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

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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 profii 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 occurred 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 a in the production function reduces the maximum volume that can be produced per acre, where $0<\alpha<1$ (see fig. 1). The proportion a can further be considered a function of the level of atmospheric pollution 6, a = $\alpha(\delta)$.

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:

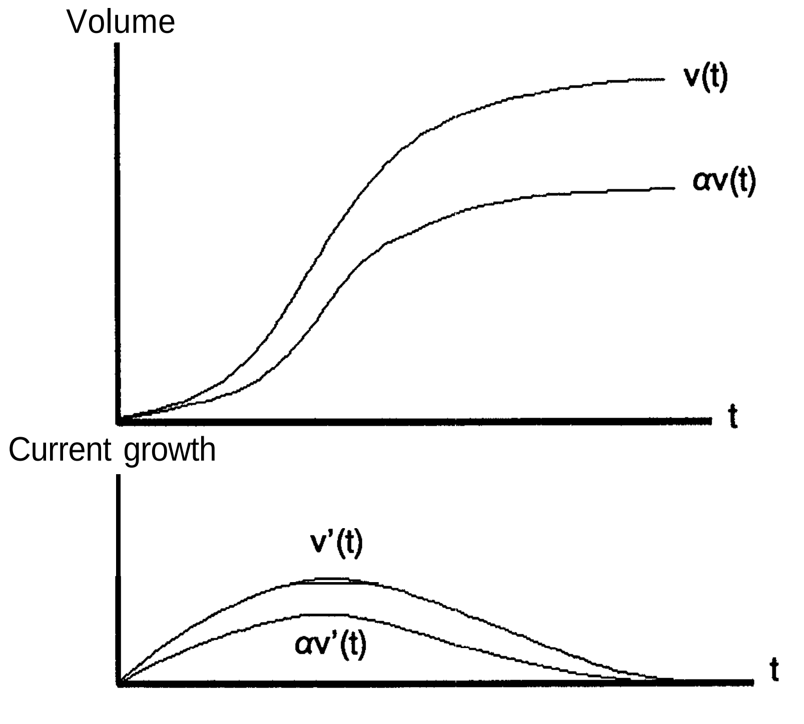

Figure 1. -A proportional decline in forest productivity.

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

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

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

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

Under this formulation, the vector $c'_t = (c_{t,1}, c_{t,2}, \ldots, c_{t,m})$ represents the number of acres harvested in period t by age class, and the vector $v' = (v_1, v_2, \ldots, v_m)$ 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 6 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 wayn is changing (Samuelson 1965, Varian 1984). Therefore, the total derivative of π with respect to 6 is exactly equal to the partial derivative of π with respect to 6, 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 1986):

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

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

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.

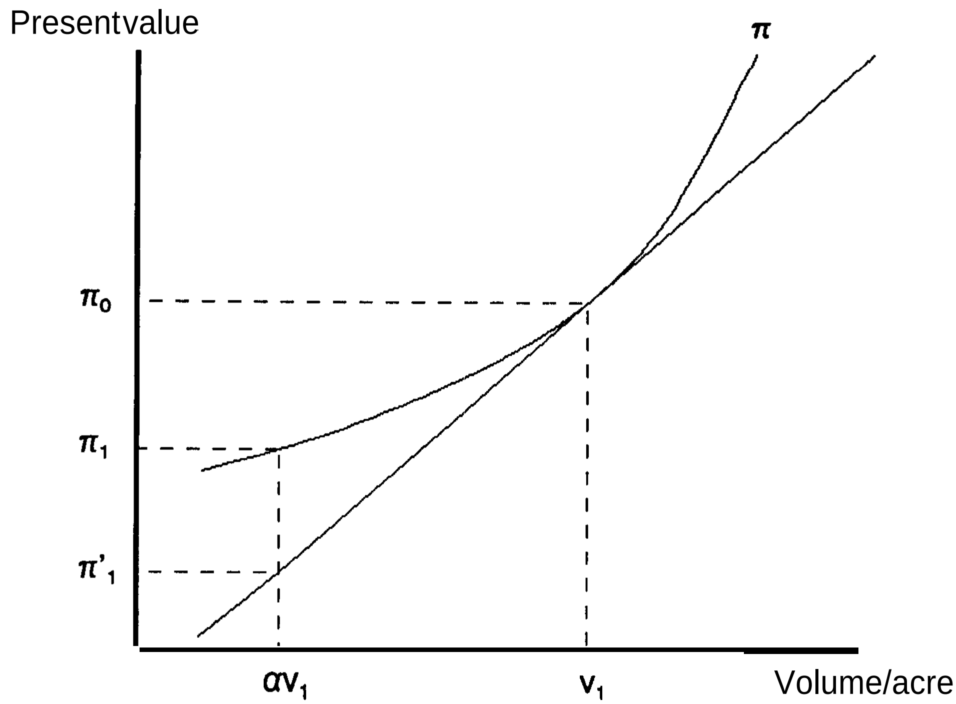

Figure 2. -Upper-bound damage estimate using the envelope theorem.

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 benefii of timber production in any year can be measured as the area above the supply curve and below the price. This area is referred 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:

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

where $\Delta\pi$ is the change in present value, π is the initial present value function, x(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

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

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

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:

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

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 α = 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 $0 < a < 1$. The area CS representing consumer surplus can be expressed as

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

and area PS representing producer surplus can be expressed as:

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

As can be seen in figure 3, the change in consumer surplus (the area above price and bslow 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.

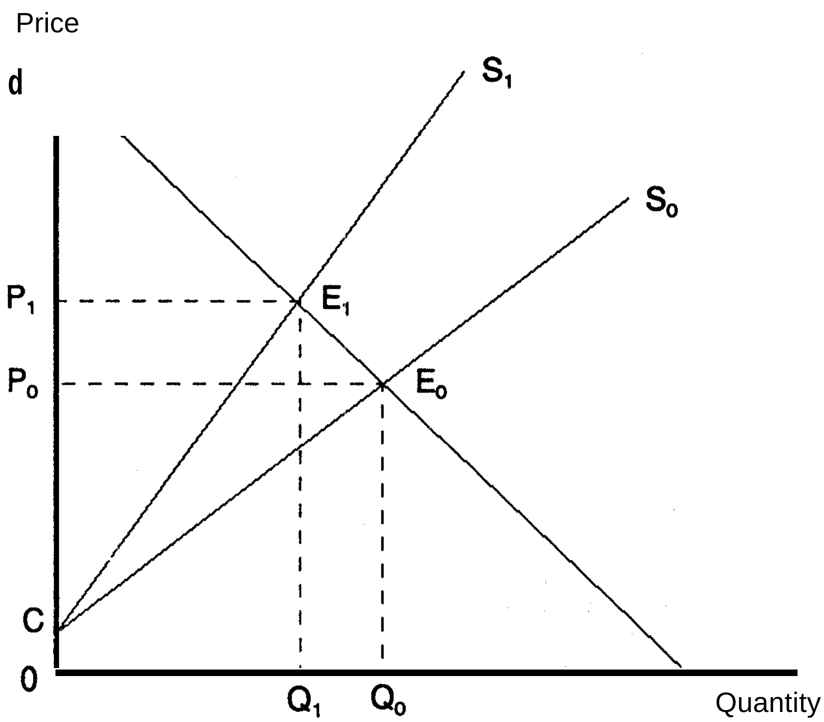

Figure 3. -Aggregate economic welfare impacts of a change in forest productivity.

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:

$$\Delta S_\tau = \frac{\tau \Delta S_T}{T(1 + r)} \quad for \ \tau \leq T$$
$$= \frac{\Delta S_T}{(1 + r)^\tau} \quad for \ \tau > T \qquad (12)$$

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 1 O-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 (ACS), producer surplus** (APS), and total welfare **(ΔTW)** resulting **from proportional changes (a) in productivity**

Proportional changes [a]	ACS	APS	ATW
	Thousands of dollars [b]		
		Solidwood	
a = .99	-56,207 (0.47) [c]	-972 (0.008)	-57,179 (0.24)
a = .95	-283,711 (2.36)	-7,964 (0.07)	-291,675 (1.23)
a = .90	-574,061 (4.81)	-24,407 (0.21)	-598,468 (2.52)
		Pulpwood	
a = .99	-30,416 (0.85)	-13,027 (0.20)	43,443 (0.43)
a = .95	-152,205 (4.26)	-55,090 (0.84)	-207,295 (2.05)
a = .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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