THE VALUE OF BIOPHYSICAL INFORMATION
FOR ASSESSING THE ECONOMIC IMPACTS
OF GLOBAL CLIMATE CHANGE

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ABSTRACT

Global climatic change has become a major policy and scientific issue during the past decade. This study was designed to identify the biological data required to evaluate the economic impacts of climate change on forestry in the southern United States. The primary data needs include changes in the range of commercially important tree species, changes in tree productivity and wood formation, and forest pest incidence.

INTRODUCTION

For the past decade, scientists, policy makers and resource managers have debated the likelihood of significant global warming, and the meaningful climatic changes induced by global warming. Despite some notable critics, much of the scientific community agrees that accelerated atmospheric warming - an enhanced greenhouse effect - is occurring or will occur primarily due to the rapid atmospheric accumulation of carbon dioxide (CO₂) and other trace gases from the burning of fossil and biomass fuels (Smith and Tirpak 1989, Blake and Roland 1988, MacDonald 1988, Ramanathan 1988). This accumulation may absorb significantly more long-wave radiation than in the past, thereby warming the earth and the raising mean global temperature (Houghton and Woodwell 1989, Dowd 1986). Because
weather and climate are partly influenced by the long-wave radiation given off by the earth, important climatic changes are possible (Henderson-Seller and Mcguffie 1987).

Figure 1 illustrates the concern of many scientists. Figure 1a exhibits the correlation between atmospheric concentration of CO₂ and changes in temperature over the past 160,000 years. Figure 1b documents the rise in CO₂ concentration in the atmosphere. Although much uncertainty exist about mechanisms the could enhance or negate global warming, the best information to date suggests that the earth’s mean temperature could rise by as much as 1.5 to 5.1 degrees Celsius within the next 50 to 100 years. Such rapid changes in temperature, accompanied by changes in precipitation patterns, would affect a wide range of ecosystems, including forests (Bazzaz 1990, Smith and Tirpak 1989, DeLaune et al. 1987). The ability to grow crops would change depending on mean temperatures and precipitation amounts and timing. The same factors would affect forest distribution. In North America, forests would likely migrate northward or to higher elevations over time. Climatic changes may occur more rapidly than forests’ ability to migrate. Stress induced mortality in the southern range extremes would likely out-pace northward migration.

While this could significantly affect the Southeastern forest industry and the economy of the southeastern United States, few researchers have attempted to investigate the economic implications of climate change on resource-based sectors or on regional economics, primarily due to a lack of information needed to conduct such analyses (Cubbage et al. 1992, Regens et al. 1989). This study will provide the initial comprehensive review of the data requirements, availability, and uncertainty for evaluating the economic impacts of climate change. Specifically, the primary purposes of the study are to identify the biophysical data required for assessing the economic effects of global climate change on timber production in the South and to assess the availability of those data. Such insights will aid future socio-economic studies of climate change, by providing a framework to:

1. identify the biophysical information needed to evaluate the socioeconomic impacts of climate change on forestry in the South;

2. inventory sources of currently available data on future climate scenarios, forest response, and potential impacts on forest management operations; and

3. appraise the uncertainties in the available data and the impact of the uncertainty on economic projections, and identify gaps in the required data.

LITERATURE REVIEW

Because of the damage that global warming may inflict in the future, evaluating the social cost of greenhouse gas emissions, determining acceptable damage levels, and examining the optimal quantity of social welfare to be provided are important research and
Carbon dioxide levels and temperatures over the last 160,000 years. From Vostok 5 Ice Core.

Source: Barnola et al. (1987).

Mean monthly concentrations of atmospheric CO$_2$ at Mauna Loa.


**FIGURE 1.** Historical correlation between the atmospheric concentration of CO$_2$ and changes in temperature (top), and the atmospheric concentration of CO$_2$ from 1958 through 1981 (bottom).
policy concerns. de Steiguer (1992) describes the process by which society determines the optimal quantity of social welfare to be provided and how society adjusts this quantity as needs change. The marginal cost that society is willing to accept from the emissions must equal the marginal benefit society receives from the emissions (see Figure 2a). At equilibrium, society has determined that at price \( p \), \( q \) units of emissions result. Consumers receive a surplus equal to the area in the triangle marked consumer surplus while producers receive a surplus equal to the area in the triangle marked producer surplus. The sum of consumer and producer surpluses represents a measure of the social welfare associated with the emissions level. Social welfare is a measure of monies consumers and producers have available to invest or spend on goods and services.

Problems occur when the marginal cost (MC) of emissions increase, as shown by a leftward shift of the MC curve to MC' in Figure 2b. Now the quantity of social welfare provided decreases, as indicated by the changes in consumer and producer surpluses. As illustrated in Figure 1b, both consumers and producers suffer a decrease in surplus, indicating both consumers and producers have less money to spend. Society may determine this situation to be unacceptable and act to increase the level of social welfare provided, or act to decrease the burden on affected groups.

Increasing social welfare to a desirable level typically involves privatizing part of the cost associated with emissions that were previously socialized (see Figure 3). This may result in higher prices for some goods and services until innovation ends unacceptable emissions. This action forces the marginal cost curve of emissions to the right, towards the original marginal cost curve shown in Figure 2a. Determining the marginal cost of greenhouse gas emissions to society is a critical step in determining the acceptable level of damage from greenhouse gas emissions.

Global Economic Theory and the Enhanced Greenhouse Effect

Maler (1992) describes the externality of greenhouse gas emissions as an overuse of a globally common resource. Overuse is the result of a Nash equilibrium. Each country maximizes its net national welfare by allowing the atmospheric emission of greenhouse gases until the national net welfare gained from the emission of an additional ton of greenhouse gases is zero (marginal costs equals marginal benefits). The sum of the emissions from each country is more than the Pareto efficient level of greenhouse gas emissions, and an efficient use of the atmosphere for greenhouse gas emissions is not possible. Because unilateral actions to limit greenhouse gas emissions by a country could result in a short-term economic disadvantage for that country, unilateral actions should not be expected.

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1Samuelson and Nordhaus (1989) describe a Nash equilibrium as a situation in which all parties 'lose' but parties who violate the stable condition 'lose big' while others who do not violate the stable condition 'gain big'. If all parties cooperated, then all parties could gain, but violation of a cooperative agreement results in big gains for the violator and big losses for the others. There is incentive to violate cooperative agreements.
FIGURE 2. (a) An illustration of consumer and producer surpluses, and the equilibrium price and quantity of social welfare provided. (b) The effect an increase in marginal cost has on consumer and producer surpluses, and the equilibrium price and quantity of social welfare provided.

MB = marginal benefit
MC = initial marginal cost
MC' = increased marginal cost curve

p = initial price
p' = price after an increase in marginal cost
q = initial quantity of social welfare provided
q' = quantity of social welfare provided after an increase in marginal cost.
\[ q = \text{initial quantity of goods consumed} \]
\[ q' = \text{quantity of goods consumed after social cost privatized} \]
\[ p = \text{initial price of goods consumed} \]
\[ p' = \text{price of goods consumed after social cost privatized} \]
\[ \text{Demand} = \text{demand for goods} \]

\[ \text{MC}_{\text{private}} = \text{private marginal cost associated the production of goods.} \]
\[ \text{MC}_{\text{private + social}} = \text{the private marginal cost + the social cost of externalities associated with the goods} \]

**FIGURE 3.** An illustration of the impact that privatizing the cost associated with externalities has on the market price of externality producing goods, and the quantity of the goods consumed.
To achieve a Pareto efficient use of a resource, countries should emit greenhouse gases only to the point at which emitting an additional ton of gases would not benefit global net welfare. Determining the globally desirable concentration of greenhouse gas emissions (the level at which the marginal benefit to global welfare equals the marginal cost to global welfare) requires international cooperation, and accurate regional information (Maler 1992).

To identify the globally acceptable level of damage from greenhouse gas emissions, specific regional damage caused by emissions must be determined (Cline 1992, Yohe 1991). Possible adaptive strategies must be identified for each region and incorporated into global policy decisions (Cline 1992). Because of the uncertainty associated with the impacts of greenhouse gas emissions, Cline (1992) suggests that ranges of damage need to be developed for specific periods in the future. Other investigators agree that regional estimates of damage are necessary.

Regional Economic Theory and the Greenhouse Effect

The literature reveals the need to link the global environmental and economic consequences of greenhouse gas emissions to regions. This linkage is necessary because, although greenhouse gases are emitted by many countries, the environmental and economic consequences associated with these emissions may differ by country and region.

First, the environmental damage and the associated economic cost of greenhouse gas emissions must be determined regionally. A globally acceptable level of environmental damage and economic cost must be determined from this regional information (Maler 1992). Next, likely regional adaptive strategies must be identified and considered in global policies to abate greenhouse gas emissions (Cline 1992). Finally, the marginal benefits and marginal costs of greenhouse gas emissions abatement must be considered for each region. To achieve a Pareto efficient use of the atmosphere for greenhouse gas emissions, the global marginal cost of abatement must equal the global marginal benefit (Maler 1992). Figure 4 illustrates Maler's central idea. The marginal costs and benefits realized from emissions abatement are not likely to be evenly distributed throughout every region of the world. Global negotiations will be necessary to insure that countries who have high marginal costs of abatement but low marginal benefits from abatement have sufficient incentive to comply with the greenhouse gas emissions levels determined to be optimal (Maler 1992).
FIGURE 4. An illustration of the supply and demand for greenhouse gas emissions abatement as the global market moves from a Nash equilibrium emissions level to a Pareto efficient use of the atmosphere for emissions.
METHODS

Data Requirement Identification

The first, and most crucial, phase of the study is to identify the data needed to evaluate the economic impacts of climate change on forestry in the southeastern United States. An analytical framework similar to that described by Hodges et al. (1992), illustrated in Figure 5, was used to emphasize the potential impacts of climate change to forest management and timber production through the first phase of processing. Our emphasis on timber production is attributable to its importance to the southern economy. Forest products constitute the first or second most important manufacturing sector in most of the southern states (USDA Forest Service 1988). As a consequence, any change in the outlook for timber management and production will be of great interest to the forestry sector and policy makers in the South.

The framework depicts the evaluation of the economic impacts from emission of greenhouse gases through the secondary impacts to forest industry. The primary biological data needs are grouped into three components. These include those listed in "Direct Impacts of Air Quality on Forests", "Impacts on Forest Productivity", and "Changes in Wood Property". The impacts of air quality on forests involve the tradeoff between damage from pollution associated with greenhouse gases and the potential fertilization effect of increased atmospheric CO₂. Several researchers have noted the possibility of increased productivity as a result of an enhanced CO₂ environment. Specifically, seedlings of several tree species increased height and diameter growth when exposed to increased CO₂ levels (Pastor and Post 1988, Rogers et al. 1983, Funksch et al. 1970). More recent studies, however, suggest that tree response could vary significantly by species and age. Whereas Bazzaz et al. (1990) found that several northeastern tree species responded positively to increased CO₂ levels, the shade-tolerant species exhibited a greater response. Clearly, one significant biological data requirement is better information on the net impact of climatic change on tree physiology.

In addition to the question of tree growth, many southern tree species are projected to shift northward or become locally extinct. Many climate scenarios project that southern pines will be eliminated or greatly reduced in Georgia, Mississippi, and North Carolina (Joyce et al. 1990). At the aggregate level, loblolly pine is projected to increase its range (Woodman and Furiness 1989, Miller et al. 1987). The northward shift, however, is projected to decrease the overall loblolly pine site index, as the range shifts to poorer sites. An additional consideration is the impact of climate change on the incidence of wildfires as well as insect and disease outbreaks. Fires could increase substantially in regions where droughts or longer, drier summers are projected (Simard and Main 1987). Similarly, insect outbreaks and disease epidemics could increase significantly, although specific levels are uncertain. It is likely, however, that the major forest pests will be able to adapt to climate change sooner than tree species (Hedden 1987).

Finally wood formation and quality are likely to be affected by climatic change. Specifically, with longer, drier summers, more low-density earlywood would be produced during the wetter spring months and the amount of high-density latewood produced during
GLOBAL EMISSIONS OF CARBON DIOXIDE & TRACE GASES

ENHANCED GREENHOUSE EFFECT

REGIONAL CLIMATE CHANGE
- Change Precipitation patterns
- Changes in Temperature Variation
- Changes in Growing Season Length

DIRECT IMPACTS OF AIR QUALITY ON FOREST
- Carbon Dioxide Fertilization
- Pollution Damage

IMPACTS OF FOREST PRODUCTIVITY
- Changes in Major Commercial Species
- Changes in Site Quality
- Changes in Forest Productivity
- Changes in Severity of Damage from Fire, Insects, And Diseases

CHANGES IN WOOD PROPERTIES
- Tree Form
- Quantity of Lathe Wood
- Specific Gravity

CHANGES IN TOTAL ACRES IN RANGE x
CHANGES IN YIELDS PER ACRE = NET CHANGE IN TOTAL INVENTORY & HARVEST (per year)

VALUATION OF PRODUCT YIELDS
- Net Yield Change X Price
- Capacity Effects
- Market Preferences

STUMPAGE VALUATION OF PHYSICAL CHANGES
- Net Yield Change X Price
- Constant Dollars
- With Real Price Increases

ESTIMATION AND EVALUATION OF EFFECTS ON INDUSTRY SECTOR
- Forest Management Practices
- Mill Reductions, Closings
- Mill Movements - Physical Problems

FIGURE 5. A framework to investigate the regional socioeconomic impact of greenhouse gas emissions on the forest dependent economy of the southeastern United States
the summer would decline. Thus, the specific gravity and the resulting strength of lumber and paper products would decline.

Based on the framework described above, we identified several key data needs. At the present time these data needs reflect some of the basic uncertainties associated with climate change, and include:

1. Ranges of commercially important tree species,

2. Changes in site quality,

3. Net effect on increased atmospheric CO₂ on forest productivity,

4. Changes in tree form and wood quality, and

5. Impact of climate change on forest insects and diseases.

Available Data Inventory

The second phase of the study entails inventorying all available sources of the required biophysical data. Because of the effort already expended on assessing General Circulation Models (see Cooter et al. 1993), we focused our attention on models designed to simulate forest response to climate change and on other biological data needs.

Forest response models are designed to process climate and biological data to project the future structure and/or distribution of forests and species composition. Solomon and West (1987) discuss some characteristics of forest response models needed for forest industry to make informed investment decisions with the possibility of climatic change affecting regional forest. These characteristics are

1. models must predict forest responses to climatic change at the tract level;

2. models must reflect the complexity of forest ecosystems
   a. multiple species must be considered,
   b. multiple developmental stages modeled,
   c. forest responses to competition must be modelled,
   d. other environmentally limiting factors must be modelled.

Computer models that simulate interactions among several species by silvical characteristics limited by environmental stress offer the most valid approach to date.
The forest response models that have been used to project the biological impacts of climate change can be broadly classified as physiologically-based models or community-based models. Physiologically-based models are designed to predict the response of individual plants to changes in the environment. These models do not consider competition between plants or possible changes in nutrient cycling (Joyce et al. 1990). Community-based models predict future forest species composition on a large scale. Such models, however, do not consider the timing of reforestation or the factors that will affect reforestation in the future. Two of the more commonly used forest response models are described below.

FORENA

FORENA (FORest of Eastern North America) is a gap phase model developed from FOREST (FORest of EAst Tennessee) and JABOWA (JAnak, BOtkin, WAllis). Forest 'grow' in annual time steps with 1/5 acre gaps occurring with the death of mature trees. FORENA has all of the characteristics listed above to some degree. FORENA predicts forest response to environmental change by allowing extrinsic environmental forcing variables to affect the intrinsic processes of birth, death, and growth that are controlled by constants characterized by species parameters. The environmentally limiting factors that are explicitly modelled include growing degree days (GDDs), drought days, and winter kill. The effects of CO₂ fertilization, changes in nutrient cycling, changes in water use efficiency, possible changes in the maximum temperature at which photosynthesis can occur, growth benefits that may occur for a longer growing season, and possible changes in fire, insect, and disease damage are not modeled.

Temperature is an essential input which general circulation models (GCMs) can provide. GDDs and winter kill are calculated from daily temperature. FORENA randomly selects daily temperatures within a predetermined variance around the input means. General circulation models provide only mean temperatures. Variance must be determined from historical or theoretical sources.

Maximum and minimum GDDs are determined for each tree species from the southern and northern range extremes, respectively. Temperatures above 5.5°C add to GDD. Tree growth is adjusted for each species by GDD. If GDDs exceed the maximum or minimum optimal GDDs determined for each tree species, growth reduction occurs. For each species maximum growth is a parameter from which only reductions in growth are possible. Longer growing seasons would result in less growth in the southern extremes. The range in which optimal growth would occur would shift North.

Monthly mean precipitation is another essential input which GCMs can provide. FORENA determines monthly precipitation by randomly selecting a value from a predetermined variance about the input mean. Again, GCMs do not provide variance data. Historical or theoretical sources must be used.

Drought tolerance is calculated by determining the minimum amount of rainfall each species must have during the growing season. The western range extreme for each species
provides this information. Minimum precipitation is divided by the length of the growing season to provide a constant for each tree species. This constant is multiplied by the length of the growing season for the modelled site to provide the drought tolerance parameter drought days (DDs) for each species that occurs on the site. Tree growth slows as DD increase form zero to the species maximum. Beyond maximum DD, growth is zero.

Changes from optimal conditions in GDD and DD adversely affect species growth. In FORENA, slow growth is defined as one tenth of the empirically measured maximum possible growth for a species. The event of slow grow increases the possibility of tree death. Two independent death processes determine tree survival. Senescence decreases radial growth, decreases crown/stem ratio, increases root mortality, decreases root regeneration capacity, and decreases tree resistance to pathogens. To account for the effects of senescence, FORENA logarithmically increases the probability of tree death with age.

Environmental factors also influence the probability of death. Late frost, to much or to little water, fire and lighting damage, shading, insect defoliation, and nutrient deficiencies all increase the probability of death. FORENA increases the probability of death after two consecutive years of slow growth. Drought tolerance, shading, stand density, winter kill, and growing season length account for some of these environmental factors.

Forena does not account for the possible effects of CO₂ fertilization; changes in water use efficiency; changes in nutrient cycling; positive changes that may occur with longer growing seasons; and changes in fire, insect, and disease damage that may occur. If these parameters become available for each tree species, they could be incorporated into FORENA.

MAESTRO

Maestro is a physiologically based forest response model. The model measures the response of established forest trees to changing climatic conditions. Maestro does not allow for forest tree replacement and cannot be used to determine future forest composition. Maestro has several desirable properties. The effects of possible CO₂ fertilization can be considered, as can changes in water use efficiency. Maestro also considers photosynthetic reactions to temperature changes. The input of specific site and soil parameters would allow Maestro to make regional predictions based on these parameters. Finally, because Maestro measures changes in net photosynthesis, crude estimates of insect and disease response to changes in forest vigor may be possible by tree species and site.

Maestro has several drawbacks. The model only permits estimating the response of coniferous monocultures. Sitka spruce and Radiata pine are used to validate the model; data needed to model southern pines must be collected. Maestro requires the X, Y, and Z coordinates of every tree in the modelled forest. Also required are parameters that describe leaf inclination angle and distribution throughout the tree crown by leaf age, as well as the total area of leaves within a tree crown. Maestro does, however, have subroutines within the model that will calculate leaf spatial distribution and inclination angles if none are provided. Other required leaf parameters include the transmittance and reflectance of PAR.
(photosynthetic radiation), NIR (near infrared radiation), and thermal radiation. Maestro is very data intensive.

The inputs Maestro would require from GCM’s are sunshine duration, cloudiness, wind speed, air temperature, water vapor saturation deficit, and hourly flux densities of PAR, NIR, and thermal radiation on horizontal surfaces and their corresponding beam fractions. Some needed soil parameters include temperature, reflectance of PAR, NIR, and thermal radiation. GCM’s may not provide radiation information as an hourly output, but they do internally predict this information.

In addition to the various types of models for forecasting future climate scenarios and forest conditions, information will also be collected on those data needs yet to be modeled with regard to climate change. Biologists are just now beginning to quantitatively evaluate the impact of climate change on forest pests, for example. Other information may be needed that has not been integrated into the climate change models, such as the impacts of a change in precipitation and temperature patterns on wood formation. These effects could have substantial impacts on the profitability of forest products manufacturing in the South. The available information on such components of the framework will be inventoried, with special emphasis placed on additional information needed for evaluating the impacts on forestry.

Evaluation of Available Information

Evaluating the currently available information as identified in phase two will involve identifying any gaps in the data requirements and evaluating the utility of the available data. Identifying data gaps will be relatively straightforward. Any data requirement characterized in phase two for which no information is currently available will be identified. For such instances, all attempts will be made to identify any research underway to provide such data and expected date of completion. An effort will also be made to identify any related information which could be used to fulfill the data requirements.

The most crucial aspect of this phase will consist of evaluating the utility of the existing data for assessing the economic impacts of climate changes. The primary problem will be to evaluate the importance of the data for economic evaluation, the range of available predictions, and the most reliable estimates. The principal objective of this phase, then, is to describe the range of currently available projections and, where feasible, evaluate how the economic impacts would be affected by the range of projections. Four broad classes of data will be examined:

1. changes in the ranges of commercial tree species;
2. changes in site quality;
3. changes in forest productivity; and
4. changes in wood formation and quality.
The uncertainty or low credibility of the estimates derived from limited biophysical information is the primary factor limiting the decision relevance of such assessments. First, uncertainty stems from major gaps in the information about underlying dose-response relationships over variable time horizons. Second, because preferences for environmental goods are not directly observable in markets, there are always questions regarding the estimated monetary value of the benefits. Third, even when those preferences are monetarized, aggregating them to derive social preferences can be problematic. As a result, doubt about the confidence which can be attached to estimates, even when preferences are well-defined, is a general constraint on the use of such analysis in the decision making process.

REFERENCES


