.01	1.03	1.00	1.02
2050	1.02	1.05	1.00	1.03
2080	1.01	1.03	0.99	1.01
2110	1.01	1.02	0.97	0.98
2140	1.01	1.02	0.97	0.97

Finally, one must account for shifts in harvests at extensive margin. The effect of ecological changes on markets leads to higher harvest of some extensive forestlands during climate change, particularly the boreal regions (Fig. 2). During dieback, harvests expand relative to the baseline because these lands serve as stocks which can be used to mitigate the effects of dieback elsewhere. The heaviest additional harvests come from the FSU boreal region because that region experiences fairly large increases in timber growth (49 to 69 percent) and the conversion of boreal inaccessible forests to more accessible types is highly profitable during climate change. Note that this change is not driven by dieback, because we do not allow for salvage in extensive margin forests during climate change.

CONCLUSION

This paper presents the results of the an ecological-economic modeling effort to assess the impacts of climate change on global timber markets. The paper begins with a description of steady state ecological models used for predicting impacts of climate change on forest biome distribution and NPP. Two transient models of ecological change are then developed which allow us to model the natural response of ecosystems to climate change. The transient results are then linked to an economic model of timber markets to determine the human response to these changes.

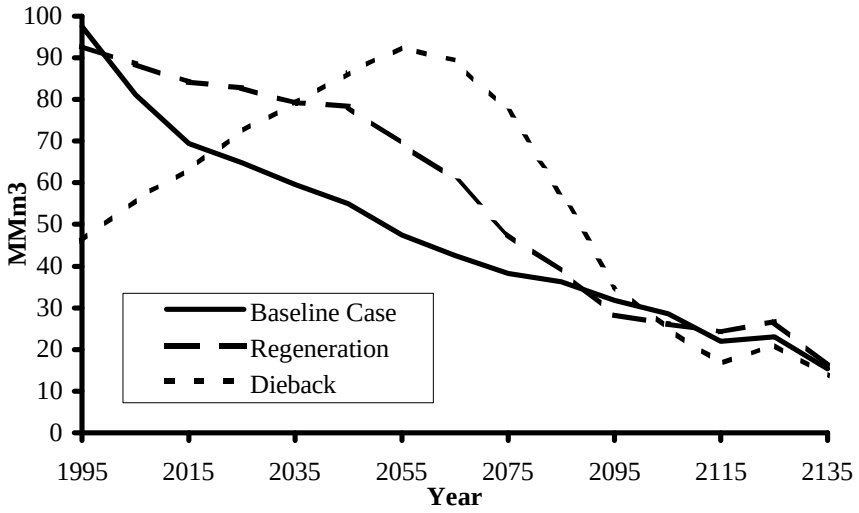
The ecological-economic model predicts that markets are likely to benefit from the changes predicted by the BIOME3 model. In the long term, the area of forests and NPP increases in general, leading to lower steady state price levels. While steady state results are interesting, the ecological models predict fairly substantial transient effects. The modeling system predicts that markets will shift harvests and management from region to region to adjust and adapt to these large scale changes.

The transient adjustments of markets shift harvests and management towards the emerging plantation region. Even in the baseline, global harvests shift strongly in this direction, but the climate change scenarios examined here suggest that these changes will be strengthened. Management in the emerging region is also enhanced relative both to the baseline and the temperate region. This occurs because these regions are less susceptible to climate change during the transition period.

Two stocks of timber prove crucial during the adjustment to climate change, emerging region plantations and inaccessible regions. The inaccessible stocks of the Former Soviet Union are perhaps the most important, as harvests there respond strongly to changes in timber growth and dieback. The effect of these two changes enhances the long term FSU response to climate change.

It is important to note that these results are broadly consistent with those presented in Sohngen and Mendelsohn (1998) for the United States. While that paper did consider a large set of ecological results, it was limited in that it considered only the United States. This paper contains only a limited set of possible ecological results, but it captures the global market adjustment. Further analysis should attempt to incorporate a broader array of ecological results.

Figure 2—Harvests in the northern extensive margin for the baseline case and the dieback and regeneration scenarios in the Hamburg T-106 scenario.



REFERENCES

ALCAMO, G.D. 1994. *IMAGE 2.0: Integrated Modeling of Global Climate Change*. Dordrecht: Kluwer. 321 p.

BINKLEY, C.S. 1988. A Case Study of the Effects of CO_2-induced Climatic Warming on Forest Growth and the Forest Sector: B. Economic Effects on the World's Forest Sector. In: *The Impact of Climatic Variations on Agriculture*. eds. M.L Parry; T.R. Carter; and N.T. Konijn. Dordrecht: Kluwer.

HAXELTINE, ALEX. 1997. *Response of Global Vegetation to Climate Change*. Mimeo.

HAXELTINE, ALEX AND PRENTICE, I. COLIN. 1996. BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition Among Plant Functional Types. *Global Biogeochemical Cycles* 10(4): 693-709.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 1996. *Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Houghton, J.T.; Meira Filho, L.G.; Callander, B.A.; Harris, N.; Kattenberg, A.; and Maskell, K. (eds.), Cambridge University Press, Cambridge.

KING, G.A. AND NEILSON, R.P. 1992. The Transient Response of Vegetation to Climate Change: A Potential Source of CO_2 to the Atmosphere. *Water, Air, and Soil Pollution* 94, 365-383.

MELILLO, JERRY. M; MCGUIRE, A. DAVID; KICKLIGHTER, DAVID W.; MOORE, BERRIEN III; VOROSMARTY, CHARLES. J; AND SCHLOSS, ANNETTE. L. 1993. Global Climate Change and Terrestrial Net Primary Production. *Nature*, 363, 234-240.

NEILSON, R. 1995. A Model for Predicting Continental-Scale Vegetation Distribution and Water Balance. *Ecological Applications*, 5, 362-385.

PEREZ-GARCIA, JOHN, JOYCE, LINDA A., MCGUIRE, A. DAVID, AND BINKLEY, CLARK S. 1997. Economic Impact of Climatic Change on the Global Forest Sector. Critical Reviews in Environmental Science and Technology, In Press.

PRENTICE, I. COLIN; CRAMER, WOLFGANG; HARRISON, SANDY P.; LEEMANS, RIK; MONSERUD, ROBERT A.; AND SOLOMON, ALLEN M. 1992. A Global Biome Model Based on Plant Physiology and Dominance, Soil Properties and Climate. *Journal of Biogeography*. 19: 117-134.

SEDJO, R. A. AND LYON, K.S. 1990. *The Long Term Adequacy of the World Timber Supply*. Washington*:* Resources For the Future.

SMITH, T.M. AND SHUGART, H.H. 1993. The Transient Response of Terrestrial Carbon Storage to a Perturbed Climate. *Nature* 361, 523-526.

SOHNGEN, B. AND MENDELSOHN, R. 1998. The US Timber Market Impacts of Climate Change. In: *The Market Impact of Climate Change on the US Economy*. Mendelsohn, R. and Neuman, J. (eds.) Cambridge University Press, Cambridge.

SOHNGEN, B.; MENDELSOHN, R.; SEDJO, R.; AND LYON, K. 1997. *An Analysis of Global Timber Markets.* Discussion Paper. Resources For the Future, Washington, D.C.

SOHNGEN, BRENT L. 1996. Integrating Ecology and Economics: The Economic Impact of Climate Change on Timber Markets in the United States. Doctoral Dissertation, Yale University.

SOLOMON, ALLEN M.; RAVINDRINATH, N.H.; STEWARD, R.B.; WEBER, M.;, NILSSON, S.; DUINKER, P.N.; FEARNSIDE, P.M.; JOYCE, L.A.; KOJIMA, S.; MAKUNDI, W.R.; POLLARD, D.F.W.; SHVIDENKO, A.; SKINNER, W.; STOCKS, B.J.; SUKUMAR, R.; AND DEYING, X. 1996. Wood Production Under Changing Climate and Land Use. pp. 487-510. In: *Climate Change 1995. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* Watson, R.T.; Zinyowera, M.C.; and Moss, R.H. (eds.). Cambridge: Cambridge University Press.

VEMAP Members. 1995. Vegetation/Ecosystem Modeling and Analysis Project (VEMAP): Comparing Biogeography and Biogeochemistry Models in a Continental-Scale Study of Terrestrial Ecosystem Responses to Climate Change and CO_2 Doubling. Global Biogeochemical Cycles, 9(4), 407-437.