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The Economic Impact of Air Pollution on Timber Markets

Studies from North America and Europe

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Edited by
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Foreword

The impact of air pollution on forest health has in recent years become an issue of major public concern. This is true despite the fact that irrefutable cause-and-effect relationships have in most instances been quite difficult to establish. Reports of "Waldsterben" in Germany, sugar maple decline in Canada, reduced growth of pines in the Southeastern United States, and other apparent instances of pollution-caused forest damage have heightened the concerns of scientists, lawmakers, and lay persons alike. While most of the attention has been focused on the physical and biological aspects of the damage, the economic impacts have also been of some interest, especially to government officials whose responsibility it is to consider costs and benefits when setting pollution limits. The purpose of this report is to assist government officials and other concerned parties by contributing to a better understanding of the economics of forest damage from air pollution.

The papers presented here were written by seven economists who have studied the forestry air pollution situation and its relationship to timber markets. The first paper explains the economic linkages among fossil fuel consumption, air pollution externalities, and losses in timber markets. The five papers that follow are concerned with the actual estimation of damages across selected large geographic areas. One study deals with the Southeastern United States; three are national studies from Finland, the U.S., and Canada; and one is concerned with the entire European continent. Yet, while each of the studies is concerned with estimating damage within a large geographic area, the methods of analysis are diverse.

The U.S. Department of Agriculture, Forest Service, does not necessarily endorse the data, methods, or conclusions presented in these papers. Most of these papers were presented at a technical session of the 19th World Congress of the International Union of Forestry Research Organizations, which was held in Montreal, Canada, on August 5-11, 1990. Special thanks are due IUFRO and its officers for providing an international forum for the presentation of this economic research and to Ms. Susan Medlarz, program manager of the USDA Forest Service's Southern Global Change Program, who generously supported the publication of this volume.

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Contents

The Economic Effects of Air Pollution on Timber Markets

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ABSTRACT

Air pollution damage to the environment has increased in recent years, and the threat to forests is now a matter of public concern. Economic assessments can provide useful information to assist lawmakers in establishing the optimal level of pollution control. Yet, despite the usefulness of economic assessments to legislators, they were largely neglected in the major air pollution assessment programs. Research papers in this volume contribute to increased understanding of the economics of air pollution forestry damages in North America and Europe.

Keywords: externalities, acid rain, ozone, forests.

Introduction

This article provides historical and technical information about the economic evaluation of air pollution damage to forests. It is intended to serve as a prologue to the following papers, which are concerned with estimating economic losses of commercial timber due to air pollution. One of the studies is from Canada, two are from the United States, and two are from Europe.

Air Pollution as a Social Concern

Society has long been aware of anthropogenic air pollution. One of the earliest recorded air pollution incidents occurred in London during the 13th century, and was related to smoke and particulate matter released by the burning of coal (Fisher and Peterson 1976). Use of coal during the Industrial Revolution led to further reports of damage to structures and clothing (Pigou 1920). In the present century, fossil fuel consumption increased due to automobile use and electrical power generation, and the concern over air pollution likewise intensified. By the mid-1950's, ozone damage in Southern California had received national media attention.

Despite society's growing awareness, however, air pollution until fairly recently was considered a problem of mostly local consequence. This is evidenced by the fact that when the United States enacted its first national air pollution legislation—the Air Pollution Control Act of 1955—the issue was regarded as one best resolved by States and municipalities (Regens and Rycroft 1988). By the 1960's and 1970's, however, the public had come to view air pollution as a national and even international issue. This new perspective was due largely to a heightened concern about the environment (de Steiguer 1991), recognition of the regional nature of some pollutants, and the emergence of the so-called "acid rain" issue.

Acid rain was first brought to public attention by Swedish scientists in a 1972 report to the United Nations entitled "Air Pollution Across National Boundaries: The Impact on the Environment of Sulfur in Air and Precipitation" (Cowling 1982). By the late 1970's, a controversy in North America had also arisen related to supposed acid deposition damage in the Northeastern United States and Southern Canada. It was thought that sulfur dioxide and heavy metals emanating from the industrialized regions of, principally, the United States had caused this damage.

In 1980, partly as a result of international political pressures, the United States government created the National Acid Precipitation Assessment Program (NAPAP) to explore the possible extent of damage to aquatic and terrestrial ecosystems, human health, and man-made materials. NAPAP's principal activities ended in the fall of 1990, at about the time of the passage of the monumental Clean Air Act of 1990 (P.L. 101-549, November 15, 1990), the first new piece of clean air legislation in the U.S. since 1977.

Air Pollution and Forest Productivity

Air pollutants such as acid deposition, ozone, heavy metals, and particulate matter are known to harm various natural biologic systems and man-made materials. Air pollutants affect forest productivity by means of complex chemical, physical, and biological processes (NAPAP 1990). When pollutants contact leaves, branches, stems, or roots they may be taken in by the tree. Once this has occurred, the primary

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physiological effects are reduced photosynthesis, increased respiration, and altered allocation of photosynthates (e.g., starches and sugars).

The extent to which individual trees are affected by air pollution is influenced by a number of factors including: (1) inherent sensitivity of the tree species, (2) genetic constitution of the individual tree, (3) chemical composition of the pollutant, (4) timing, duration, and concentration of the exposure, (5) time elapsed between exposures, and (6) buffering capacity of the soil. Thus, the effects may vary considerably among individual trees within a forest stand. This variability coupled with the possibility for compensatory growth by unaffected trees, may result in very little decrease in net stand productivity. Also, certain pollutants contain plant nutrients, such as sulfur and nitrogen, which may even stimulate tree growth.

The manifestations of pollution-induced forest changes typically are subtle and difficult to detect. Indeed, symptoms seldom are so unique and graphic that air pollution can be unequivocally identified as the primary cause of forest injury. In 1984 Cowling reported on a trip to West Germany, where he had observed the evidence of "Waldsterben"—a rapidly developing pattern of coniferous and deciduous forest conditions that some hypothesize may be linked to air pollution. The evidence that Cowling saw included a general thinning and change of color in the canopy, smaller than normal leaves, loss of needles and leaves, decrease in diameter growth during the previous 10 to 20 years, and very heavy cone and seed crops symptomatic of tree distress. Cowling (1985) also reported that symptoms similar to these had spread very rapidly and by 1984 affected approximately 50 percent of the West German forests.

In North America, reports of changes in forest conditions during the 1980's gave rise to concern about pollution-caused declines in forest health. These changes included growth rate decreases and mortality in high-elevation spruce-fir forests of the Appalachian Mountains, growth rate reductions among pines in the Southeast, crown dieback and decreased syrup production among sugar maples in Canada and the United States, and mortality, decreased growth rates, and reduced regeneration among ponderosa and Jeffrey pines in California (NAPAP 1990). Scientists engaged in forestry air pollution studies judged that ozone was the most likely cause of forest damage in the U.S. and that acid deposition was probably a contributing factor only in high elevation spruce-fir forests of the Appalachian Mountains (de Steiguer and others 1990).

Air Pollution Damage as an Economic Problem

Few would dispute that society is poorer when its forests are harmed by pollution. Yet, as desirable as pollution reduction may seem, that too involves costs that can be large. Thus, the question "How much pollution control?" is largely a resource allocation issue within the purview of the economist.

Environmental economists maintain that, in a particular market, economic welfare is maximized when marginal social costs (MCs) are equated with marginal social benefits (MBs) as illustrated in figure 1 (Just and others 1982). The hypothetical market pictured here achieves equilibrium with a socially optimal production level of q* sold at the price of p*. Society's net welfare is measured by the value of the triangular area bounded above by the schedule of marginal social benefits and below by the schedule of marginal social costs (area a + area b).

The marginal social benefits curve represents society's "total willingness to pay." In other words, it represents the maximum amount that members of society would be willing to pay in order to consume various quantities of the good. The marginal social cost curve is, in effect, society's supply schedule for the good in question. The area under this curve represents the total cost to society of obtaining the good. And the price line at p*, of course, represents the amount which must be paid for the good.

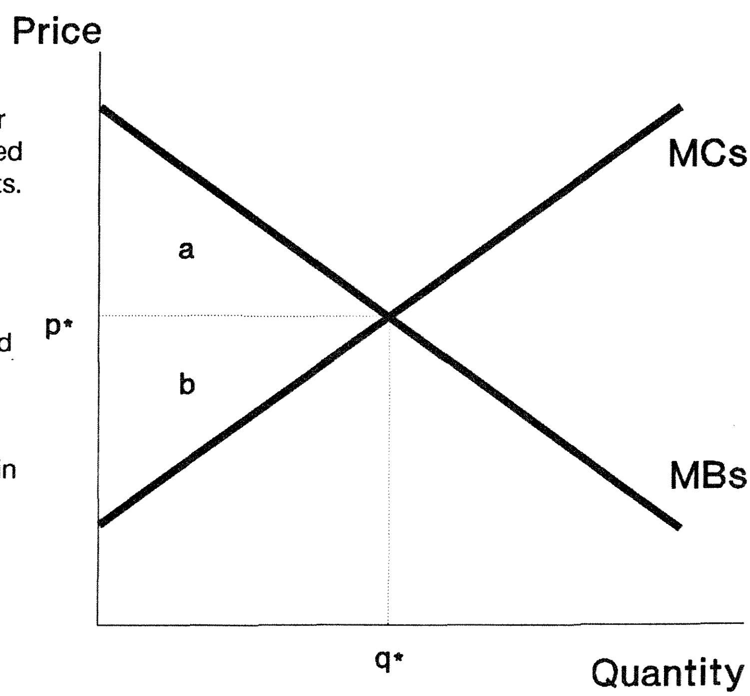

Figure 1.—Equating marginal social benefits with marginal social costs will insure that economic welfare is maximized. Area a represents welfare accruing to consumers, while producers derive the value of area b.

It is possible to apportion total welfare between two general groups of economic agents: producers and consumers. In figure 1, the right triangle a, the area below the marginal social benefit curve and above the price line, is that portion of total welfare received by consumers in the form of "consumer surplus." The notion of consumer surplus derives from the fact that area a represents the satisfaction that consumers receive in excess of the price that they must pay to obtain the good in question. Area b represents the value received by producers in the form of producer surplus. It can be analogous to profits earned by a firm—the difference between costs and revenues. The distribution of producer and consumer surplus is said to be Pareto optimal if no economic agent can make a gain in welfare (i.e., surplus) except at the expense of another.

In contrast to this hypothetical market, some actual markets may fail to reach a socially desirable equilibrium due to market failure in the form of external diseconomies. An external diseconomy is said to occur when marginal social costs exceed marginal private costs. In other words, the cost to the parties who directly produce and consume the good (i.e., private cost) is less than the overall cost to society. An external diseconomy exists usually because of a market failure related to the common property nature of resources such as air or water. Ownership rights for these common property resources are not well specified; such resources belong to everyone and hence to no one. Thus, air and water can be used freely for disposal of noxious materials, and an environmental cost "external" to the initial market transaction is borne by innocent third parties.

The effect of an external diseconomy on economic welfare is depicted in figure 2. In this example, the market is for fossil fuel energy resources, those being the main source of air pollutants. In figure 2, a marginal external cost (MCe) is imposed on society due to the production and consumption of fossil fuels. (More on the forestry portion of this external cost later.) When this marginal external cost is added to marginal private production cost (MCp) the result is marginal social cost (MCs). In the marketplace, production will occur where MCp=MBp (in this case MBp=MBs). The equilibrium output is quantity q' units of fuel at price p' per unit. The total external cost is equal to area f + area g, and this is identical, by definition, to the area bounded by ABFD.

At this q' level of market activity, the triangle ABC appears to be the appropriate measure of consumer and producer surplus, and hence economic welfare. However, the cross-hatched area is in fact received at the expense of external agents (those innocent third parties), and thus the true measure of economic welfare is the area of triangle DEC minus the deadweight social loss represented by triangle h. If

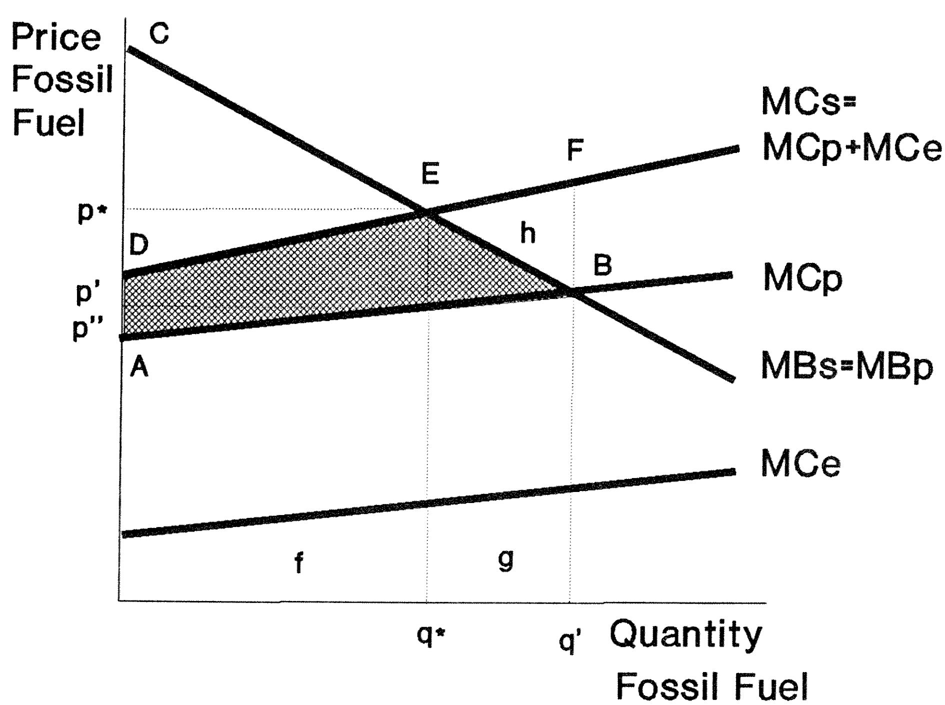

Figure 2.—Air pollution externalities resulting from fossil fuel combustion decrease the economic welfare of society. Society would increase its well being by raising fuel price from p' to p* thus lowering fuel consumption from q' to q*.

production were to occur at the socially optimal level MCs=MBs, then fossil fuel output would be q* at price p*. Social welfare would be maximized at a size equal to triangle DEC. Therefore, in the situation we have analyzed, the value of the optimal level of pollution control would be equal to the vertical distance between MCp and MCs at production level q* (i.e., p*-p") times q*. This would lower external damages by an amount equal to the area of g. An external cost in the amount of area f would remain, and could be justified on the grounds that it would be economically inefficient to eliminate all pollution. This economic efficiency argument is ignored by those who argue for complete elimination of all pollutants.

This analysis of external diseconomies allows some general statements to be made. When an external diseconomy exists in the fossil fuel market, too much fuel is produced and consumed, and prices charged for the fuel are too low. Social welfare is not maximized, and there are no existing market incentives to search for a welfare maximizing level of production. Also, very importantly, the presence of externalities defines a possible role for outside intervention to correct market failure and thus maximize economic welfare in a Pareto optimal manner.

Thus far we have discussed how the existence of air pollution-related externalities imposes costs on society. Recall that, in the case illustrated by figure 2, the amount of the external social cost was equal to area f + area g (which was also equivalent to the area bounded by ABFD). These areas represent all external costs related to pollutant damage stemming from the consumption and production of fossil fuels—the value of human morbidity and mortality, crop losses, damage to paint, buildings, and other man-made items, as well as damages to commercial timber. Economic theory does not specify how much of area f + area g in figure 2 consists of forestry damages. This is an empirical issue the following articles will address. However, we can specify how those calculations should be made.

Figure 3 represents supply and demand conditions for the timber market. If the market is free of pollution-related forestry losses, timber supply schedule S and timber demand schedule D will prevail. Thus the market equilibrium occurs where timber demand D is equal to supply S, and quantity q* clears the market at price p*. Surplus accrues to timber growers in the amount of a+b+c. Mill owners enjoy surplus in the amount area d+e+f+g.

In order to assess the impact of air pollution on timber markets, it is necessary to briefly review the concepts of timber demand and supply (Johansson and Lofgren 1985). The market demand schedule in figure 3 represents an aggregation of the demands of individual agents in the market. It is a derived demand, in the sense that it stems from consumers' demand for final products manufactured from timber. The

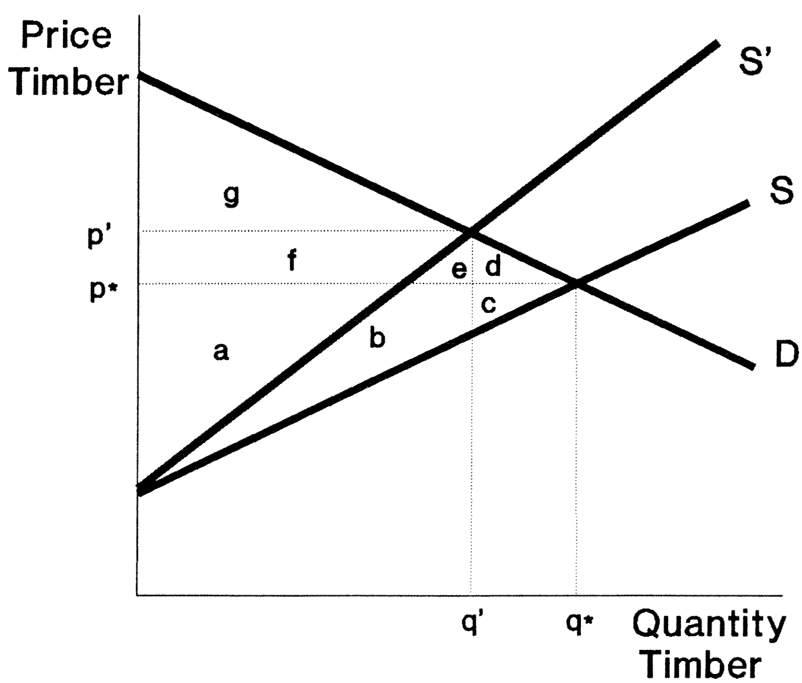

Figure 3.—Air pollution damage to standing timber causes the timber supply function to decrease by the amount of the shift from S to S'. The net value loss to society is equivalent to area b+c+d+e.

market demand for timber is a function not only of timber price (as shown in figure 3) but also of the prices of final wood products and all other variable factors of production.

The market timber supply schedule in figure 3 also represents an aggregation of all individual agents' supply functions. Market supply, like demand, is a function of timber price, although the relationship between supply and price is positive rather than negative. Supply is also a function of other timber production costs which are related to the amount of standing timber inventory. Changes in timber prices will cause movements along a supply schedule; however, changes in production costs or inventory will bring about upward or downward shifts in the entire supply function. If, for example, air pollution causes losses to timber inventory through growth reduction or mortality, the supply schedule will rotate upward toward the price axis. This case is illustrated in figure 3 by supply curve S'. The intersection of the new timber supply schedule S' and the old demand curve D sets a lower equilibrium harvest quantity q' at the higher price p'. Mill owners now have a surplus equal to area g, and the value equal to area f has been transferred to growers, who retain area a. Area b+c+d+e now represents forestry's contribution to total external costs (i.e., forestry's portion of area f + area g in figure 2). Any reduction in air pollution will cause a shift of S' back toward its original position at S. The amount of that shift measured as a decrease in the triangular area between S' and S would be the economic benefit from commercial forestry due to pollution reduction.

NAPAP and Forestry Economic Assessments

From the foregoing, we have seen that economic assessments can provide helpful information to guide in the reduction of air pollution damage. However, despite the apparent usefulness of economic analyses in resolving air pollution problems, there has been surprisingly little support for these studies. This lack of support is nowhere better exemplified than by NAPAP's neglect of their own economic assessment. Said the NAPAP Oversight Review Board (1991) in its final appraisal of the Program:

> "...somewhere along the way, the assessment focus...was lost and priorities appeared to be set by scientific and technical rather than assessment needs...major questions such as those involving economic effects...were not given enough attention (p.27)."

NAPAP's shortcomings apparently were due to administrative personnel changes which occurred midway through the Program. Nevertheless, the lack of a proper economic assessment will be a lasting NAPAP legacy. NAPAP was a also missed opportunity to advance the state of knowledge regarding methods for air pollution economic assessments. The economic information NAPAP did contribute is contained in NAPAP State of the Science and Technology Report 27, "Methods for valuing acidic deposition and air pollution effects" (Brown and Callaway 1990). The forestry portion of that document is largely reflected in the article by Haynes and Adams in the present volume.

The papers that follow are a series of studies from North America and Europe on the economic evaluation of air pollution damage to forests. They represent the current state of knowledge about the subject. It is our hope that those who read these papers will be encouraged to develop new economic studies which will help us to manage the environment more effectively.

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The Potential Benefits to Canadian Commercial Forestry from Acid Rain Control

G. Alex. Fraser[1]

ABSTRACT

Forestry Canada conducted a Delphi survey of 39 Canadian and American scientific experts on the effects of air pollution on forests. Information obtained indicates that forest productivity will decline by between 8 and 11 percent in Eastern Canada and between 1 and 2 percent in Western Canada by the year 2014 under a status quo scenario. If long-range air pollution is reduced by 50 percent, productivity will increase modestly in Eastern Canada and will change little in other regions. The total difference between harvests under the two scenarios would be about 10-11 million cubic meters per year. Reduction of long-range air pollution by 50 percent would result in annual gains of $154 million in wages and salaries and overall annual economic efficiency benefits of more than $800 million.

Keywords: pollution, forestry, acid rain, economic benefits

Introduction

Forests cover much of the Canadian landscape and forestry is one of Canada's most important resource industries, providing income and employment to many thousands of Canadians. Numerous studies conducted near smelters and other point source polluters have demonstrated a relationship between air pollution and forest damage in Canada. Very obvious forest damage near Sudbury, Ontario, site of the world's largest nickel smelter, is a high-profile example of potential adverse effects of air pollution. In the early 1980's, extensive damage to European forests (most notably in West Germany) received significant media attention and raised much public concern over the potential impact of acid rain on Canadian forests. Although the cause of the European forest decline was uncertain, circumstantial evidence pointed to air pollution as a primary causal factor.

In 1984, Canadian public concern was expressed at a political level in the demand for an assessment of the potential economic consequences of pollution-caused forest decline. In response to this demand, Forestry Canada (Canada's national forestry agency) initiated a major research project to:

(1) Document the long-run impacts of acid rain on Canada's national forest resources.
(2) Estimate the potential long-run impacts of acid rain on Canada's forest harvest.
(3) Estimate the impacts of acid rain on the income and employment generated by Canada's forest industry.

This paper summarizes the results of the research.

Impacts on the Forest Resource

By 1984, the impact of acid rain (or more generally the long-range transport of air pollutants) on forest growth and mortality in North America had been studied intensively for several years. However, laboratory investigations had indicated that acidic deposition had beneficial, adverse, or undetectable effects on forests depending upon the particular tree species studied, the soil type, the experimental conditions, and a number of other considerations. Similarly, field investigations that were supposed to identify relationships between changes in tree growth and pollution level had been inconclusive.

Given the uncertainty about the nature and extent of forest productivity effects, the only feasible approach to developing forest impact scenarios was the pooling of expert opinion. A group of 39 recognized Canadian and American scientific experts on interactions between air pollution and forests was selected through peer nomination,[2] and these individuals were asked to participate in a Delphi survey process. The Delphi technique was developed by Dalkey and his associates at the Rand Corporation in the 1950's. The method employs carefully designed sequential questionnaires, summarized information, and feedback of opinions from earlier responses to establish consensus on an uncertain subject.

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[2]More than 60 scientists working in the area of air pollution and forest interactions were contacted and asked to nominate colleagues whom they considered to be the most knowledgeable in the field. Those named most frequently were chosen as the panel of experts.

In this instance, four questionnaires were used. The first contained general questions intended to identify the full range of potential relationships between acid rain and forest productivity. Respondents were encouraged to give written responses and to support their opinions fully. The information obtained was summarized and used to structure focused statements and hypotheses about the relationship between acid rain and forest productivity. The respondents were then asked to rate the likelihoods of these hypotheses on a five-point scale from "most likely" to "most unlikely." In addition, the respondents were asked to estimate the size of any quantitative impacts of acid rain on forest productivity.

The final results were the aggregated views of scientific experts on a wide variety of issues. For example, the likelihood of specific physical processes causing forest productivity changes was reviewed and assessed. Also, the sensitivity of individual tree species to long-range air pollution was rated. The findings we will discuss here relate to the likely effects of acid rain on forest productivity under alternative scenarios of the future. In the second scenario ("50-percent decline"), the respondents estimated these effects for four regions of Canada (Atlantic Provinces, Quebec-Ontario, Prairies, and British Columbia) and for two time frames (10 years and 30 years).

The first scenario ("status quo") was one in which no additional pollution control measures are imposed. The respondents judged it likely that pollution levels will increase as a result of economic and population growth in the absence of additional control measures. The experts also judged it highly likely that forest productivity would decline in both the Atlantic Provinces and the Quebec-Ontario regions under this scenario. The average expected forest productivity losses were 8 percent (Atlantic Provinces) and 11 percent (Quebec-Ontario) over 30 years (to the year 2014). Expectations for Western Canada were somewhat more optimistic. Even with increasing pollution levels under a status quo scenario, "no change" in forest productivity was considered the most likely outcome. However, mean quantitative responses indicated that the experts expected forest productivity in Western Canada to decline by 2 percent over the 30-year forecast period.

In the second scenario ("50-percent decline"), the respondents were asked to assume that pollution levels would be reduced by 50 percent over a 10-year period (by 1994) and that the new lower pollution levels would then be maintained indefinitely. In this case, "no change" in forest productivity was considered the most likely outcome for all regions of the country. An increase in forest productivity was considered the next most likely outcome for Eastern Canada. Mean quantitative responses indicated small (1-2 percent) statistically insignificant incidences in forest productivity in Eastern Canada and smaller (0-1 percent) statistically insignificant declines in Western Canada.

The mean estimated percentage changes in forest productivity by the year 2014 under both scenarios are summarized in table 1. While some caution should be exercised in interpreting these results, it should be remembered that these results represent the aggregate judgment of scientists who are considered to be the most knowledgeable in this particular area of research. Their opinions represent the best informed judgment about the impact of acid rain on forest productivity.

Table 1--Estimated Percentage Changes in Forest Productivity by the year 2014 under alternative pollution control scenarios

Region	"Status quo"	"50-percent decline"
	- - - - - Percent	- - - - -
Atlantic Provinces	- 8.35	+ 1.20*
Quebec-Ontario	-11.53	+ 1.68*
Prairies	- 1.63	- 0.16*
British Columbia	- 2.30	- 0.07*

*Not significantly different from zero at a 95-percent confidence level.

Impacts on the Harvest Rate

The previous section reported the aggregate judgment of expert scientists regarding the impact of acid rain on Canadian forest productivity under alternative scenarios of the future. However, the relationship between forest productivity and the harvest rate is not necessarily direct or immediate. The nature of the forest productivity change, the response of forest management agencies, and other variables significantly affect the impacts of productivity change on the flow of harvests.

Studies of point source pollution have shown that forest productivity losses result from two types of forest damage. First, there may be a widespread reduction in forest growth and yield as a result of pollution. Second, there may be mortality of certain sensitive tree species. In the Delphi survey, the scientific experts were asked to estimate how any potential forest productivity loss would be distributed between these categories. Very clearly, scientists expect growth reduction to be the predominant effect in any forest productivity loss (table 2). Tree mortality is expected to account for only 26 to 28 percent of total losses even in Eastern Canada. Mortality is expected to account for only 15 to 18 percent of productivity loss in Western Canada.

Forest managers can respond to both types of damage in a variety of ways. It was assumed that the effects of pollution-induced tree mortality in Canada would be diffused throughout the entire forest and over the entire rotation period. Thus, an X-percent productivity loss due to pollution-induced mortality was assumed to result in an immediate X-percent reduction in the harvest rate. In contrast, growth reductions were assumed to affect the harvest rate gradually over 50 years. Because each tree accumulates growth over its entire life cycle, an immediate reduction in harvest rates to reflect the full pollution-induced growth reduction would be inappropriate.

The above assumptions were applied to annual average 1981-1985 harvest levels in order to generate an 80-year harvest projection for each region. The national forecasts under the two alternative pollution

Table 2--Estimated distribution of forest productivity effects between mortality and growth reduction by the year 2014

Region	Mortality	Growth reduction
	Percent	Percent
Atlantic Provinces	26	74
Quebec-Ontario	28	72
Prairies-NWT	15	85
BC-Yukon	18	82

control scenarios are summarized in table 3. Under the status quo scenario (no additional pollution control measures), harvests are projected to decline. When there is a 50-percent reduction in pollution levels, harvest levels are generally maintained in all regions and are projected to increase slightly in Eastern Canada.

The difference between the projected volumes of timber harvested under the status quo and the increased regulation scenarios, represents the estimated harvest rate benefit of pollution control. These benefits are low in the short term. However, the benefits increase consistently over time as growth reduction begins to affect the system. By the year 2064, nationwide differences between projected status quo and increased regulation harvest volumes exceed 10 million cubic meters (about 6 percent of the current national harvest). Approximately 70 percent of this difference is accounted for by the Quebec-Ontario region, the area most significantly affected by acid rain.

Economic and Social Impacts

The preceding sections outline the potential impacts of acid rain on forest productivity and provide an estimate of Canadian harvests under two scenarios of the future. Lower harvest rates under the status quo scenario imply a reduced supply of raw material for forest industry. A reduction in the supply of raw material can be expected to result in lower employment, wages, and net returns to forest industry. The differences between employment, wages, and net returns under the status quo and employment, wages, and net returns under the pollution control scenario are the economic and social benefits of pollution control (table 4).

It is estimated that the increased harvests resulting from a 50-percent reduction in pollution levels, will generate a 5,500 person year increase in employment and additional annual wages and salaries of Can $154 million in 1983 dollars. These benefits are expected to be realized within 20 years. This is because the increased harvests resulting from the avoidance of tree mortality are expected to affect employment and income in forest industry more directly than is the avoidance of forest growth reductions.

However, the avoidance of growth reduction is expected to have the more significant effect on economic efficiency or net returns to forest industry. The availability of larger trees as a result of pollution control will result in more efficient harvesting and processing. In effect, average costs per unit of harvest are expected to decline gradually over a significant period of time. As a result, the major economic efficiency benefits are modest early in the projection period and then increase dramatically well into the future. Eventual economic benefits of additional pollution control are estimated at Can $814 million (1983 dollars) per annum. However, these levels of economic benefit are not realized until the year 2064.

Summary

Public concerns about acid rain in the early 1980's encouraged Forestry Canada to undertake a detailed assessment of the potential effects of air pollution on Canada's forest resources and forest industry. Initial investigation indicated that there was considerable scientific uncertainty about the effect of long-range air pollution on forest productivity. However, a survey of scientific experts in the field of forest and air pollution interactions showed that there was a strong consensus that forest damage was already occurring and would intensify in the future in the absence of steps to control pollution levels.

Estimates provided by the scientific experts suggested that forest productivity in Eastern Canada would decline by between 8 and 11 percent over a 30-year period under a status quo scenario. While no change in forest productivity was considered the most likely outcome in Western Canada, small percentage declines in forest productivity were still projected. In contrast, an aggressive program of pollution controls that reduced long-range air pollution levels by 50 percent was expected to maintain current levels of forest productivity and effect some modest improvements in Eastern Canada.

Analysis indicated that Canada's annual timber harvest will be 10 to 11 million cubic meters (6 percent) greater if long-range air pollution levels are reduced to 50 percent of 1984 levels then it will be if no additional control measures are imposed. This difference is interpreted in this paper as the potential

Table 3--Projected harvests under alternative pollution control scenarios

Year	"Status quo"	"50-percent decline"	Benefits of control
	Million cubic meters		
1994	151.2	152.8	1.6
2004	150.3	153.0	2.7
2014	148.5	153.2	4.7
2024	147.4	153.3	5.9
2034	146.3	153.4	7.1
2044	145.2	153.6	8.4
2054	144.1	153.7	9.6
2064	143.1	153.9	10.8

Table 4--Economic and social benefits of a 50-percent reduction in pollution for selected years

	Year			
Benefit[a]	1994	2014	2034	2064
Wages and salaries (million 1983 Can $)	75.6	154.3	154.3	154.3
Employment (person years)	2708	5509	5509	5509
Economic efficiency (million 1983 Can $)	3.2	199.9	445.5	814.3

[a]Difference between value of item with a 50-percent reduction in pollution and value of item if no additional pollution control measures are imposed.

benefit of additional pollution control. However, it can also be viewed as the potential cost of failing to control pollution levels.

The increased harvests possible with pollution control would generate substantial social and economic benefits. Employment would be increased by approximately 5,500 person years, while wages and salaries would be increased by Can $154 million. Overall economic efficiency benefits might exceed Can $800 million per annum. However, it is worth emphasizing that most of these benefits would be realized only well in the future.

The risk of forest damage without additional controls and the potential size of the benefits from controls justifies significant effort to control pollution.

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Assessing Economic Impacts of Air Pollution Damage to U.S. Forests

Richard W. Haynes and Darius M. Adams[1]

ABSTRACT

This past decade has seen the emergence of concerns regarding forest decline possibly caused by acid rain or other air pollutants. In the U.S. attempts to estimate the economic impacts associated with forest decline have involved the application of forest sector models that combine economic and biological models. The economic impacts associated with prospective forest (growth) declines are concentrated in the Southern United States. On net, declines in forest growth lead to a reduction in overall welfare because they cause prices to increase throughout the forest sector. Consumers are impacted more than producers but these impacts are slow to develop as they depend on changes in timber inventories.

Keywords: forest sector models, timber supply-demand models.

Introduction

This past decade has seen the emergence in the United States of scientific concern about forest decline possibly caused by acid rain, other air pollutants, or global climate change. These concerns have evoked public apprehension and led to large-scale research programs such as the Forest Response Program (FRP) (Schroeder and Kiester 1989) and the National Acid Precipitation Assessment Program (NAPAP).[2] A major goal of NAPAP was to generate information useful in assessing the biologic and economic benefits of regulating specific pollutants.

Most of the research concern has focused on physical impacts and the need to integrate results from fundamentally different kinds of research. There has been less interest in determining how to measure prospective economic impacts or evaluate equity implications of forest decline. Without this type of analysis, however, it will be difficult to convince policy makers of the need to shift policy. This is especially true for decisions that involve intergenerational equity.

The purpose of this paper is to describe both the method for valuing the effects of acidic deposition, air pollution, or global climate change on forests and some of the prospective economic impacts. This work was originally done as part of the NAPAP effort (Haynes and Kaiser 1990).

Methods Used in the U.S. To Estimate Economic Impacts

The methods used to identify and value the economic impacts of changes in forest productivity induced by acid deposition are largely those used by the U.S. Department of Agriculture Forest Service in the periodic assessments required by the Resources Planning Act (RPA).[3] The primary tool used is a model of the U.S. forest sector.[4] This model, TAMM (the Timber Assessment Market Model[5]), provides an integrated structure for considering the behavior of prices, consumption, and production in both stumpage and product markets. It includes a timber inventory projection system (ATLAS) that is an age-class yield function model. With TAMM, the simulation process for acidic deposition involves reducing the yield functions for various forest types by specified amounts. Reductions in the yield functions represent lower growth and, consequently, lower inventories. Lower inventories over time result in lower stumpage supplies, higher stumpage prices, and reduced product consumption and production. In the TAMM framework, the impact of reduced growth is not felt until inventories change enough to affect harvest levels since stumpage supply relationships are a function of timber inventory levels and prices.

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[2]The NAPAP effort includes studies of the causes and effects of acidic deposition and related control and mitigation strategies.

[3]More precisely the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 and its subsequent amendment by the National Forest Management Act (NFMA) of 1976.

[4]Forest sector models generally combine 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 and others 1987).

[5]The original model is described in Adams and Haynes (1980) and Haynes and Adams (1985).

Further, the eventual impact depends on the markets for timber. Impacts in strong markets, such as those for southern pine, will show up faster than impacts in weaker markets.

The solution of TAMM represents a spatial equilibrium in the markets modeled for each year of the projection period. These solutions do not represent, nor can the basic market solution algorithm[6] be readily used to find, intertemporal production or consumption strategies that are in some sense optimal. The production, consumption, and price time paths are only estimates of outcomes of contemporaneous interactions in freely competitive markets. Details about the various input assumptions used in TAMM are described in the 1989 RPA Timber Assessment (Haynes 1990).

TAMM is composed of 10 major parts with inputs from 4 other models—Pulp, Trade, Fuelwood, and Land Area Change (fig. 1). TAMM includes four types of supply and demand functions. Supply and demand are explicitly defined for each of the product markets. In the stumpage market, supply is explicitly defined for different timberland ownerships but stumpage demand is derived from roundwood input requirements.

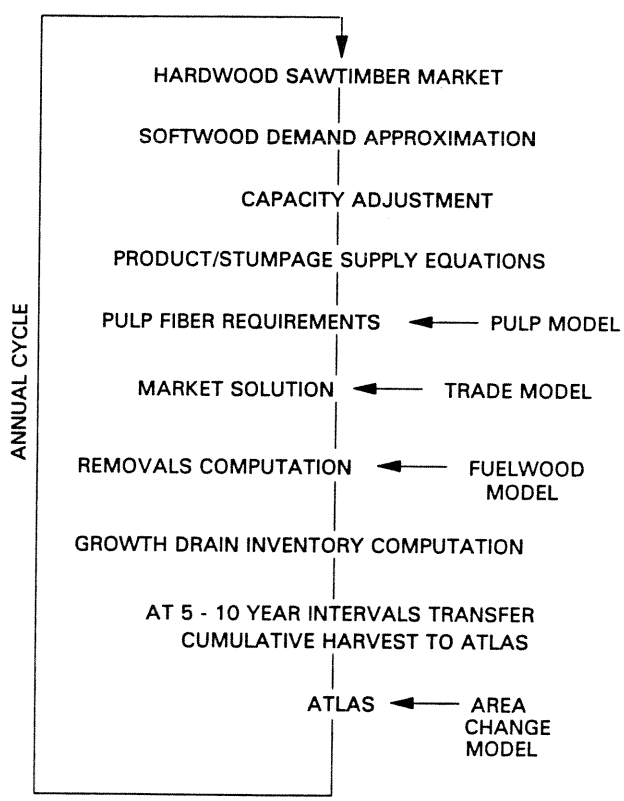

Figure 1.—General Structure of the TAMM/ATLAS Model

Model solution involves the simultaneous solution of both product and factor (stumpage) markets. Since these relations are defined for regions as well, the solution represents an equilibrium in both markets across regions. The procedure used for model solution is much the same as that described in Adams and Haynes (1980). Briefly, product demand, such as demand for softwood lumber, is obtained by multiplying the ratio of product use per unit of activity (for example, the amount of lumber used per house) times the number of units (in this example, the number of housing starts) and summing these results over all the end uses for the product. The activity measures are exogenous and taken from long-term macro forecasts (see WEFA 1987). The demand relationships are regionalized by accounting for differences in regional per capita consumption and the ratio of regional prices to national prices. On the demand side, hardwood lumber is treated in about the same end use detail as softwood lumber but the model is not spatial. Price is determined by simple supply and demand equality.

The product supply equations are generally functions of product prices, average variable production costs, and installed capacity. Average variable costs are costs of wood and nonwood elements that have been converted to a unit output basis by means of product recovery and productivity factors that reflect the current (or projected) technology of the industry. The role of capacity has been expanded in TAMM in that each product supply function has installed capacity as an independent variable. Capacity change is modeled as a function of anticipated changes in relative regional profitability or rate of return. Private sawtimber[7] supply is modeled for each region and ownership class as a function of stumpage price and growing stock timber inventory. Public sawtimber supplies the allowable sale quantity determined by each agency. Finally, the sawtimber demand functions are the sum of the roundwood equivalents of lumber demand, plywood demand, and log exports. Wood volumes used for OSB-waferboard output, pulp, miscellaneous products, and fuelwood are determined outside TAMM and deducted from inventories but do

[6]A revised reactive programming algorithm is used (Brooks and Kincaid 1987). Briefly, reactive programming is a method for solving continuous demand and supply functions by successive adjustment of quantities produced and their distribution to demand regions so as to maximize producer profits net of transport costs in each supply region.

[7]Sawtimber stumpage includes live trees of commercial species containing at least one 4-meter sawlog or two noncontiguous 3-meter logs, and meeting regional specifications for freedom from defect. Softwood trees must be at least 23 centimeters dbh, and hardwood trees must be at least 28 centimeters dbh.

not directly influence sawtimber stumpage prices. The pulp fiber requirements are input variables from a pulp model developed by Ince, Durbak, and Howard (in press). Trade and fuelwood projections are also input variables. The trade projections used in these simulations reflect a future in which the U.S. remains a net importer of softwood forest products.
Since the supply of timber at any point in time is a function of private timber inventory levels, TAMM includes a biological model of U.S. timberlands. The inventory projection system currently used is the Aggregate Timberland Assessment System (ATLAS). It only considers the timber inventory on private timberland producing or capable of producing crops of industrial wood and not withdrawn from timber harvesting by statute or administrative regulation. Currently, areas qualifying as timberland have the capability of producing in excess of 0.6 cubic meters of industrial wood per hectare per year in natural stands and may be inaccessible, inoperable, or both. Further, these models include only live trees 13 centimeters dbh and larger of commercial species and meeting specified standards of quality or vigor. Cull trees are excluded.

ATLAS is an age-based, yield-table system that projects acres by detailed strata for periods consistent with the inventory stand-age classes. It evolved from earlier work by Beuter, Johnson, and Scheurman (1976) and Tedder, LaMont, and Kincaid (1987). In the model, the inventory is represented by acreage cells classified by region, ownership, management type, management intensity, and age class. In the South, the strata were also identified by site productivity class and stocking class. This study used 10-year age classes in all regions except the South, where 5-year age classes were used.

In each simulation period, inventory change is the result of growth, area change, and timber harvest. Growth is the result of acres following upward-sloping net yield functions that are calculated with approach-to-normal assumptions. Each cell in the starting inventory may have an independent yield function. An important attribute of the model is that it can simulate shifts in management intensities and consequent changes in yields based upon alternative assumptions about the future. The inventory model is not exclusively an even-age model since it can simulate growth and removal processes across all age classes. ATLAS can also account for both partial harvests and commercial thinning. Volume can be removed at harvest from the oldest age class or spread across several age classes. Final-harvested acres can be assumed to be regenerated to any management type or leave the timberland base entirely. Partial cutting is assumed to remove the overstory, and the residual stand takes on the characteristics of the understory stand. Simulating the effects of growth declines involves shifting the yield functions downward.

Inputs to the inventory model include estimates of harvest, acreage shifts, and growth parameters. The levels of harvest are derived through interaction with TAMM. Area change information is supplied by a modified version of the Southern Area Model (SAM) (Alig 1985). Yield tables and approach-to-normal parameters were derived from timberland inventory plot data collected by the various USDA Forest Service Forest Inventory and Analysis Units and from previous studies. The inventory data inputs are summarized in Mills (1988).

Estimation of Economic Impacts

De Steiguer and Pye (1988) recently estimated the damage air pollutants cause to major U.S. forest ecosystems. Their purpose was to provide information to be used in the economic assessments required under NAPAP. De Steiguer and Pye's findings regarding periodic growth reductions can be summarized as follows:

Growth Reductions

	Hardwood types	Softwood types
	- - - - - - - - -Percent-	*- - - - - - - - -*
North	-5	- 5
South	-5	-10

We incorporate these growth reductions into TAMM by lowering projected yields in all ages and stand types by the appropriate percentages for softwoods or hardwoods. Softwood growth reductions were assumed to be 10 percent in all regions. The yield shifts take place immediately (by 1990) so that all future stands have reduced volumes at harvest.

The impacts of these changes are presented as deviations from the 1989 RPA Timber Assessment's base simulation of future market and resource conditions with no growth reductions (Haynes 1990). This projection portrays a future of continued increases in final product demand, somewhat slower increases in product and stumpage supply, and rising real product and stumpage prices. The projections also portray tight stumpage markets in the South, especially during the period 2000-2010. It is expected that stumpage supply in the North will be ample and that prices will increase modestly in that region.

Growth, inventory, and harvest projections for two regions in the Eastern U.S. are shown in table 1. Projected growth falls quickly relative to the base simulation but not by the exact amounts (5 to 10 percent) of the yield function shifts. The difference results from shifts in the age classes, stand density, and species composition of the inventory relative to the base case.

Inventories change somewhat less rapidly and the impacts cumulate over time. By 2000, inventories for all species in the Northeast and hardwoods in the Southeast are only 3 to 4 percent less than in the base simulation. Softwood inventories in the Southeast, however, are 9 percent lower than the base. This reflects the strong markets for softwood stumpage in the Southeast and the close balance between harvest and growth, with reduced yields forcing harvest into younger age classes. Hardwood inventories decline by 2040 to 6 percent less than the base projection in the Northeast and 10 percent less than the base projection in the Southeast.

Changes in harvest are a reflection of the market model. The reductions in inventories in the North for both softwoods and hardwoods are relatively small and insufficient to stimulate changes in sawtimber harvest. In the Southeast, there are changes in harvest levels for both softwoods and hardwoods but sawtimber harvest impacts are significant only for softwoods. Softwood sawtimber harvest drops 6 percent by 2000 and 21 percent by 2040. Smaller reductions in the near term reflect continued competitiveness of Southern products despite cost increases. The heavy harvesting in earlier years eventually forces inventory down and prices up sufficiently to constrict the South's market share.

Market impacts vary by species, regions, and product and stumpage markets, and over time (table 2). Except in the case of softwoods in the Southeast, near-term impacts are modest. Stumpage price increases in the Southeast are significant. They rise rapidly in the near term as the slowness of downward capacity adjustment (modeled as a function of profitability) leads to tight stumpage markets. Product prices rise and, in the case of softwood lumber, reduce U.S. consumption by 1 percent in 2000 and nearly 3 percent by 2040. The relationship between lumber and stumpage prices varies over time because of interregional adjustments in supply. U.S. lumber imports from Canada are 4 percent higher by 2000 and 38 percent higher by 2040. In general, production expands in Canada and slightly in western regions to offset reductions in the Eastern regions. Reduced growth rates eventually lower timber inventories and harvests. Economic impacts are based on the harvest declines. The most severe economic impacts are in the South, and especially in the Southeast, where expected declines in softwood inventories in the base case are further aggravated by the assumed declines in growth. Economic impacts for the North and for hardwoods are generally more modest. Another way to gauge economic impacts is to look at which groups (consumers, producers, and stumpage owners) gain or lose because of growth reductions associated with acidic deposition. Sample impacts are shown in table 3. As a group, consumers are the most affected. Changes in consumer expenditures for softwood lumber average 15 1988 dollars per household by 2040. In the near term (during the next two decades) potential consumer impacts are partially reduced by increased production in other regions and Canada. By 2020, the opportunities for this offsetting production are exhausted, and this increases total impacts. Producers lose revenue as stumpage prices increase in affected regions. In the South, these losses are greatest in the next decade but decrease after 2000 as producers reduce installed lumber capacity in response to lower harvest levels and higher stumpage prices. One interesting development is that reduced growth leads to increased plywood profits and production levels in the Southeast. As less timber becomes available, there is a shift from lumber to plywood production in the Southeast. This shift occurs because alternative sources of lumber are more numerous than alternative sources of plywood.

Least affected are stumpage owners who, in spite of lower harvest levels (because of reduced timber inventories), in the long-run see increases in revenues derived from the sale of sawtimber. These results are due, in large part, to the inelastic nature of the demand for stumpage.

Conclusions

Forest sector models such as TAMM/ATLAS provide a means of placing growth reductions or changes in the timberland base in perspective. They help show the relationship between biological and economic impacts, by species and regions, and make clear the temporal dimension of the impacts. These models provide a scientific framework for communication among those developing process models, those assessing future renewable natural resources, and those developing policies for managing those resources. These models can also show the impacts of changes in the forest sector in terms of changes in the economic welfare of producers and consumers and on the real wealth of timber producers. On net, sample gain and loss comparisons suggest that growth reductions will reult in higher prices throughout the forest sector and thus a reduction in overall welfare.

Table 1--Growth, inventory, and harvest reductions[a] due to possible damage caused by air pollutants

	Reduction					
	Growth		Inventory		Harvest[b]	
	Hardwood	Softwood	Hardwood	Softwood	Hardwood	Softwood
	Percent					
Northeast						
2000	6	10	3	4	--	--
2020	6	9	5	8	--	--
2040	5	8	6	11	--	--
Southeast						
2000	6	9	3	9	--	6
2020	6	8	9	15	--	18
2040	8	8	10	21	--	21

[a] Relative to base projection.
[b] Sawtimber harvest only.

Table 2--Economic impacts associated with growth reductions

	Price increase				
	Stumpage[a]			Lumber	
Year	Hardwood All Regions	Softwood Northeast	Softwood Southeast	Hardwood	Softwood
	Percent				
2000	2	8	31	11	3
2020	3	23	27	6	13
2040	3	31	51	2	10

[a]Sawtimber harvest only.

Table 3--Estimates of annual changes in economic welfare for lumber and plywood producers and consumers

Year	Consumer Surplus	Producer Surplus	Stumpage owners' revenues[a] (Southeast)
	Billions of 1988 dollars		
2000	-1.2	-0.30	0.03
2040	-7.2	-1.80	0.06

[a]Computed as the difference in stumpage price per thousand board feet times harvest.

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Economic Welfare Impacts of Air Pollution Damage to Forests in the Southern United States

Thomas P. Holmes[1]

ABSTRACT

The economic impact of a change in forest productivity due to atmospheric pollution is considered from an analytical perspective. A straightforward method is presented for estimating economic damage based on the properties of timber producers' indirect profit function and constant market demand. *Ex ante* estimates of the loss in producer and consumer welfare are derived for anticipated increases in pollution damage. The major conclusions of the study are that economic losses develop slowly over time and are relatively more severe in pulpwood markets than in solidwood markets.

Introduction

During the past decade a considerable amount of effort has been expended by the forestry research community in the United States to try and understand the impacts of air pollutants on forest ecosystems. Relatively little attention, however, has focused on understanding economic impacts of potential changes in forest productivity. Economic welfare analysis can inform the policy-making process by providing ex ante estimates of the costs and benefits associated with changes in the status quo. The purpose of this paper is to present a methodology for estimating the benefits accruing to the forest production sector (i.e. timber producers and consumers) associated with reductions in ambient air pollution. In this case, benefits represent damages avoided in terms of protecting forest productivity. The current analysis is limited in that we do not consider nontimber impacts such as recreation and wildlife.

Despite the controlled experiments and field studies conducted under the auspices of the National Acid Precipitation Assessment Program, considerable uncertainty remains regarding the physical impacts of air pollutants on forest ecosystems. A continuing cause for concern is forest inventory (FIA) data collected by the U.S. Forest Service which shows that net annual growth of natural pine forests in the Southeast has decreased during the past few decades (Sheffield and others 1985). While causal factors have not been positively identified, subsequent analysis of FIA data for Georgia and Alabama suggests that stand dynamics are not responsible for the growth decline (Ruark and others 1991). Dendroecological analysis has corroborated the existence of a growth decline and concluded that a decline in radial increment of 1 percent per year has occured in natural pine stands in the Piedmont region of the Southeast since 1950 (Zahner and others 1989).

An alternative method for evaluating regional forest decline is to survey scientists engaged in experimental and field research. This approach offers merit for policy analysis where a variety of scientific opinion exists. The results of an expert opinion survey reported by de Steiguer and others (1990) suggest that the annual volume growth changes in southern pine forests due to ambient levels of air pollution range between zero and 20 percent, with a median of 5 percent. Further, scientific opinion was that growth declines in southern pine forests were due to ozone pollution and not sulfur dioxide and nitrogen oxides, and that damage would become increasingly severe over time.

Preliminary estimates of forestry benefits resulting from reductions in atmospheric pollutants have been provided by Crocker (1985) and Haynes and Adams (1990). Crocker's model measures timber productivity damage as timber price times an anticipated reduction in market volume, yielding an estimated loss of $1.75 billion to the forestry sector. The Haynes and Adams model computes a spatial equilibrium for the national forest products economy. Perturbations of forest growth force changes in timber inventory which, in turn, shift timber supply curves. Estimates of damage for the year 2000 are a loss of $300 million for solidwood and pulp producers and a loss of $1.2 billion for wood products consumers. Impacts for timber producers are a revenue gain of $30 million due to higher prices.

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The inelastic nature of mill demand for timber as a raw material input suggests that reductions in timber supply lead to increases in revenue for timber producers. However, it does not necessarily follow that timber producers are better off following a reduction in timber supply because of impacts on production costs. To analyze the economic impacts of air pollution on the stumpage market, we combine economic theory with estimates of stumpage supply and demand and find that both timber producers and consumers are worse off following a reduction in forest productivity.

In the following section, a theoretical model of timber producer behavior is presented to demonstrate how changes in biological productivity can affect economic decisions, and how economic impacts can be estimated. Then the firm model of production is aggregated to a market model and welfare impacts are considered. Based on the theoretical development, a quantitative analysis is performed for southern pine forests. The final section discusses the implications of our analysis.

Southern Pine Economic Impacts of Potential Air Pollution Damage

Since the physiological impacts of atmospheric pollutants on forest growth are not certain, we utilize a particularly simple model of forest damage. The model we propose is consistent with gradual decline and could result from acid deposition or ozone impacts. A simple way to model a physiologic response which occurs over a tree's lifetime is to assume that timber volume decreases proportionally across all ages.

In particular, let v(t) represent timber volume as a function of time. Then a proportional change α in the production function reduces the maximum volume that can be produced per acre, where $0<\alpha<1$ (see fig. 1). The proportion α can further be considered a function of the level of atmospheric pollution δ, $\alpha = \alpha(\delta)$.

A proportional decline in the growth function does not affect the rate of current annual increment: $\alpha v'(t)/\alpha v(t) = v'(t)/v(t)$, where the prime indicates the first derivative. Consequently, the optimum rotation does not change if regeneration costs are zero (Ovaskainen 1987). If regeneration costs are positive, the impact of a proportional decline in the growth function is the same as an increase in regeneration cost or a decline in price. In this case, the optimum rotation increases (Ovaskainen 1987; Johansson and Löfgren 1985).

Timber Producer Impacts

To understand the economic impacts of a decline in forest productivity, we need a model of producer behavior. The simplest formulation of the timber producer's problem is to maximize net present value π subject to a set of constraints describing forest dynamics under even-aged management:

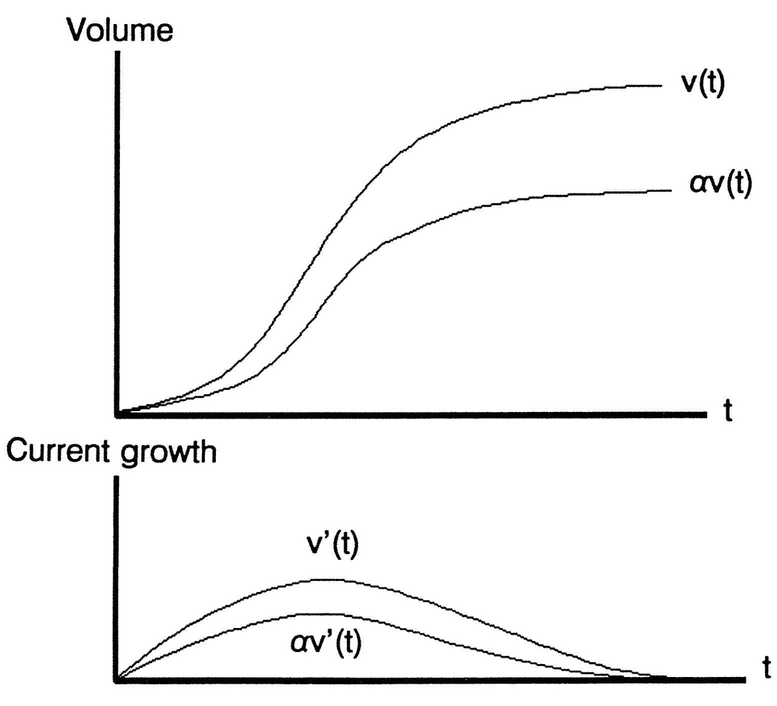

Figure 1.—A proportional decline in forest productivity.

$$\pi(p,w,v) = Max \sum_{t=1}^{T} (p_t c_t' v - w_t l_t)$$

$$\text{s.t. } x_{t+1,0} = \sum_{i=1}^{m} c_{t,i} \qquad (1)$$

$$x_{t+1,i+1} = x_{t,i} - c_{t,i}$$

$$x_{t+1,m} = x_{t,m} + x_{t,m-1} - c_{t,m} - c_{t,m-1}$$

Under this formulation, the vector $c'_t = (c_{t,1}, c_{t,2}, ..., c_{t,m})$ represents the number of acres harvested in period t by age class, and the vector $v' = (v_1, v_2, ..., v_m)$ represents the volume produced per acre by age class. During period t, x_{ti} acres are in age class i; p_t is the present value of timber price; w_t is the present value of the wage rate; and l_t is the labor input. Finally, a once-and-for-all proportional productivity loss can be written as:

$$v^{\alpha'} = (\alpha v_1, \alpha v_2, \ldots, \alpha v_m) \ . \qquad (2)$$

Note that the volume per acre vector could be generalized to account for differences in species, management effort, and site quality by appending appropriate subscripts. However, for notational convenience, these subscripts are omitted.

A straightforward method for estimating the economic impact of a change in forest growth can be derived using a mathematical theorem known as the envelope theorem. The envelope theorem states the tangency relation between the envelope of a family of curves and the curves which it touches. Specifically, the first-order change in the indirect objective function π with respect to parameter δ adjusting the variables c optimally is exactly equal to the change in π when the c's are not adjusted optimally—only the higher order terms reflect a difference in the way π is changing (Samuelson 1965, Varian 1984). Therefore, the total derivative of π with respect to δ is exactly equal to the partial derivative of π with respect to δ, evaluated at the optimal choice of c.

By assuming that the present value function is twice differentiable and convex in prices, the optimal cutting program and labor input program are expressed (using the envelope theorem) as the tangent of the present value function π with respect to prices p_t and w_t, respectively (Johansson and Löfgren 1985):

$$\frac{\partial \pi}{\partial p_t} = c_t' v = q_t(p, w, v)$$

$$\frac{\partial \pi}{\partial w_t} = -l_t(p, w, v). \qquad (3)$$

Differentiation of the right hand side of equation (3) provides the result that timber supply slopes upwards:

$$\frac{\partial q_t}{\partial p_t} = \frac{\partial^2 \pi}{\partial p_t^2} \geq 0 \qquad (4)$$

Now, by assuming that the present value function is convex and twice differentiable with respect to the growth function, the envelope theorem can be used to derive the following expression (Löfgren 1988):

$$\frac{d\pi}{dv} = pc' \qquad (5)$$

That is, the gradient of the present value function with respect to the growth function can be expressed as a vector formed by the product of discounted prices and acres cut under the current cutting plan. This expression can be used to estimate the economic damage attributable to air pollution impacts by utilizing the fact that a convex function lies everywhere not below its tangent plane:

$$\pi(v) - \pi(v^{\alpha}) \leq \frac{d\pi}{dv}(v)(v - v^{\alpha}) \qquad (6)$$

where $d\pi/dv$ is the gradient of the present value function with respect to v. Equation (6) says that an upper bound on economic damages to an individual producer can be estimated as the gradient of the present value function with respect to v (evaluated at the initial growth function) times the vector of growth loss. This concept is illustrated in figure 2, where the change in π with respect to a change in the growth parameter for a stand i years old is represented. As can be seen, using the tangent to estimate the loss in π resulting from a loss in growth overestimates the result by amount $\pi_1 - \pi'_1$. Intuitively, this is an upper bound because the timber producer is constrained to the cutting plan that is optimal under the "old" growth function.

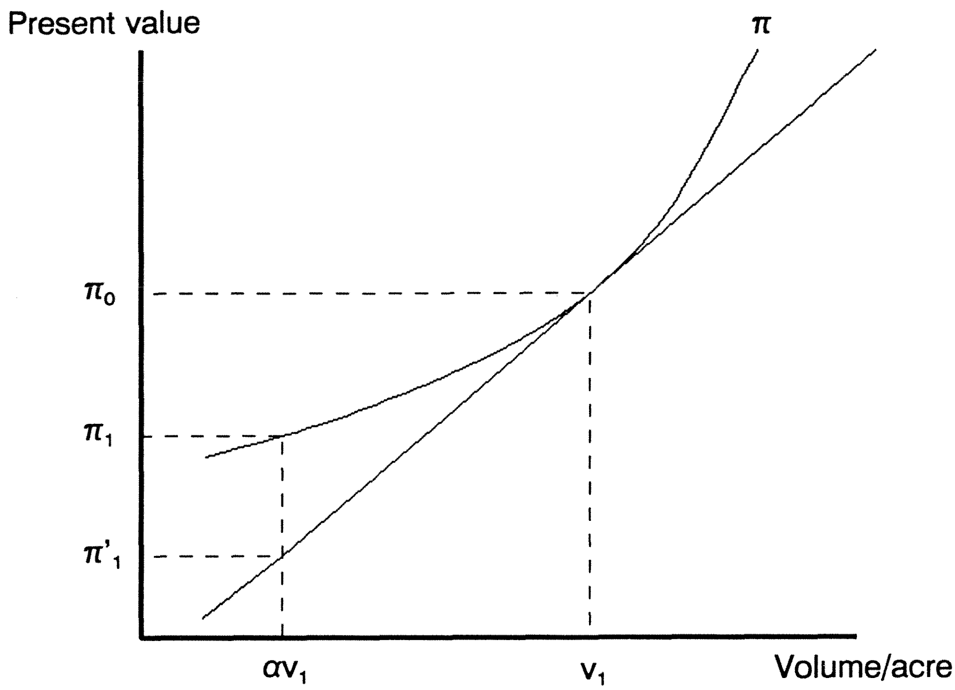

Figure 2.—Upper-bound damage estimate using the envelope theorem.

Finally, by assuming that the timber cutting cost function is linear homogeneous in v (i.e. a 5-percent decrease in volume results in a 5-percent decrease in cutting costs), Löfgren (1988) shows that the present value function is linear homogeneous in v: $\alpha\pi(v) = \pi(\alpha v)$. In other words, a 5-percent decrease in growth decreases present value 5-percent. That is, the upper bound presented above is exact.

This result can be translated into an operational framework by considering the relationship between timber supply and profit. The net benefit of timber production in any year can be measured as the area above the supply curve and below the price. This area is refered to as economic rent or producer surplus (Just and others 1982). The total change in welfare (i.e. present value) to timber producers resulting from a once-and-for-all change in forest productivity requires the summation of changes in discounted yearly rents over the infinite future.

The welfare change to an individual timber producer is computed as the difference between economic rent before and after the once-and-for-all change in productivity. The loss to an individual producer resulting from a loss in productivity can be generally written as:

$$\Delta\pi = \pi(v) - \pi(v^{\alpha}) = \sum_{t=1}^{\infty} \int_{p^0}^{p^*} \frac{d\pi}{dp_t} dp_t - \sum_{t=1}^{\infty} \int_{p^0}^{p^*} \frac{d\pi^d}{dp_t} dp_t \qquad (7)$$

where $\Delta\pi$ is the change in present value, π is the initial present value function, $\pi(v)$ is the initial present value at p^*, π^d is the present value function for forests damaged by air pollution, $\pi(v^{\alpha})$ is the subsequent present value at p^*, p^0 is the minimum reservation price, and p^* is the exogenous stumpage price.

Given a linear form for timber supply, it is straight- forward to see that

$$\frac{\partial\pi^d}{\partial p_t} = \alpha c_t' v \qquad (8)$$

That is, the individual firm's timber supply curve is also reduced by α.

To summarize, our method for estimating the loss in timber producer welfare resulting from a change in timber productivity is based on the assumption that proportional productivity impacts translate into proportional supply impacts and proportional profit impacts. This method overestimates the supply and profit impacts by holding the number of acres cut constant at the old cutting plan. That is, producers are not allowed to adjust the rotation age in response to a change in the timber production function. The degree of bias in this method is not too bad if the present value function is relatively linear with respect to timber growth. This is probably true for small productivity changes, or where regeneration costs are zero.

Aggregate Economic Impacts

Market supply is the horizontal sum of supply over all (n) firms in the market area:

$$S_t(p,w,v) \equiv \sum_{j=1}^{n} q_{jt}(p,w,v) = Q_t \qquad (9)$$

Market price and quantity are found at the intersection of market demand D(p,y) and supply S(p,w,v), where y is a vector of demand shifters. Once supply and demand functions are estimated, timber supply can be shifted by incorporating proportional productivity impacts assuming that cutting plans do not change. For example, if air pollution is expected to decrease timber growth by 5 percent, then the quantity supplied at each price is multiplied by $\alpha = 0.95$ (or, the marginal cost of each quantity is multiplied by $1/\alpha = 1.05$).

The economic welfare impact associated with a change in supply is measured as the change in consumer and producer surplus allowing for the change in equilibrium price and quantity as shown in figure 3. The curve S_0 represents the initial supply, D represents demand, and S_1 represents the new supply curve after a once-and-for-all change in forest productivity. The net change in consumer and producer surplus is the area cE_1E_0.

In figure 3, let the inverse supply and demand curves be represented by $P = S_0(Q) = aQ + c$, $P = S_1(Q) = (1/\alpha)aQ + c$, and $P = D(Q) = -bQ + d$, respectively, where $a,b,d > 0$, $c < d$, and $0 < \alpha < 1$. The area CS representing consumer surplus can be expressed as

$$CS = \frac{b(d - c)^2}{2(a + b)^2} \qquad (10)$$

and area PS representing producer surplus can be expressed as:

$$PS = \frac{a(d - c)^2}{2(a + b)^2} \qquad (11)$$

As can be seen in figure 3, the change in consumer surplus (the area above price and below the demand function) clearly decreases with a backward rotation in the supply curve. While the change in producer surplus is not as obvious, it can be demonstrated that $\partial PS/\partial a > 0$, < 0, or $= 0$ as $b > a$, $b < a$, or $b = a$, respectively (Miller and others 1988).

Consequently, if a > b and a increases, then PS decreases.

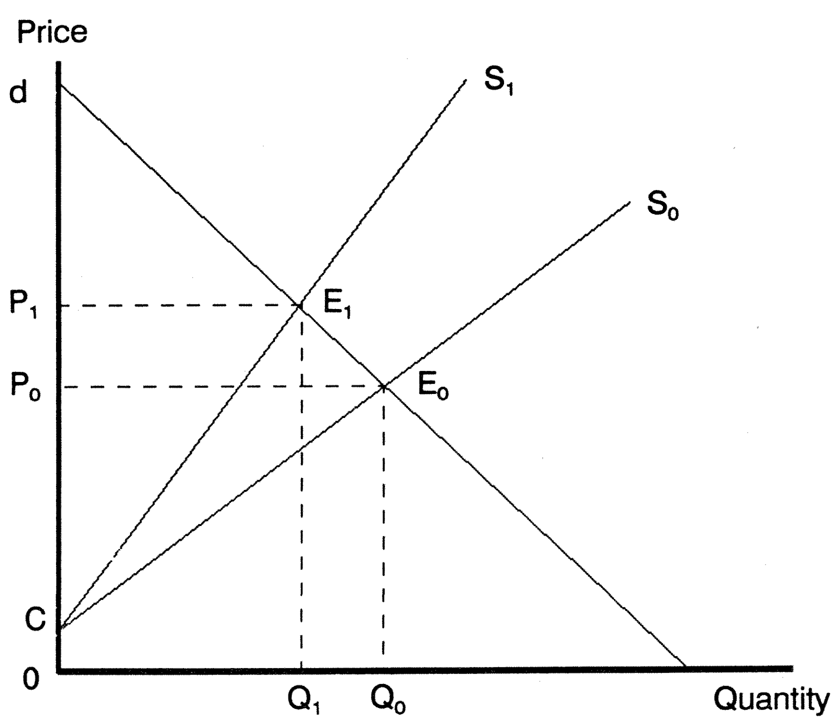

Figure 3.—Aggregate economic welfare impacts of a change in forest productivity.

To estimate the change in consumer and producer surplus associated with a shift in supply, we make several simplifying assumptions. First, assume that current timber supply and demand functions for the South are adequately represented by Newman's (1987) econometric estimates. Second, assume that demand is constant over time. This allows us to measure deviations over time from a known base case equilibrium. Third, assume that the only change affecting supply is a sudden increase in ambient air pollution resulting in a proportional productivity decrease. Fourth, assume that sawtimber rotations are 35 years and that pulpwood rotations are 20 years. Decreases in the standing inventory of timber resulting from growth declines are then prorated over the initial rotations by the factor τ/T, where τ is the number of periods after the change in productivity and T is the rotation age. The change in surplus (S) in year τ is then computed as:

$$\begin{aligned} \Delta S_\tau &= \frac{\tau \Delta S_T}{T(1+r)^\tau} \quad \text{for } \tau \le T \\ &= \frac{\Delta S_T}{(1+r)^\tau} \quad \text{for } \tau > T \end{aligned} \tag{12}$$

where r is the rate of interest (assumed to be 0.04).

Using the timber market analysis provided by Newman (1987) , values of the inverse supply and demand parameters for the solidwood market are: a = 0.0003255, b = 0.0003162, c = -239.82, and d = 939.7. The inverse supply and demand parameters for the pulpwood market are: a = 0.0002032, b = 0.00011, c = -289.80, and d = 253.70. As can be seen immediately, a > b in both the solidwood and pulpwood markets. Consequently, producer surplus will decreases in both markets as a result of a proportional decrease in productivity.

Results and Implications

Table 1 presents the cumulative welfare impacts over 50 years associated with 1-, 5-, and 10-percent proportional declines in southern yellow pine forest productivity. Total welfare losses range from $57.1 million to $598.5 million in the solidwood market and from $43.4 million to $448.7 million in the pulpwood market. As expected, both stumpage producers and consumers suffer a decline in economic welfare from the imposed changes in forest productivity. Overall, stumpage consumers lose more economic surplus than do stumpage producers. This is because producers are compensated to some degree for the loss in volume by higher stumpage prices. On the other hand, stumpage buyers pay more for an increasingly scarce resource.

The transition to increased resource scarcity occurs sooner in pulp markets because rotations are shorter than for solidwood, and the full impact of the reduced productivity regime is therefore expressed more quickly. Consequently, the percentage loss in producer surplus is greater for pulpwood producers than for solidwood producers. Pulpwood producers that recognize this dilemma may shift production to solidwood. However, historical evidence (Newman 1987) demonstrates a relatively inelastic own price pulpwood supply and a very inelastic cross price pulpwood supply, suggesting that pulpwood production plans are relatively fixed. If the historical supply relationships continue to hold under an altered forest production regime, then pulpwood producers would fare relatively worse than solidwood producers.

Table 1 shows that while the absolute losses are higher for solidwood consumers than for pulpwood consumers, the percentage losses are higher for pulpwood consumers. This is because demand elasticity is higher for consumers of solidwood stumpage than for pulpwood. This reflects the fact that pulp production is relatively fixed, while sawmills can more easily adjust production (or go out of business) as prices change. Consequently, pulpwood consumers are more locked in to the costs of increasing resource scarcity than are solidwood consumers.

Several simplifying assumptions were made to perform the analysis reported above. This type of analysis could be extended as more pertinent information is generated. For example, we assumed that air pollution impacts trees of all ages and species in the same way. If future research indicated that certain (e.g. older) trees are more susceptible, or that susceptibility takes certain forms (e.g. periodic insect outbreaks), then this information could be included. Further, a continuous change in productivity, rather than the discrete change considered here, could be modeled. We also heroically assumed that demand for timber is constant. Future demand shifts could be incorporated in a straightforward manner. Finally, our estimates are biased by the degree of curvature in timber producers' indirect profit functions. That is, we just don't know how sensitive rotation ages and input use are to changes in the biological growth function. Better information on production functions and consequent producer behavior is clearly needed before more refined estimates of economic losses can be derived.

Table 1 — Fifty-year changes in consumer surplus (ΔCS), producer surplus (ΔPS), and total welfare (ΔTW) resulting from proportional changes (α) in productivity

Proportional changes [a]	ΔCS	ΔPS	ΔTW
	- - - - - - - - - Thousands of dollars [b] - - - - - - - - -		
		Solidwood	
$\alpha = .99$	-56,207 (0.47) [c]	-972 (0.008)	-57,179 (0.24)
$\alpha = .95$	-283,711 (2.38)	-7,964 (0.07)	-291,675 (1.23)
$\alpha = .90$	-574,061 (4.81)	-24,407 (0.21)	-598,468 (2.52)
		Pulpwood	
$\alpha = .99$	-30,416 (0.85)	-13,027 (0.20)	-43,443 (0.43)
$\alpha = .95$	-152,205 (4.28)	-55,090 (0.84)	-207,295 (2.05)
$\alpha = .90$	-304,558 (8.56)	-144,106 (2.19)	-448,664 (4.43)

[a] Relative to base case (50 years of 1980 market conditions).

[b] Adjusted to common base year 1967.

[c] Values in parentheses are percentage changes relative to base case.

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Economic Impacts of Forest Decline Caused by Air Pollutants in Europe

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ABSTRACT

Both present and future generations will pay the costs of forest damage resulting from air pollution. These costs will include social welfare costs. Intergenerational justice requires that we do not discount costs that will be borne by future generations. The IIASA (International Institute for Applied Systems Analysis) Forest Study predicts the incidence and costs of pollution-caused damage to European forests to the period 2000-2005. The present paper summarizes the IIASA study's estimates of undiscounted costs of pollution-caused forest damage in European nations and regions.

Keywords: timber supply, air pollutants, sustainability, ecological economics

Introduction

The IIASA (International Institute for Applied Systems Analysis) Forest Study begun in 1986 addresses questions relating to the long-term development of forests in Western and Eastern Europe and the European USSR. Detailed country-by-country data on European forest resources have been assembled and linked to a matrix-type simulation model. The model predicts growing-stock and timber-harvest levels over time by country, species, group, and age, making it possible to undertake a general assessment of timber-supply. The model makes provision for forest decline caused by air pollutants and for mitigating effects of improved silvicultural practices. Aggregrated results of these analyses are presented by Nilsson and others (1991).

The emission of air pollutants today will cause negative effects, not only for the existing European generation, but also for future generations. There will be long-term negative effects on both welfare and well-being. Thus economic analysis must have a long-term, political-economical perspective. It is also important that the economic and social effects of forest decline be evaluated in a way that is morally sound.

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Economic Valuation: Perspectives of Different Interest Groups

The major interest groups for a valuation of forest decline attributed to air pollutants are forest owners, forest industry, and society.

Forest owners and forest industry often must choose among different business strategies. At the enterprise level, economic analysis employs discounting procedures to standardize comparisons of different projects. These procedures are designed to answer questions about the future profits and survival of enterprises.

However, forest decline is caused by factors outside the jurisdiction of forest owners and forest industry. Policies on control of emissions must be set by individual governments and intergovernmental organizations. Therefore, valuation should reflect societal values: it should be politically economic or nationally economic evaluation. There are additional reasons for making the evaluation on a national scale. Bonus (1984) argues than an ever-increasing part of the national economic revenue from forests is for the benefit of the society as a whole. Thoroe (1985) stresses that, because air pollutants affect society as a whole, effects must be evaluated at the level of the national economy. Wibecke (1983) stresses that forest decline caused by air pollutants will influence national forest policies, and these policies affect national economies. If the values of costs and benefits are to be computed at the society level, the discounting rate must be regarded as a social rate including political, moral, and social aspects.

We conclude that the effects of air pollution on forests should be evaluated at the level of the national (political) economy. The aggregate or bottom-line impact of different policies and effects on national economies is understood by studying changes in national income accounts or GNP (OECD 1990).

GNP has three basic components: consumption, investment, and government purchases of goods and services. A fourth component, net exports of goods and services, is usually added. A nation's GNP is the money value of all final products newly produced in a year at current prices. The money value of the final products is the final sale price. To avoid double counting of intermediate products, the value added at each stage of the production process is calculated. For example, the value added at the production process is calculated by subtracting the costs of raw materials. When all value added at each stage is totaled, the sum will equal the final sale price of the product.

From the viewpoint of natural resources and environmental quality, GNP calculations have several shortcomings:

- In most cases, national accounts do not incorporate changes in renewable resource stocks.
- They do not reflect the impact on future flows and related income potential.
- They do not include services outside the market sector.
- They ignore the ecological capital.
- They do not account for environmental effects. A healthy environment is essential to support the national economy. The Asian Development Bank (ADB 1990) says that "it is now widely recognized that environmental degradation often undermines the economic development."
- They do not deal with defensive expenditures like costs for environmental protection.

These shortcomings are identified by Repetto (1990), Muthoo (1990), Barbier (1990), Collard and others (1988), and Daly (1990) among others. Daly (1988) questions whether GNP "may be more an index of cost than of benefit in many cases."

Economic development is a much broader concept than economic growth measured by GNP. Economic development should also include well-being and the quality of life. UNDP (1990) points out that the link between economic growth, development, and human progress is not automatic. Pearce (1990) states that a "reasonable definition of wealth creation requires that we leave the future with a stock of assets which includes financial and industrial capital, as well as environmental capital."

There is a special problem with future flows and related income potential in traditional GNP calculations, which are based on the prices of final products newly produced within a year at current prices. The problem is that of determining how to treat future, long-term environmental effects caused by operations today. Altwegg (1989) has identified four methods for dealing with forest decline attributed to air pollutants:

(1) The damage is discounted to the time of its cause. Altwegg suggests that the total costs of damage be divided by total number of years of damage.

(2) The damage is connected to the declining operation from the time it is recognized to its end.

(3) The damage is connected to the declining operation from the present to the end of the operation.

(4) The damage is independent of the time of its cause and its duration, and is discounted to the time the damage is first recognized.

El Serafy (1989) has moved away from the pure depreciation approach in GNP calculations. His opinion is that it is wrong to describe something as current production (as defined by GNP) by something that is not. He points out that the pure depreciation approach does not give a fair comparison between countries because each country has different stocks of marketable natural resources. He would like to split the income stream into two components: an income component, which can be spent on consumption, and a capital component, which should be set aside each year for sustainable production. The first component should be included in GNP, while the second should be excluded.

Daly (1988) suggests that replacement costs or discounted willingness to pay should be considered when income streams influenced by the degeneration and depletion of natural resources and the environment are valued. Because traditional GNP calculations have the shortcomings discussed above, Daly (1988) suggests that GNP should be replaced by sustainable social net national product (SSNNP). He defines SSNNP as net national product minus defensive expenditures minus depletion of natural capital. Defensive expenditures are defined as the costs for environmental protection, environmental damage compensation, spatial concentration, expenditures arising from unhealthy consumption, expenditures arising from bad working environments, and so on.

However, there are ways to include economic losses caused by environmental deterioration in the traditional, national accounting system (Pearce and others 1989; Pearce 1990). One approach is to set a monetary value on the direct environmental decline and subtract that value from GNP. This method has already been introduced in the United States and Japan. A second approach is to attach a monetary value to the degeneration of the environmental capital. This approach is much more difficult.

The process of restructuring national accounts with respect to national resources and the environment has already started. Work is being conducted to improve the United Nations System of National Accounts (Ahmad and others 1989). The World Resources Institute is carrying out pilot studies on resource accounting for some developing countries.

The World Bank and UN Environment Programme are doing similar work for other developing countries (Repetto 1989). Norway and France are working with resource accounts to supplement their national economic accounts. Germany has started work to include environmental degradation in its national income accounts. The OECD (1990) is working with natural resource accounting and also with methods of adjusting traditional national economic accounting. The OECD stresses that the latter approach is increasingly under fire by the environmental community for not considering changes in natural resource capital and environmental values. Environmentalists argue that accounts should consider environmental expenditures (costs for cleanup and restoration) and impacts on and changes in natural resource stocks. The OECD's ultimate goal is to include these costs in new GNP calculations.

Earlier Work on Evaluation of Forest Decline Attributed to Air Pollutants

Brandl and Matthies (1984) have developed a manual on the components that should be included in the valuation of forest decline attributed to air pollutants. These components are:

A. Forest Stands

1. Increment losses
2. Losses by harvesting of immature stands
3. Decreased value on assortments
4. Decreased value on remaining stands after sanitation harvests
5. Decrease of gross forestland rent
6. Increased regeneration costs
7. Increased costs for protection
8. Decreased expected yield
9. Damage to neighboring stands due to sanitation harvests
10. Damage by insects and fungi
11. Increased risk (for example, increased risk of windfalls)
12. Secondary use of stands
13. Decreased protection and recreation functions
14. Other damage

B. Forest Soil

15. Fertilizing to halt decline effects
16. Decrease in forest land value

C. Forestry Administration - Forestry Enterprise

17. Increased management costs
18. Decreased productivity (adjustment of site classes)
19. Decreased flexibility in management
20. Changed assortment distribution
21. Decreased property value
22. Disturbances of the financial balance
23. Decreased function as employer
24. Decreased protection and recreational functions (special countermeasures required)
25. Changed forest policy for the forest owner
26. Increased risk for the forest enterprise
27. Other Losses

D. Society

28. Decreased industrial production
29. Disturbances of market and price changes
30. Loss of employment potential in the forest sector
31. Loss of forest enterprises
32. Changed utility of forest resources
33. Disturbances of forest land markets
34. Decreased tax payment from the forest sector
35. Increased costs for research and development
36. Compensation to forest owners due to forest decline
37. Decreased employment potential outside the forest sector
38. Effects on society through decreased protection function of forests
39. Decreased recreation opportunities
40. Effects on landscape and bio-diversity

Ewers and others (1986) started with scenarios on forest development during a 100-year period. The so-called trend scenario projected decline effects similar to IIASA's Forest Study Scenario. The long-term effects (including incremental losses) on forestry were discounted by 0, 1, 2, and 3 percent. The authors did not make any decision about the choice of discount rate. The decline costs for forestry in Germany (excluding the former German Democratic Republic) were estimated in this study to range between DM 1.7 and 4.8 billion per year (in 1984 DM), depending on the discount rate.

In this study, the losses of increment are valued at roundwood market prices and constitute only 24 to 45 percent (depending on the discount rate) of the estimated total forestry losses. Ewers and others

Table 1--Estimated losses in the FRG from air pollutants (Ewers and others 1986)

Discount rate in %	Forestry losses	Recreation	Water and protection	Total losses
Percent	- - - - - - - -	Billions of DM[a]	- - - - - - - - -	
0	4.8	6.3	0.4	11.5
1	3.1	4.1	0.3	7.4
2	2.3	2.9	0.3	5.5
3	1.7	2.3	0.3	4.3

[a]1984 value.

(1986) did not conduct any economic valuation of the effects on the forest industry. However, they did analyze the effects of decline on water, soil, and recreation. The estimated losses are presented in table 1. Again, the authors have not expressed any preference to the rate of discount which should be employed. It may be important to underline that the choice of the discount rate includes a strong political component. The political aspect in the valuation is not efficiently fulfilled by just presenting standardized alternatives. Based on table 1 and the earlier discussion, it can be seen that the economic value of increment losses constitutes a minor part of the total losses.

Brabander (1987) used the results from the analyses of Ewers and others (1986) for further analysis on the economic effects of air pollutants at the level of forest owners. In these analyses he used an interest rate of 0 percent. Brabander (1987) also underlines that the forest decline should not be valuated from a forest management viewpoint alone. The valuation should also consider all affected groups and interests of the society.

Bergen and others (1988) have carried out econometric analyses of the market effects of forest decline caused by air pollutants on softwood roundwood in the former Federal Republic of Germany for the period 1980-85. The authors underline that the results of the econometric analyses are uncertain due to the short time frame for the same.

However, their conclusion is that an increased decline of 10 percent (forest area) leads to a yearly economic loss for the forest owners of about 26 percent. Based on these analyses it can be seen that forest decline increased the costs and decreases the prices. The forest enterprises try to compensate for the losses by increasing the supply. Such behavior leads to decreases in the market prices and profit reductions.

Kroth and others (1989) have specifically studied the changes in forest management due to air pollutants in former West Germany. This was partly achieved by sending out questionnaires to the forest managers of 2.2 million hectares of State forests and 4.3 million hectares of private forests. The study dealt with what changes had actually taken place during the period 1983-87, and planned actions for the period 1988-1992 due to air pollution effects. The responses dealt with about 15 different changed management actions. Thus, the study did not deal with valuation of direct growth impacts at all. The additional costs for the changed management actions due to air pollutants were estimated to be 22 DM/hectare/year at average. It was estimated that the costs could double for the period 1988-1992.

Table 2--Valuation of forest decline in Switzerland (Basler and others 1986)

Item	Losses	
	Phase I	Phase II
	- Billions of SFr/year -	
Forestry	0.50	0.30
Protection	0.90	0.30
Additional damage	0.38	0.53
Total	1.78	1.13

A major study on national economic impacts in Switzerland by forest decline attributed to air pollutants was conducted by Basler and others (1986). The study analyzes different scenarios with time horizons of 20 to 40 years; the time horizons are divided into two equal phases of 10 to 20 years. The analysis deals with three major features: forestry, protection, and additional damage. The additional damage mainly deals with effects in secondary and tertiary sectors. The authors have chosen a discount rate of 0 percent. The results are presented in table 2. Here again, this study indicates that direct increment losses range between 20 and 40 percent of the total losses of the forestry component.

These studies have not considered the effects on GNP from the forest industry due to the decline. Puwein (1988) has estimated that the losses for the Austrian forest industry in the national economy is similar to that in forestry.

The results are consistent with basic data collected in a study by Stoklasa and Duinker (1988) dealing with the socio-economic consequences of forest decline in the CSFR.

Various studies have been conducted in North America. Callaway and others (1986) employed hypothetical reductions in tree growth due to air pollution and calculated effects on future wood supply by existing forest sector market models. In Canada, Crocker and Forster (1986) analyzed the economic effects of increment losses on wildlife and recreation.

None of the studies discussed above has been able to incorporate all items presented in the evaluation schedule of Brandl and Matthies.

Estimated Losses

The IIASA Forest Study has estimated the average annual timber volume losses in Europe (incremental losses) caused by air pollution occurring to the period 2000-2005. The average losses are expressed in cubic meters per year for 100 years.

Estimated average losses of forestry production in closed forests caused by known air pollutants to 2000-2005 in Eastern and Western Europe are:

Region/Country	Average losses in million m³/year during the period 1985-2085
NORDIC	11.1
Finland	4.5
Norway	0.8
Sweden	5.8
EEC-9	23.9
Belgium	0.7
Denmark	0.4
France	3.5
FRG	11.9
Ireland	0.2
Italy	3.1
Luxembourg	0.1
Netherlands	0.2
UK	3.7
CENTRAL	5.8
Austria	3.4
Switzerland	2.4
SOUTHERN	7.2 (Spain not included)
Greece	0.1
Portugal	1.5
Spain	n.a.
Turkey	2.8
Yugoslavia	2.8
EASTERN	34.5
Bulgaria	2.2
CSFR	9.5
GDR	4.9
Hungary	3.0
Poland	11.1
Romania	3.8
EUROPE Total	82.5

Estimated average losses of forestry production in closed forests caused by known air pollutants to 2000-2005 in the European USSR are:

Region	Average losses in million m³/year during the period 1985-2085
Northern	2.8
North-West	2.0
Central	3.4
Pre-Baltic	0.1
Volgo-Uratsky	2.0
Central-Chernozyomny	0.4
Pouol-Zksky	0.8
Ural	8.5
North-Caucasia	0.4
Carpathians	1.3
Polesye	1.0
Forest-Steppe	1.6
Moldavia	0.2
Byelorussia	4.4
Estonia	0.4
Latvia	0.7
Lithuania	0.5
Total	30.5

Value losses caused by air pollution have been calculated for:

(1) *Timber—Decreased value related to forestry.* Only incremental losses are taken into account, and the incremental losses should be valued at their current market prices (Blades 1989). The market prices we used reflect the 1987-1988 level and are expressed in 1987 US dollars.

(2) *Timber and primary forest products industry—Decreased value for the forest sector.* This case considers the value-added component by industrial production. The market prices for final products have been used. Only primary industrial products are considered in the valuation, meaning softwood and hardwood lumber, pulp, and wood for energy. Specific yield figures for production of the industrial products have been employed. The prices used for lumber and pulp are export prices (FAO 1989).

The price calculations for wood as energy are based on energy content and the local energy prices. Prices are expressed in 1987 US dollars. Lumber and pulp are products with low value added. Therefore, the losses are undervalued where joinery, paper, and board production ought to be considered.

(3) *Multiple-use forestry—Decreased value resulting from incremental losses and reductions in social welfare (nonwood benefits).* The social welfare aspects of forestry are in many cases provided at no cost or at subsidized prices. According to Blades (1989), these benefits should be valued at their cost of production. Daly (1988) states that the depletion of natural capital and related nonwood benefits should be valued on the principle of replacement or on the basis of discounted value of willingness to pay (WTP).

Metz (1988) collected data on the economic impacts of air pollutants in Europe. Stoklasa and Duinker (1988) did the same in the CSFR. Based on the basic data collected by these two studies a social welfare value was estimated, which is 3.7 times greater than the pure roundwood value. The basic data used took mainly into account the recreation and protection components of the social welfare value. It should be emphasized that recreation and protection are not the only components of the social welfare value, and therefore the estimate used is probably an underestimate of the real social welfare costs of forest decline.

(4) *Multiple-use forestry and primary forest products industry (social welfare value).* In this case timber incremental losses, reductions in value added in industry, and reductions in social welfare value are taken into account. There is no double counting; each cost component is considered only once in the total calculation. The values are expressed in 1987 US dollars.

The values for the different starting points of valuation, in dollars per cubic meter, are presented in table 3. The prices used are unrelated to the decline event; if forest decline causes the supply of wood to increase, the price of wood may decline. And if the wood supply decreases because of forest decline, then the price of wood may increase. In the long run, prices may also be influenced by substitution. We do not consider it realistic to project price changes during the next 100 years. Therefore, we use constant prices in our estimations.

Impacts of Losses on GNP

By combining the preceding information on decline and the four starting points for valuation presented in table 3, it is possible to obtain at least initial approximations of decreases in GNP resulting from forest decline caused by air pollutants. The results for Eastern and Western Europe are presented in table 4; the values are expressed in 1987 US dollars. Provisional cost estimates for the European USSR are presented in table 5.

For Europe as a whole, GNP reductions resulting from forest decline are estimated to be almost $29 billion US (1987 value) per year over 100 years. Annual GNP reductions are 13.7 billion dollars for Western Europe, 8.5 billion dollars for Eastern Europe and 6.6 billion dollars for the European USSR. These estimated economic impacts are not discounted. It is our view that discounting effects with a time horizon longer than 20 years is rather meaningless. In the case of air pollution, we have effects during a 100-year period. Therefore it seems reasonable to apply a 0-percent discount rate. We also believe that a 0-percent discount rate is the obvious choice from an ethical and moral perspective. The fact that forest decline caused by air pollutants is an international problem supports this conclusion. The notion of equality has deep roots in international law (see, for example, the Universal Declaration of Human Rights, the United Nations Charter, the International Convention on Civil and Political Rights, the Convention on the Prevention and Punishment of the Crime, etc.). Weiss (1989, 1990) has discussed the interpretation of intergenerational equity and equality in international law. Weiss stresses that the current generation must extend its concerns to longer time horizons and broader geographic scales.

Another reason for selecting a 0-percent discount rate is that the cost of abating the air pollution has to be paid on a yearly basis during the period when the decline effects occur, and the magnitude of the cost is similar to that of the economic impacts we have discussed. There are no reasons for introducing discounting in such a case. However, the choice of rate is ultimately a political and moral one (Heal 1981). In the end, the decision is up to European politicians. We have argued that social welfare impacts of air pollution must be taken into account by those who formulate abatement policies.

Table 3--Price or value per cubic meter of roundwood according to the different valuations, expressed in 1987 US dollars

County	Timber	Timber, primary forest products	Multiple-use forestry	Multiple-use forestry, primary forest products
	- - - - - - - - - -	- - - U.S. dollars[a]	- - - - - - - - - -	- - - - - -
Albania	51.5	102.9	190.7	242.2
Austria	56.4	117.9	208.9	270.4
Belgium and Luxembourg	68.4	147.5	253.3	332.4
Bulgaria	48.9	104.6	181.1	236.8
CSFR	56.9	95.8	210.7	249.6
Denmark	56.4	140.3	208.8	292.7
Finland	52.2	122.8	193.3	263.9
France	66.3	156.0	245.6	335.3
FRG	58.9	144.5	218.1	303.7
GDR	51.1	98.7	189.3	236.9
Greece	41.3	122.1	153.0	233.8
Hungary	57.0	109.2	211.1	263.3
Italy	57.5	160.1	213.0	315.6
Netherlands	66.5	157.4	246.3	337.2
Norway	52.5	121.1	194.4	263.0
Poland	52.7	97.0	195.2	239.5
Portugal	43.0	106.4	159.3	222.7
Romania	57.7	106.4	213.7	262.4
Spain	48.3	118.9	178.9	249.5
Sweden	52.2	122.2	193.3	263.3
Switzerland	58.5	116.9	216.7	275.1
Turkey	44.8	118.7	216.7	275.1
USSR	43.7	97.0	161.9	215.2
UK	60.0	138.6	222.2	300.8
Yugoslavia	62.6	105.2	231.9	274.5

[a]1987 dollars.

Therefore, we conclude that GNP reductions attributable to impacts on multiple-use forestry and primary forest products industry (a loss of $29 billion US per year) should be considered by makers of international policy when abatement strategies are discussed. We should be aware that not all social welfare aspects are taken into account by the existing valuations, however.

Norgaard (1989) has discussed the dilemmas of environmental accounting. He argues that it will take time to solve these problems and that the development of critically important environmental policies should not be deferred while new accounting methods are being perfected. He concludes that "efforts to contrive economic values to justify these critical policies will only further degrade economics as a scientific effort and weaken its effectiveness when it is needed to help with the fine tuning."

Table 4--Economic impact of air pollutants to the period 2000-2005 in Western and Eastern Europe

County	Timber	Timber, primary forest products	Multiple-use forestry	Multiple-use forestry, primary forest products
	- - - - - - - Millions of U.S. dollars[a] per year - - - - - - -			
Finland	234.9	552.6	869.9	1187.6
Norway	42.0	96.9	155.5	210.4
Sweden	302.8	708.8	1121.1	1527.1
Belgium and Luxembourg	52.0	112.1	192.5	252.6
Denmark	22.6	56.1	83.5	117.1
France	232.1	546.0	859.6	1173.6
FRG	700.9	1719.6	2595.4	3614.0
Italy	178.3	496.3	660.3	978.3
Netherlands	13.3	31.5	49.3	67.4
UK	234.0	540.5	866.6	1173.1
Austria	191.8	400.9	710.3	913.4
Switzerland	140.4	280.6	520.0	660.2
Greece	4.1	12.2	15.3	23.4
Portugal	64.5	159.6	239.0	334.1
Turkey	125.4	332.4	464.5	671.4
Spain	n.a.	n.a.	n.a.	n.a.
Yugoslavia	175.3	294.6	649.3	768.6
Bulgaria	107.6	230.1	398.4	520.9
CSFR	540.6	910.1	2001.7	2371.2
GDR	250.4	483.6	927.6	1160.8
Hungary	171.0	327.6	633.3	789.9
Poland	585.0	1076.7	2166.7	2658.5
Romania	219.3	404.3	812.1	997.1

[a]1987 dollars.

Table 5--Economic impact of air pollutants to the period 2000-2005 in the European USSR

Region	Timber	Timber, primary forest products	Multiple-use forestry	Multiple-use forestry, primary forest products
	Millions of U.S. dollars[a] per year			
Northern	122	272	453	603
North-West	87	194	324	430
Central	149	330	551	732
Pre-Baltic	4	10	16	22
Volgo-Uratsky	87	194	324	430
Central-Chernozyomny	18	39	65	86
Pouol-Zksky	35	78	130	172
Ural	372	825	1376	1829
North-Caucasia	18	39	65	86
Carpathians	57	126	211	280
Polesye	44	97	162	215
Forest-Steppe	70	155	259	344
Moldavia	9	19	32	43
Byelorussia	192	427	712	947
Estonia	18	39	65	86
Latvia	31	68	113	151
Lithuania	22	49	81	108
Total	1337	2968	4954	6585

[a]1987 dollars.

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Western European Air Pollution and the Finnish Forest Sector

Heikki Seppälä

ABSTRACT

The paper describes the possible effects of Western European novel forest damage on the Finnish forest sector. A model revised from GTM, the global forest sector model developed at IIASA (International Institute for Applied Systems Analysis), is used in the scenario analysis. The main finding is that impacts in the forest sector as a whole are slow and that the market mechanism efficiently smooths the impact of changes in timber supply caused by forest damage. Except in the case of really drastic and widespread forest dieback, harvests and forest industry production in Finland are affected only a little. Indirect linkages of international forest products markets may, however, cause unexpected long-term impacts.

Keywords: air pollution, forest sector, economic modeling, scenario analysis

Introduction

This paper deals with the economic effects of Western European forest damage on the Finnish forest industries. "Western Europe" is here defined as Western European countries other than Finland and Sweden. These two countries are the principal European exporters of forest industry products to the region. Although possible domestic forest damage may have a serious affect on the Finnish economy in the long run, this topic is not discussed here.

Finland is more dependent on forest industries than any other developed country. At present, 40 percent of Finland's export earnings come from wood-based industries. Western Europe imports more than two-thirds of Finnish forest industrial exports.

By "forest damage" we mean "novel" forest damage; i.e., geographically widespread and chronic forest decline (e.g., Metz 1988). The main causes of novel damage are harmful substances in the air.

In 1985, the Forest Sector Project of the International Institute for Applied Systems Analysis (IIASA) completed a comprehensive global model, GTM (Global Trade Model), to analyze policies relating to forestry and the forest industries (Kallio and others 1987). The IIASA project developed an "Acid Rain Scenario" that illustrated the potential economic effects of prolonged atmospheric pollution.

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With respect to product assortment and regional distribution, the IIASA model is a global compromise. It does not always meet the needs of individual countries. Therefore, it was decided to tailor the model for Finnish purposes, and at the same time update the model's data base (Seppala and Seppala 1987). This new model version was used in the work described here.

This paper is based on an article (Seppala and others 1990) in the final report of the Acidification Project of Finland.

Nature of Damages

Forest damage caused by air pollution is not the only damage that can influence the health and productivity of the forest. In fact other causes, such as forest fires, storms, and insect damages, have so far affected the forest sector much more than the novel damages.

Forest damage, as it affects timber markets, can be divided into two classes (United Nations 1986; Ovaskainen 1987):

1. Damage causing short-term impacts. This damage may affect the timing of the availability of the wood to the market, but does not affect the long-term productivity of the site. Insect epidemics and storms cause damage of this kind. Novel forest damage may cause these short-term impacts also, by stimulating sanitation cutting.

2. Damage causing long term impacts. This damage may affect the productivity of the site, increment rates, and hence the volume of the long-term wood supply. Most of the damage in this category is novel forest damage, and results from damage to forest soils.

It is often difficult to separate these two categories. For example, forest fire has the short-term effect of destroying standing timber, but it can cause the deterioration of forest ecosystems over long periods in the Mediterranean and other regions. In other areas, such as the Nordic countries, fire can improve site quality for several tree generations. Short-term damage to Western European forests outside Finland is seen as a threat to the Finnish forest sector, whereas long-term damage to those forests is seen as an opportunity for the Finnish forest sector.

Damage Situation

Measuring the extent of forest damage in Western European countries involves several uncertainties. Different methods have been used in different countries.

Although it is difficult enough to get comparable figures on the present damage situation, it is even more difficult to evaluate the progression of damage over time, both in the past and in the future. This is one of the main reasons why sensitivity analysis is needed to test and compare the effects of different assumptions on the magnitude of forest damage.

The forest damage attributed to air pollution does not affect all European forests equally. National surveys usually measure the percentage of trees affected. Based on 1988 estimates, the proportion of coniferous trees that had lost 10 percent or more of their needles varied from 17 percent in Portugal to 82 percent in Poland (United Nations 1990). The proportions in the FRG and Finland were 49 percent and 41 percent respectively.

Increase in the proportion of damaged trees since the mid-1980's has been very minor in most regions. In some countries (e.g. Switzerland and the FRG) and in some tree species (mostly coniferous) the proportion of damaged trees has decreased.

Impacts of Forest Decline

From the Finnish point of view, the economic impact of Western European forest decline and increased sanitation harvesting is significant if it affects foreign trade of forest products, i.e., roundwood and industrial goods. The increased supply will materialize as increased industrial production, as increased export of roundwood, or both. If the increase in supply is noticeable, a fall in timber price may follow. On the other hand, harvesting costs may rise due to accelerated cuttings. Up to the late 1980's it was possible, in most cases, to adjust normal fellings to increased sanitation cuttings. Consequently, there has thus far been no significant market disruption at the European or even national level due to oversupply.

Timber sawn from damaged trees is technically usable without restriction (e.g. Becker 1987). Pulpwood from damaged trees is, however, attacked sooner by damaging organisms than wood from unaffected trees. If the wood is not allowed to dry out, it can be used as raw material for most industrial purposes. Once allowed to dry out, it is often only suitable for use as fuel (United Nations 1986).

In the long run, the growing stock and increment may be reduced as a result of novel forest damage. This would decrease timber supply and increase the anticipated gap between demand and supply in Western Europe. A rise in timber price would follow, not only because of reduced supply, but also due to increases in timber production costs.

For Finland, the key question concerning the Western European forest damage is how the wood processing industry in Western Europe can absorb the changes in timber supply. The industry should first adjust itself to an increasing supply by investing in new capacity, and then later to a decreasing supply by reducing capacity.

The Model

The model used in this study is a partial economic market equilibrium model of the kind suggested by Samuelson (1952). It has linear constraints and partly nonlinear demand functions. The model finds the market equilibrium solution for 16 forest product categories in 18 regions comprising the world for any 5-year period (for product categories and regions, see Appendix). No consideration is made for any possible influence of future time periods. The model is then advanced to the next time period, and a new market equilibrium solution is computed for that time period.

The global forest sector is sufficiently complex that none of its individual components can be analyzed in isolation. It is necessary to link formal analytical models of the various forest sector components for each region of the world. Our model links four component models for each of the 18 regions. These component models (modules) are a model of timber supply, a model of processing industries, a model of product demand, and a model of trade among regions to account for the spatial aspects. The theoretical number of bilateral trade flows is 4896 (=18*17*16).

The solution for a given time period indicates the annual quantity of logs and pulpwood removals for the next 5-year period, the quantity of logs and pulpwood to be traded between regions or converted into products within each region, the quantity of final products to be produced within each region, and the quantity of final products to be traded among regions. The dual solution also indicates the marginal prices of both raw materials and final products.

Information from the solution for a particular period is used to project timber growing stock, processing costs, capacities, and other relevant factors for the subsequent period. The solution and updating sequence is repeated until the model's time horizon (in this case 6 periods or 25 years) has been reached.

The starting point of the analysis is a base scenario. This base scenario is meant to provide a useful basis against which alternative forest damage scenarios can be measured. For this reason, the base scenario should represent a future development that is based on a satisfactorily neutral set of assumptions.

The world's forests, the forest products industry, and consumers of forest products are inevitably affected by many decisions or changes that occur outside the forest sector. Such key exogenous variables include economic growth, income and price elasticities, population growth, exchange rates, and tariffs. We assume that values of most variables (see also Kallio and others 1987) will continue to change as in the past. However, we assume that economic and population growth will be slightly slower than in the 1960's and 1970's. Rates of growth in income per capita are assumed to decline as real income per capita rises. The base scenario assumes that there will be no substantial changes in forest growth rates, forest area, or mortality rates due to atmospheric pollution or climatic change during the period 1985-2010.

The base scenario results in quite decent development for the Finnish forest sector. The industry retains or—in some higher grade paper products (such as printing papers)—even increases its market shares in Western Europe. For paper and board production the average growth rate is about three percent per year. The market shares, as well as the production, of pulp and coniferous sawnwood decrease slightly. Timber harvests, however, increase very slowly only after 2000. This is due to decreasing export of market pulp and increasing imports of roundwood from the Soviet Union and other nations during the 1990's.

Air Pollution Scenarios

Assumptions

In summary, the assumptions of the air pollution scenarios are as follows:

1. Only the forests of Western Europe (excluding Finland and Sweden) are assumed to be affected significantly by atmospheric pollution. The interpretation of this assumption is that increases in sanitation harvesting are assumed to be fully compensated for by decreases in normal harvesting in Eastern Europe, the Soviet Union, Finland, and Sweden (see also Kallio and others 1987).

2. Sanitation harvests are assumed to increase the supply of timber in Western Europe from 1990 to 2000. Sanitation harvests represent trees that would not otherwise have been harvested during the period concerned. The corresponding increase in timber supply is modeled by shifting short-run roundwood supply curves to the right. This means that the fraction of removals attributable to sanitation harvests is treated as an inelastic part of timber supply.

3. The decrease of forest growth due to pollution is assumed to begin in 1985. The growth is measured as a percentage of growing stock volume. The reduction in growth rates is assumed to be a long-term phenomenon lasting the whole projection horizon. The reduction is assumed to change linearly over time, reaching its maximum value in 2010 and remaining constant thereafter.

4. The dieback effect in these scenarios concerns only coniferous timber. The reason is that air pollution normally affects coniferous trees more severely than it affects nonconiferous tree species. Coniferous timber is much more important to the Finnish forest sector than nonconiferous timber.

5. In the scenario assumptions, no distinction is made between the quality of timber removed in sanitation harvests and the quality of timber removed in normal harvests.

Table 1--Scenario assumptions in terms of growth and mortality parameters

Scenario	Growth parameter	Mortality parameter	Duration of sanitation harvests
Scenario 1 (base)	1.00	1.00	
Scenario 2	0.67	1.20	1990-2000
Scenario 3	0.50	1.00	
Scenario 4	1.00	2.00	1990-2000
Scenario 5	1.00	2.00	1990-2010

Table 1 summarizes the scenario assumptions. The growth parameter in each scenario is the growth rate of trees in 2010 compared to the base. The mortality parameter is the multiplier, when the supply curve is shifted to the right compared to the base.

Main Results

The main purpose of this article is to demonstrate the sensitivity of potential economic effects on the Finnish forest sector of prolonged forest damage in Western Europe. These effects are, however, only a part of the world-wide mechanism by which forest sector markets adjust to a new equilibrium. Therefore, we also have to study global trade flows and other international development paths to gain an idea of the damage impacts as a whole.

For the sake of clarity and brevity, we present our principal findings mainly in graphical form. In figures 1-4 the base scenario always equals 100, and quantities in scenarios 2-5 are expressed as index numbers in relation to the base.

Figure 1 shows the development of industrial coniferous timber harvests in Western Europe in the five scenarios. Especially for coniferous logs, timber harvests change only very modestly as a result of changes in timber supply. The effect on timber harvests in Finland is even smaller, but in an opposite

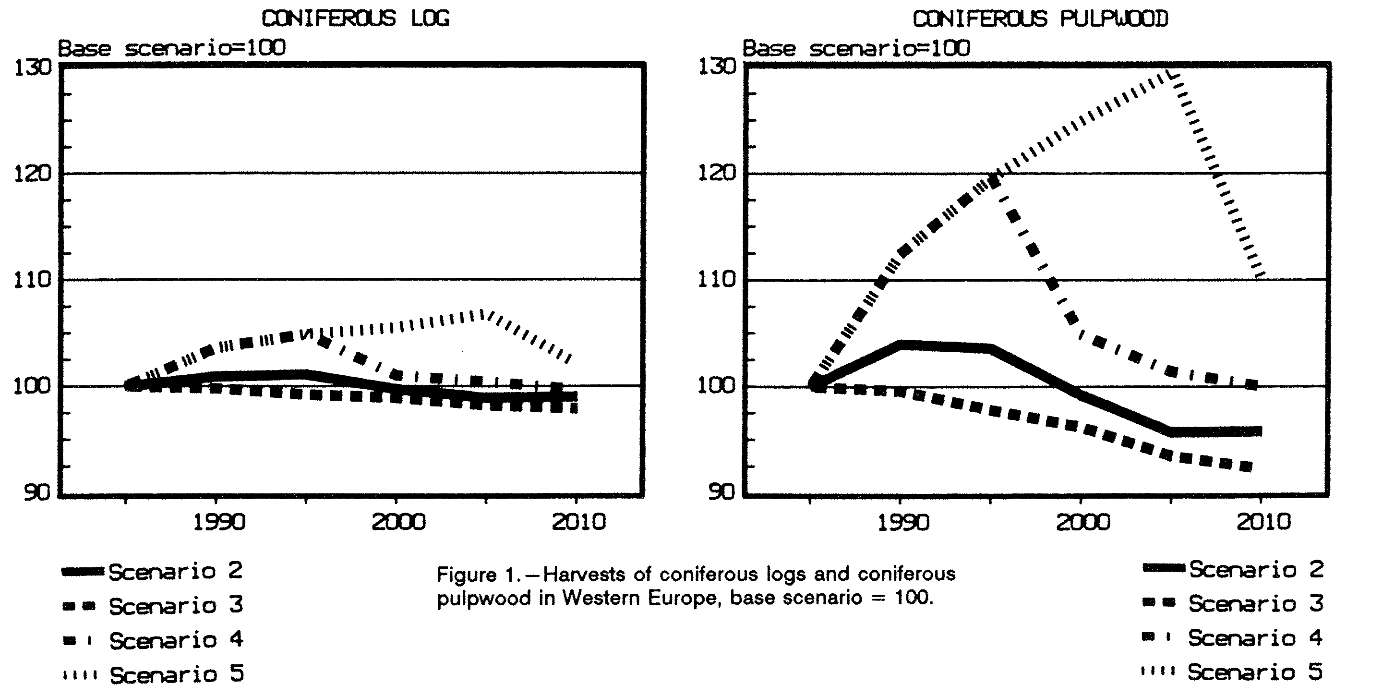


Figure 1.—Harvests of coniferous logs and coniferous pulpwood in Western Europe, base scenario = 100.

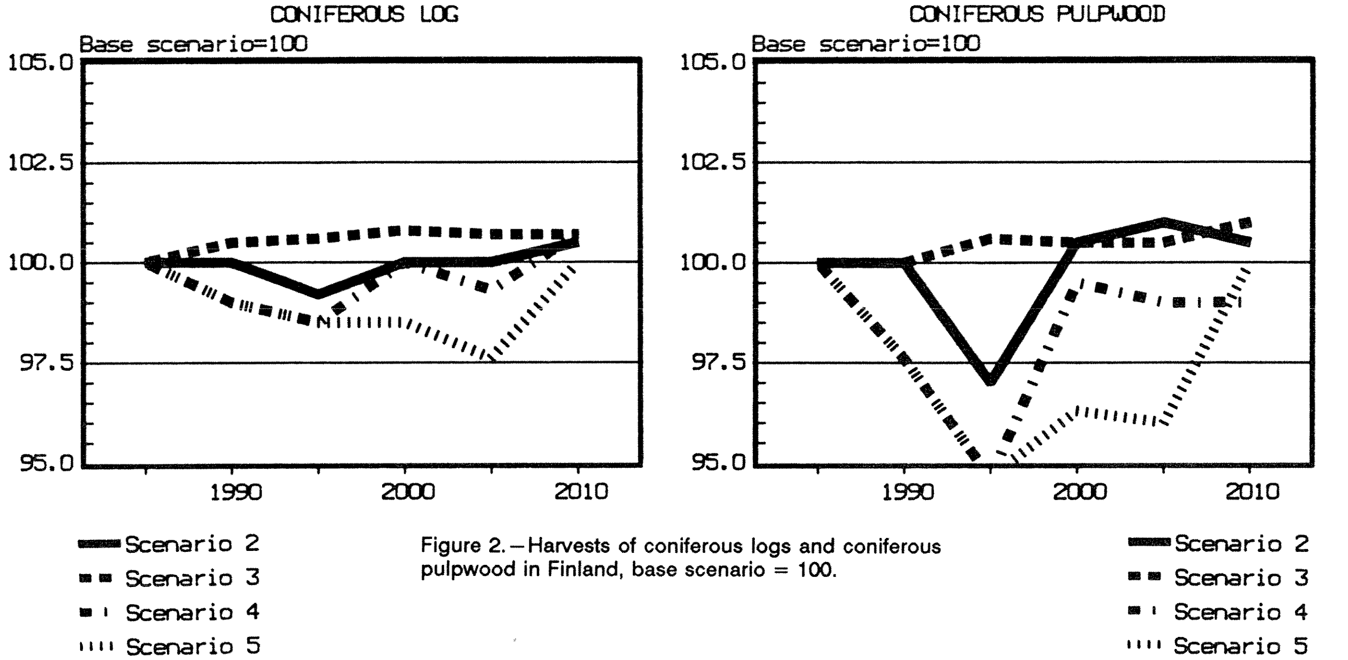


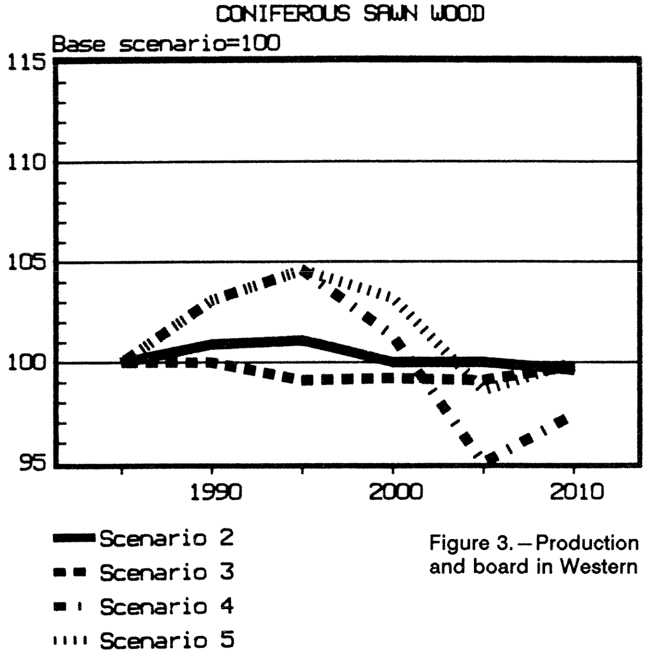
Figure 2.—Harvests of coniferous logs and coniferous pulpwood in Finland, base scenario = 100.

direction (figure 2). This countertrend reflects increased industrial production in Western Europe and increased importation of wood into Finland. The smallness of the increase in harvests is mainly due to the substitution of sanitation harvests for some "normal" harvests. In scenario 2, in which coniferous timber supply is increased by 20 percent due to the mortality effect, Western European coniferous timber removals are only 3 percent over the base scenario by 1995. The modest increase of removals in scenario 2 is also partly explained by a decreasing timber growth rate: 87 percent compared to the base by 1995. The increase of roundwood exports also reduces the effect of sanitation harvests on production by forest industry in Western Europe. In addition, the decrease in prices of both wood and final products smothers the pressures to change production levels.

Scenarios 3 and 4 also indicate the slow response of harvesting to changes in roundwood supply. A 100-percent increase in coniferous timber supply increases timber removals only by 10 percent during a 10-year period. In scenario 5, where the same increase in timber supply lasts another 10 years, the increase in removals is 17 percent at the end of the 20-year period. Timber harvest levels also respond slowly to timber growth decreases. In scenario 3, the growth rate declines 50 percent by 2010, but timber harvest decrease only 5 percent from 1985 by 2010.

Changes in timber supply in Western Europe result in changes in timber harvests, which cause changes in timber prices. This leads to changes in production costs and product prices, and finally in consumption. In scenarios 2-4 changes in consumption are, however, quite marginal. Thus changes in production are small. Changes in production of coniferous sawnwood and paper and board are shown in Figures 3 and 4. For sawn wood, only scenarios 4 and 5 produce clear changes compared to the base prior to 2005. The airborne pollution forest damages seem to have practically no effect on the production of paper and board in Finland. A partial explanation for this is that, in paper products, Western Europe reduces mainly the import of "other paper and board." The U.S. is the principal importer of these products, whereas Finland and Sweden are the largest exporters of printing and writing papers.

The market mechanism plays a major role in absorbing the effects of potential forest damages in Western Europe on other regions. The forest sector as a whole reacts slowly to, and smothers, the changes in timber supply. Inertia is also present, especially in investments and trade. Changes in timber supply change wood prices, which causes changes in consumption. Finally, changes in harvests and production in one region are absorbed by a large number of often intricately linked changes in production, consumption, and trade in other regions. Global changes in coniferous timber harvests and forest industry production in scenario 5 are summarized in table 2 (for a more detailed description, see H. Seppala and others 1990).



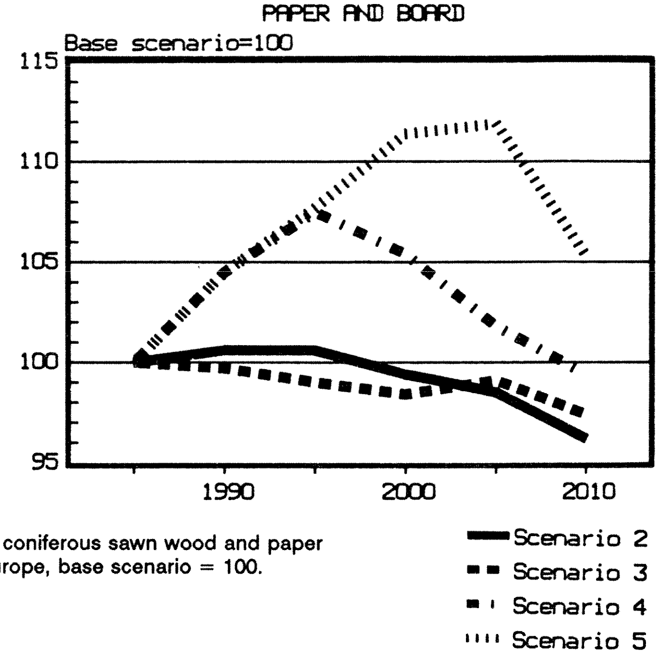
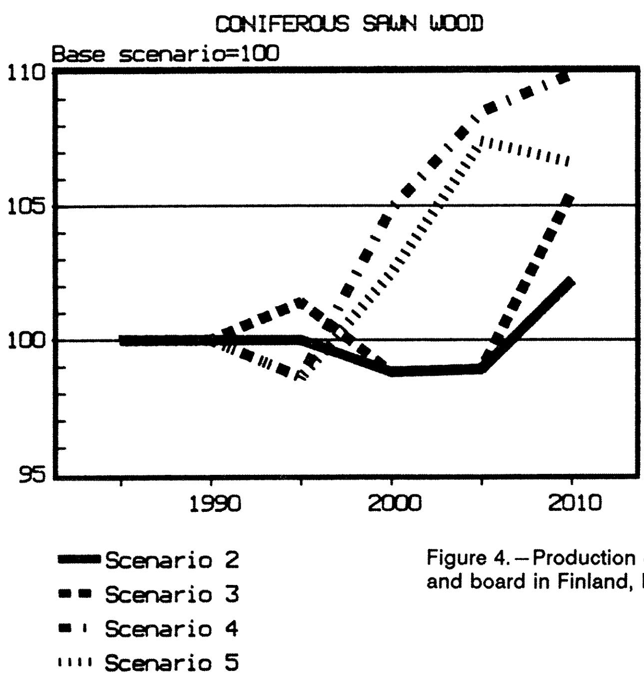


Figure 3.—Production of coniferous sawn wood and paper and board in Western Europe, base scenario = 100.



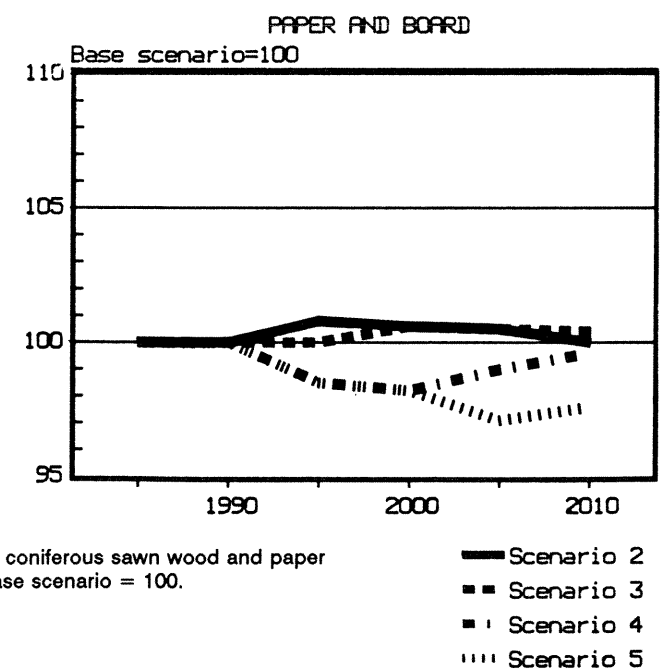


Figure 4.—Production of coniferous sawn wood and paper and board in Finland, base scenario = 100.

Table 2--Regional changes in coniferous timber harvests, production of coniferous sawn wood, and total paper and board in year 2000 in scenario 5. Figures represent comparisons with the base scenario

Region	Coniferous harvest	Coniferous sawn wood production	Paper and board production
	------Million m^3------		Million tons
Western Europe	+12.7	+1.2	+3.6
Finland	-1.0	+0.2	-0.3
Sweden	-0.9	-0.2	-0.7
North America	-5.6	-2.2	-2.6
Latin America	-0.8	+0.1	-0.3
Rest of world	-0.5	+2.8	-0.1
World total	+3.9	+1.7	-0.4

According to scenario 5, a 100-percent shift of the supply curve of coniferous timber will increase coniferous harvests in Western Europe by 12.7 million m^3 or 14 percent by year 2000 compared to the base scenario. The increase in world coniferous timber consumption as a result of decreased timber prices, however, is marginal (3.9 million m^3).

The increase in harvests and production of the forest industry in Western Europe results in a reduction in imports to the area and hence a decrease in production in other regions. In absolute terms, the largest decrease in harvests is experienced in North America (5.6 million m^3), but this decrease is equivalent to only about 1 percent of total coniferous harvests in the region. In Finland and Sweden, combined harvests decrease by 1.9 million m^3 or 2.7 percent of the total coniferous harvests.

The analysis indicates that only catastrophic forest dieback or essential changes in cutting behavior (as a result of regulatory forest policy, for example) might have crucially important effects on the Finnish forest sector. Indirect linkages may cause unexpected developments in Finland, however.

Discussion

To a certain extent, the results presented above contradict a common belief that Western European forest damage will disturb roundwood markets and in the long run substantially decrease cuttings in Finland. The future is uncertain, and we do not know which, if any, of the alternative futures will occur. The common belief is not based on scientific investigation. Although the results of this paper are so based, they are dependent on the structure and parameter values of the model employed. Some of the assumptions used in the model runs can be questioned.

In constructing the model, we assumed that sanitation harvests concern only coniferous timber. Forest damage in Western Europe has so far been discovered mainly in coniferous species, and nonconiferous species make up less than 20 percent of the growing stock in Finland. Western European broad-leaved timber is not very competitive for reasons of quality. Birch logs are used mainly for plywood production especially in Finland; and the Finnish birch plywood is so superior that there is no danger of increasing Western European competition. There is a chronic shortage of nonconiferous pulpwood in the Finnish forest industry, and this pulpwood is the most important item in roundwood imports. Therefore, any increase in imports is warmly welcomed by the industry if only the wood quality satisfies requirements.

In the model, the decrease in the growth rate of trees due to soil acidification is assumed to be gradual and advance rather slowly. There are strong opinions (e.g. Hari and others 1987) that the reduction would be sudden. This alternative was studied by Dykstra and Kallio (1986). They found that roundwood markets react very slowly even to a drastic and sudden drop in growth rates. Furthermore, it must be remembered that most Western European forests are overaged and overstocked, and that there is a silvicultural need for increased harvesting during the next 10 to 20 years whatever the growth rates are (Kuusela 1987).

We have assumed that the wood supply in Eastern Europe and the Soviet Union, as well as in Finland and Sweden, is neither increased by sanitation harvests nor reduced by diminished timber growth rates. It is, however, assumed that the Eastern Bloc will increase its timber supply by 15 percent from 1985 to 2010. This increase can be interpreted as resulting at least in part from forest dieback in some Eastern Bloc countries. It is very probable that any sanitation harvests can easily substitute for normal harvests in Finland and Sweden, where timber-harvesting logistics are well established. So far, the growth rates have increased – not decreased – and the structure of forests is such that cuttings should increase during the next 10 to 20 years even if the growth rates decrease.

In the model, the dynamic aspects of timber supply are handled by shifting a short-run marginal cost curve through time in response to changes in the level of timber inventory. This procedure does not, however, account for any intertemporal conditions of market equilibrium. As a consequence, reduced future growth affects only future prices, not current ones. A specific Hotelling-type specification of the timber supply component (see Hotelling 1931) would produce immediate increases in current prices: producers would shift production out of current years into future years to take advantage of the higher prices anticipated in the future. In the short run, this process might tend, at least in part, to smooth out the price effect and to sharpen the quantity effect. In the long run it might, however, smother the quantity effect (see Ovaskainen 1987).

An advantage of this kind of approach is that it is comparative in its nature. This means that air pollution alternatives are compared to a base scenario, and hence only the deviations from the base are analyzed. This smothers the possible errors in assumptions and in the structure of the model. We are therefore safe in predicting that air pollution damage in Western Europe will have only a minor effect on the Finnish forest sector during the next 25 years.

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Appendix

List of Product Categories:

1. Coniferous logs
2. Nonconiferous logs
3. Coniferous pulpwood and chips
4. Nonconiferous pulpwood and chips
5. Fuelwood
6. Coniferous sawn wood
7. Nonconiferous sawn wood
8. Veneer and plywood
9. Composition panels
10. Coniferous white pulp
11. Nonconiferous white pulp
12. Newsprint
13. Wood containing printing and writing paper
14. Wood-free printing and writing paper
15. Other paper and board
16. Recycled paper

List of Regions:

1. Western Canada
2. Eastern Canada
3. Western US
4. Eastern US
5. Brazil
6. Chile
7. Rest of Latin America
8. Finland
9. Sweden
10. Rest of Western Europe
11. USSR
12. Eastern Europe
13. Africa
14. China
15. Japan
16. Southeast Asia
17. Australia-New Zealand
18. Rest of the world

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Six papers analyze potential economic effects of forest damage resulting from air pollution. Economic effects in the Southeastern United States, the United States as a whole, Canada, Finland, and Europe as a whole are considered. The authors interpret the problem in different ways and employ different analytical methods. Several of the papers were presented at the 19th IUFRO World Conference in Montreal in 1990.

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