EPA-230-12-85-025
September 1985

METHODS DEVELOPMENT FOR ENVIRONMENTAL CONTROL BENEFITS ASSESSMENT

Volume VII

METHODS DEVELOPMENT FOR ASSESSING ACID DEPOSITION CONTROL BENEFITS

by

Thomas D. Crocker, John T. Tschirhart, and Richard M. Adams
University of Wyoming
Laramie, Wyoming 82071

Bruce Forster
University of Guelph
Guelph, Ontario NIG 2W 1

USEPA Grant # R806972-01-0

Project Officer

Dr. Alan Carlin
Office of Policy Analysis
Office of Policy, Planning and Evaluation
U*S. Environmental Protection Agency
Washington, D.C. 20460

OFFICE OF POLICY ANALYSIS
OFFICE OF POLICY, PLANNING AND EVALUATION
Us. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OTHER VOLUMES IN THIS SERIES

Volume 1, Measuring the Benefits of Clean Air and Water, EPA-230-12-85-021.

This volume is a nontechnical report summarizing recent research for EPA on methods development for better estimates of economic benefits from environmental improvement. The report presents the basic economic concepts and research methods underlying benefits estimation as well as a number of case studies, including several from other volumes of this series. Finally, it offers insights regarding the quantitative benefits of environmental improvement.

Volume 2, Six Studies of Health Benefits fran Air Pollution Control, EPA-230-12-85-020.

This volume contains six statistical epidemiology studies. They show that large associations between health and current levels of air pollution are not robust with respect to the statistical model specification either for mortality or morbidity. They also find that significant relationships, mostly small, occasionally appear.

Volume 3, Five Studies on Non-Market Valuation Techniques, EPA-230-12-85-021.

This volume presents analytical and empirical canparisons of alternative techniques for the valuation of non-market goods. The methodological base of the survey approach - directly asking individuals to reveal their preference in a structured hypothetical market - is examined for bias, replication, and validation characteristics.

Volume 4, Measuring the Benefits of Air Quality Changes in the San Francisco Bay Area: Property Value and Contingent Valuation Studies, EPA-230-12-85-022.

This volume replicates a property value study conducted in the Los Angeles Basin for the San Francisco Bay area. A taxonomy series of air quality types and socioeconomic typoligies are defined for cities in the area to examine how property values vary with pollution levels. The contingent valuation method surveys individuals, directly asking their willingness to pay for changes in air quality. The survey method yields benefit values that are about half the property value benefits in both the Bay area and Los Angeles.

Volume 5, Measurinq Household Soiling Damages from Suspended Particulate: A Methodological Inquiry, EPA 230-12-85-023.

This volume estimates the benefits of reducing particulate matter levels by examining the reduced costs of household cleaning. The analysis considers the reduced frequency of cleaning for households that clean themselves or hire a cleaning service. These estimates were compared with willingness to pay estimates for total elimination of air pollutants in several U.S. cities. The report concludes that the willingness-to-pay approach to estimate particulate-related household soiling damages is not feasible.

Volume 6, The Value of Air Pollution Damages to Agricultural Activities in Southern California, EPA-230-12-85-024.

This volume contains three papers that address the economic implications of air pollution-induced output, input pricing, cropping, and location pattern adjustments for Southern California agriculture. The first paper estimates the economic losses to fourteen highly valued vegetable and field crops due to pollution. The second estimates earnings losses to field workers exposed to oxidants. The last uses an econometric model to measure the reduction of econanic surpluses in Southern California due to oxidants.

Volume 8, The Benefits of Preserving Visibility in the National Parklands of the Southwest, EPA-230-12-85-026.

This volume examines the willingness-t-pay responses of individuals surveyed in several U.S. cities for visibility improvements or preservation in several National Parks. The respondents were asked to state their willlingness to pay in the form of higher utility bills to prevent visibility deterioration. The sampled responses were extrapolated to the entire U.S. to estimate the national benefits of visibility preservation.

Volume 9, Evaluation of Decision Models for Environmental Management, EPA-230-12-85-027.

This volume discusses how EPA can use decision models to achieve the proper role of the government in a market economy. The report recanmends three models useful for environmental management with a focus on those that allow for a consideration of all tradeoffs.

Volume 10, Executive Summary, EPA-230-12-85-028.

This volume summarizes the methodological and empirical findings of the series. The concensus of the empirical reports is the benefits of air pollution control appear to be sufficient to warrant current ambient air quality standards. The report indicates the greatest proportion of benefits from control resides, not in health benefits, but in aesthetic improvements, maintenance of the ecosystem for recreation, and the reduction of danages to artifacts and materials.

PREFACE

Many individuals have made useful contributions to the preparation of this report. Drs. Alan Carlin and Dennis Tirpak of the USEPA were particularly helpful in setting bounds on the nature of the problem during the early stages of the research. A meeting in October 1979, with the members of the Committee on Biological Effects of the National Atmospheric Deposition Program was also helpful in this respect. Michael Marcus of the Department of Zoology at the [University of Wyoming has provided written material which has been used as the basis for several lengthy passages in Chapters II and V. Intermittent conversations with and written commentaries from Dennis Knight, William Schulze, and Harold Bergman have been instrumental in shaping some of what appears in the following pages. None bears any responsibility for any errors or omissions. Reza Sepassi has contributed in numerous wavs as the primary research assistant for the research effort. Finally, Carol Steadman has employed her multiple talents to provide worthy research, editing, bookkeeping, organizational, and typing services throughout the project.

ABSTRACT

There has recently been increasing awareness that some environmental pollutants, because of the broad geographical scope of their effects, impose not only the direct affronts to human life and property of the traditional urban pollutants, but also attack the pleasures and the life support services that the earth's ecosystem scaffolding can provide. Acid precipitation might be one of these pollutants. The basic purpose of this report is to suggest those types of natural science research that would be most helpful to the economist faced with the task of assessing the economic benefits of controlling acid precipitation. However, while trying to formulate these suggestions, inadequacies in the supporting material the ecologist could offer the economist, and in what the economist could do with whatever the ecologist offered him, became apparent. Therefore part of our effort has been devoted to initial development of a resource allocation process framework for explaining the behavior of ecosystems that can be integrated into a broadened benefit-cost analysis which captures traditional ecological concerns about ecosystem diversity and stability. Our intent has been to make a start at providing a basis for the ecological and the economic disciplines to ask better-defined questions of each other.

Some reasonably well-defined questions have nevertheless been asked and tentative answers have been provided for a few of them. In particular, most of the existing techniques for assessing the benefits of pollution control require knowledge of the magnitude of the response of the entity of interest to variations in the quantity of pollution to which it is exposed. The entity that is the object of interest in these estimates of response surfaces or functions must itself have value to humans or it must contribute in some known fashion to another entity having value to humans. Otherwise, the economist is unable to perform his tasks. Additional properties that response surface research must have to be most valuable for the empirical implementation of the techniques of benefit-cost analysis are outlined in the text.

The simplest of these available techniques is applied in a first exercise at using known response surfaces to assess the benefits of controlling acid precipitation in Minnesota and the states east of the Mississippi River. Current annual benefits of control are estimated to be $\$5 \times 10^9$ in 1978 dollars, with materials damages constituting the largest portion of these

benefits. The reader must not treat this estimate as definitive, although the ordering of current annual control benefits by sector is highly plausible.

The known response surfaces used to construct the above estimate sometimes displayed two properties that could impart "all-or-nothing" and "now-or-never" features to the acid precipitation control decision problem, These two features arise because the marginal benefits of reducing acid precipitation appear to be increasing over a substantial interval of increasing pH values, and because the effects of acid precipitation upon ecosystem buffering capacities are less than fully reversible, both technically and economically.

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

It is now widely accepted that the average pH of the annual precipitation in nearly the entire United States east of the Mississippi River was below 5.0 in 1972-73 [Glass (1978, pp. vii, 19)]. Only northern Wisconsin and southern Florida were exempted. Since 1972-73, no increase in rainfall pH is believed to have occurred. With the likely increased combustion of coal in Canada and the United States, most commentators expect further reductions in pH levels and a further spreading of the geographical areas subjected to acid precipitation and acidifying depositions. This expectation persists even though doubts have been publicly expressed about whether some of the instrumentation used to measure precipitation acidity is accurate [Galloway, et al. (1.979)] , and whether current measures actually represent a decline from historical pH levels [Perhac (1979)].

Substantial concern has been expressed in both scientific and lay circles about the impacts of increasingly acidic precipitation upon the flows of material resources and amenity and life support services provided by forest and aquatic ecosystems. Because of these potential impacts, policymakers in the U.S. and Canada are now being asked to weigh the benefits provided by these resources and services against the costs of controlling emissions of acid precursors from fossil fuel combustion. Allied with these concerns are numerous proposals for more research on the biological and economic effects of acid precipitation. In this report we attempt to provide policymakers with some of the information they need to choose intelligently from among these proposals and to prepare adequately for the findings of whatever research programs are ultimately adopted. Although researchers have made considerable progress in identifying those features of different ecosystems that render their economically valuable components and processes more-or-less vulnerable to disruption as a consequence on long-term acid precipitation, the goal of providing consistently dependable guidance to policymakers has not yet been reached.

Toward this end, we have, after this introduction, structured this report in four chapters. The next chapter provides an economist's review of the existing literature on the biological and physical effects of acid precipitation. The overview content is combined with limited information on the market values of the affected material resources and amenity and life support services to arrive at no better than order-of-ma.gnitude assessments of the current annual economic losses to existing activities caused by acid precipitation in the eastern United States (Minnesota and the states east of the Mississippi River). The emphasis in this second chapter is on identifying the economic sectors that appear to be suffering the greatest damages from acid precipitation. Only the simplest of economic methods are used to perform this first exercise in assessment. A third chapter raises two plausible special features, nonconvexities and irreversibilities, of the ecosystem effects of acid precipitation that are likely to cause special. difficulties for control decisionmaking as well as difficulties for the application of both the simple and more sophisticated methods of assessing the economic benefits of control. In a fourth chapter, we present a somewhat broader framework for assessing the economic benefits of control than the framework that underlies traditional assessment methods: we provide a start in the development of a framework which, in principle, allows one to assess the economic impact of pollution or anv source of stress upon ecosystem yields and ecosystem diversity. This framework has been developed because of the inattention given by traditional economic assessment procedures to questions of fundamental concern to ecologists, and because of our perceived lack of an ecological-theoretical. framework which could guide the questions the economist asks of the ecologist. Finally, while drawing upon the information generated in the previous parts, we develop and try to defend a set of recommendations for natural science research on the biological effects of acid precipitation. Our recommendations assume that without exception all natural science research into these effects is directed toward the provision of information for assessing the economic benefits of acid precipitation control. This last chapter is the culmination of our current efforts. The reader should therefore view the report not as an assessment of the economic benefits of specific control alternatives but rather as a prelude to that assessment.

The Tasks of the Economist

We divide into six tasks the role of the economist in providing decisionmakers with information to assess the benefits of controlling acid precipitation. Since attempts to treat these tasks, within the limits of research time and resources, compose the bulk of this report, we offer only the briefest treatment here:

1.) To enumerate a set of economic indicators capable of communicating national. and regional. economic benefits of alternative types and degrees of control of acid precipitation.

2) To identify those features of acid precipitation that when altered have direct implications for the aforementioned indicators. These features may affect directly the components of ecosystems and the economic activities that depend upon them. Alternatively, they may alter the behavior of these components, resulting in changes in ecosystem processes and the economic

activities which employ them. An example of a direct effect is a reduction in the yield of a vegetable due to acid precipitation-induced inhibition of photosynthesis in the standing stock of vegetable plants. An indirect effect might consist of the changes in successional Patterns of a forest due to the differential effects of acid precipitation upon particular tree, understory, and soil microbe species.

3) To identify and, where appropriate, develop a theoretical framework for assessing the potential national and regional economic benefits of alternative acid precipitation control strategies. This framework should generate refutable hypotheses about the causal relationships between the features of various control strategies and the responses in economic terms of relevant ecosystem processes and components. In short, the framework should make easier the appropriate specification and estimation of the economic and ecosystem parameters needed to explain and to make predictions of the magnitudes and the timing of the potential benefits of alternative control strategies.

4) To identify the data required to estimate the aforementioned parameters. The data requirements should be as parsimonious as the theoretical framework will allow.

5) Given the current state-of-the-world, to estimate the current values of the relevant economic and ecosystem parameters, while employing properly constructed variables, applicable statistical and numerical tools, and an appropriate sample of ecosystems.

6) To incorporate the estimated parameters into a body of knowledge that will predict the values of the economic indicators resulting from adoption of alternative acid precipitation control strategies.

Generally speaking, each of these tasks is served by an analytical framework or model encompassing a greater range of phenomena than did previous models. Of the six tasks, however, the third and the fourth are most likely to be of greatest relative interest to the professional researcher, while the other four tasks assume greatest relative importance for the decisionmaker. In those parts of economics relevant to the assessment of the benefits of air pollution control, there has frequently been inadequate attention by analytical investigators to possibilities for improved empirical implementation. Analytical investigators have on occasion indulged in illicit intercourse with beautiful models, as at least one economist has remarked. On the other hand, economists having some interest in empirical implementation have occasionally been too ready to indulge requests to generate estimates of the benefits of air pollution control. From some perspectives, this report might accomplish the unusual act of being culpable on both counts. The second chapter of the report engages in an empirical exercise that is not solidly embedded in a theoretical framework. The fourth chapter goes through a theoretical exercise which could be empirically implemented. Nevertheless, in this report any beauty it has must be judged as an abstraction; it is provided little empirical flesh. Only the third chapter makes a limited attempt to clothe the abstract in the empirical. We nevertheless feel that these rather disparate chapters do result in a set of natural science research recommendations, that when accomplished, are likely to be useful and inputs for assessing the economic benefits of alternative acid precipitation control strategies.

A Dynamic Economic Sketch of the Ecosystem Effects of Acid Precipitation

In order to frame our discussion, we present in this section a model which outlines the economic nature of the problem of preventing ecosystem damages from acid precipitation. As will be near-universal throughout this report, knowledge of the dose-response function relating ecosystem effects to acid precipitation is central to any empirical application of the model.

Assume an industrial region, I, that generates a constant waste flow, $\bar{W}$, per time period. Some of these wastes are carried and transformed by atmospheric processes to a lake region, L. The waste that travels the distance, x^L, from I to L each period is given by:

$$W(x^L) = \frac{W}{Hu} - \int_0^{x^L} \ell(x)dx, \tag{1}$$

where H is the mixing or scavenging height of the air column and u is the wind speed. H and u are assumed constant over $[o,x^L]$. $\bar{W}/Hu = \bar{W}/k$ is then the initial pollution concentration at I. $\ell(x)$ is a pollution loss or transformation function which is assumed constant over distance.[1] Thus

$$W(x^L) = \bar{W}/k - \bar{\ell}x^L \tag{2}$$

is the waste concentration arriving each period at L as a result of $\bar{W}$ being generated in I.

Atmospheric processes cause the waste to be deposited and accumulated in L as a stock of pollution, P. This accumulation is:

$$\frac{dP}{dt} = g(W(x^L)) - \alpha P, \tag{3}$$

where $g(\cdot)$ measures the waste concentration in the lake region, and αP measures the abilities of the region's forest and aquatic ecosystems, R, to cleanse themselves of the pollutant.[2] We assume that α is constant and independent of pollution. Forster (1975) discusses a model in which a is a decreasing function of P.

The dynamic evolution of R is governed by a pollution version of the Lotka (1925) biological growth function:

$$\frac{dR}{dt} = F(R,P), \tag{4}$$

where, for a given $\bar{P}$, the F function has the usual Lotka shape. Increases in P will shift the entire curve downward in Figure 1. The environmental carrying capacity, $\bar{R}$, is thus an inverse function of the level of pollution. That is:

$$\bar{R} = \bar{R}(P); \ \bar{R}'<0 \tag{5}$$

Expression (5) is an example of what is commonly called a dose-response function. The loss in $\bar{R}$ may be thought of as the ecosystem damages caused by a change in the pollution level. Its critical importance to system behavior and thus human welfare can be illustrated by introducing a harvesting function relating man's harvest, H, from the system to his harvesting effort, a, and the size of the lake region's forest and aquatic ecosystem resources.

$$H = aR \tag{6}$$

For a given level of effort, the harvest will be larger if the resources are more plentiful. Using (6) and the previous expressions, the dynamic structure of the lake region ecosystem is governed by:

$$\frac{dP}{dt} = g(\bar{W}/k - \bar{\ell}x^L) - \alpha P. \tag{7}$$

$$\frac{dR}{dt} = F(R,P) - aR. \tag{8}$$

The limiting solution for pollution, PB, depends upon meteorological factors, the level of waste emissions in I, and the self-cleansing abilities of the lake region's ecosystems:

$$P\infty = \frac{1}{\alpha} g(\bar{W}/k - \bar{\ell}x^L). \tag{9}$$

This solution, which is globally stable, can be substituted into (9) to examine the limiting solution for R. The result of doing so is illustrated in Figure 2.

In Figure 2, pollution reduces the growth rate of the lake region's resources and thereby reduces the region's environmental carrying capacity from $\bar{R}(0)$ to $\bar{R}(P\infty)$. With a given level of harvesting effort, the bioeconomic equilibrium stock size is reduced from R* to R∞ and the equilibrium harvest suffers a decline from H* to H∞. The equilibrium resource stock size is

Figure 1.1

Evolution of the Resource Stock

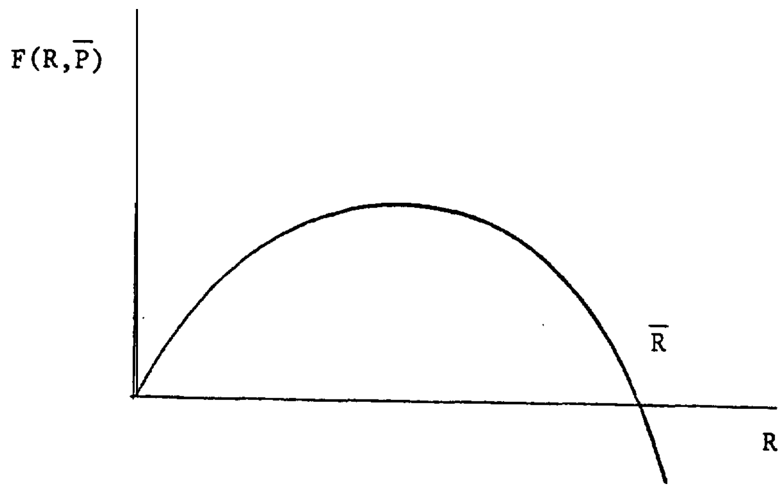
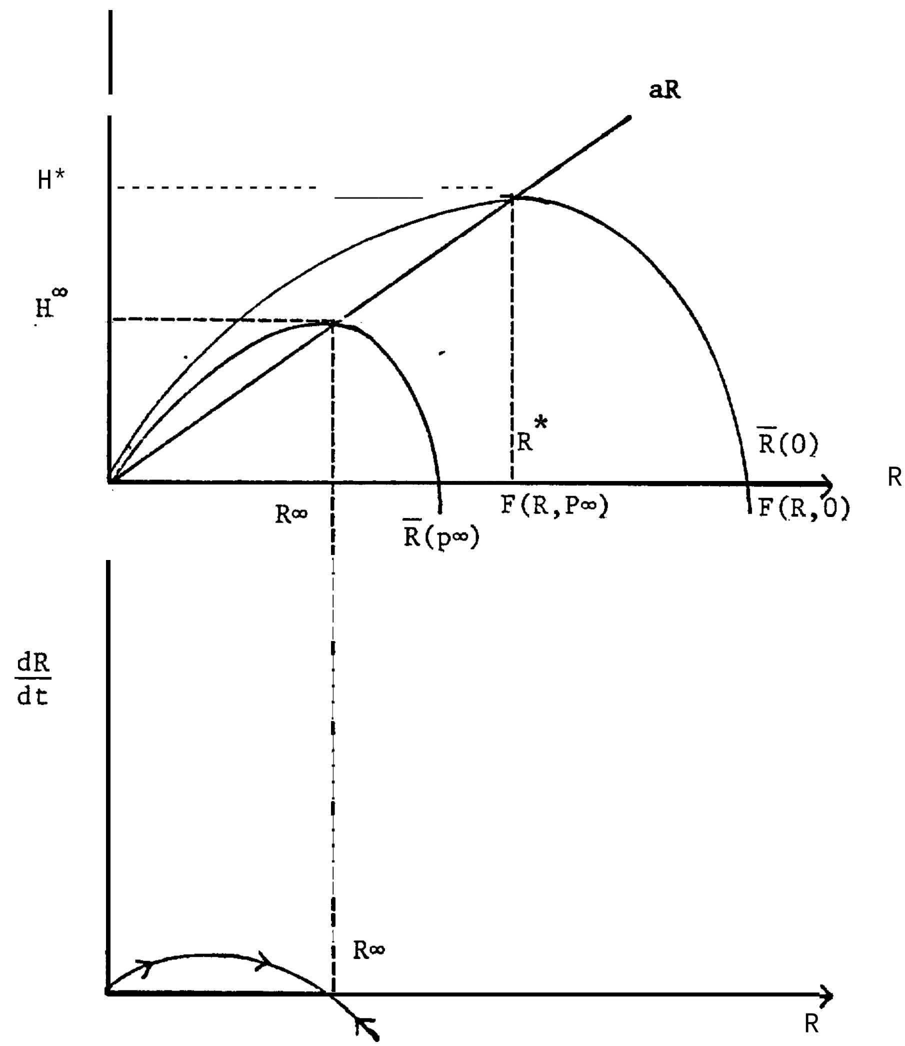


Figure 1.2

Equilibrium Pollution and Resource Stock



stable. Efforts to enhance the resource base by restocking fish or fertilizing forest soils may offer temporary respites by raising the resource stock above R^{∞}. However, with P continuing at P^{∞}, the stock must over time decline again to R^{∞}.

The Meaning of Economic Benefits

Everything said in this report unequivocally assumes that man is the measure of all things. As Adams and Crocker (forthcoming) point out, whatever a person does must be the best thing for him to do, given his knowledge of his circumstances of the moment--otherwise, he would not do it: thus the person's autonomous preferences are revealed by his behavior. This is the perspective of value that pervades economic analysis. Contrary, however, to much common usage, "economics" and "pecuniary" are not viewed as synonymous. For example, human behavior and the health, production, or aesthetic effects of a pollutant on that behavior are directly "economic." The effects of a pollutant on vegetation are "economic" only insofar as that vegetation contributes to human health and happiness.

The preceding perhaps conveys the stance of economics with respect to the basis of values. It fails, however, to state the units in which values are to be measured or the context that bestows meaning on these units. Assume, for example, that a person derives satisfaction from an aesthetic phenomenon, such as lush vegetation. Tf there is a local decline in the lushness of vegetation, the person will possibly feel he has been made worse off, However, if there are other worldly things capable of providing him satisfaction, then some additional provision of these other things may cause him to feel as well off as he would without the decline in vegetation lushness. Finally, if these things can be secured by the expenditure of income, or time that can be used to earn income, then there is some additional income that in the face of the lushness decline, would make the person feel no worse off. The unit, therefore, in which economics would have us measure value is money stated in terms of income. Implicit in the acceptance of this unit is the presumption that, even if the thing being valued cannot be secured in the marketplace, there are in this marketplace collections of other things from which the person receives equal satisfaction. These other things, which have market prices attached, can under a quite wide range of well-specified conditions, serve as vehicles to infer the "values" of entities and services for which no directly observable pecuniary prices exist.

In spite of the common sense approach to valuation sketched above, it will often yield, depending on the conditions adopted for the analysis, different values for the same quantity variation in the entity being valued. For example, if one is interested in the control of a pollutant that is damaging vegetation, the value that a person will attach to the reduction of the pollutant can depend on whether one is measuring what the person is willing to pay for the reduction or what the person would have to be paid in order not to have the reduction. In the latter case, because the person is viewed as holding the legal right to stop the pollution, his revelation of preferences is not limited by his income. However, his income does limit what he can do when he must buy a cessation of pollution from someone else. As his money becomes scarce, he becomes reluctant to trade money for goods. Thus, the two measures would be identical only when variations in income play a trivial role in determining the quantity of the good that the person will choose to hold.

Other sources of variations in values of identical changes in the quantity of a particular good include whether, in an original and in a new state, the original is the most preferred or the least preferred quantity; whether the valuation in the new state is independent of adjustments in overall patterns of consumption in moving from the original quantity of the good to the new quantity; and whether the person can by his own actions adjust his consumption of the good in question or, as with many pollutants, must become resigned to an externally imposed fate. In short, to be meaningful and communicable, the exact context of a particular economic valuation measure must be explicitly and fully stated. The criteria for judging which of the several analytically correct valuation measures to apply to a particular real problem must often come from outside economics.

Benefits Assessment Methodologies

Schulze, et al. (forthcoming) provide an informative and succinct common theoretical basis for the alternative economic methodologies available to assess the benefits of controlling acid precipitation and other plausible environmental insults. They start their analysis with the recognition that all assessment methodologies presume that there exist marketplace collections of things other than the entity being valued from which the representative individual could receive equal satisfaction. These substitution possibilities are said to exist across alternative activities and locations, both of which are denoted $A_1, \ldots, A_i, \ldots, A_n$. Each of these activities and/or locations is associated with a particular level of environmental quality, $Q_1, \ldots, Q_i, \ldots, Q_n$. Increases in the Q_i represent environmental quality improvements.

The individual's weakly separable, quasi-concave utility function is written as:

$$U(A_i, Q_i, X), \qquad (10)$$

where X is a composite commodity the magnitude of which is unaffected by A_1 and Q_1. Utility is assumed to be increasing in A_i, Q_i, and X. The individual's decision problem is then to maximize (1) subject to a budget constraint:[4]

$$Y - \sum_{i=1}^{n} P_i A_i - X = 0, \tag{11}$$

where Y is current period income, P_i is the price of the ith activity, and X is assumed to have a price of unity. The necessary conditions for solution of the problem include

$$\frac{\partial U/\partial A_i}{\partial U/\partial X} \leq P_i, \quad \text{and} \quad \left(\frac{\partial U/\partial A_i}{\partial U/\partial X} - P_i\right) A_i = 0, \tag{12}$$

assuming that A_i is consumed in some positive quantity. This says that the individual will equate the marginal rate of substitution of the ith activity for X to the price, P_i, of that activity.

To determine the marginal willingness-to-pay for the environmental quality associated with a particular activity, i=1, Schulze et al. set (10) equal to a constant and then totally differentiate this expression as well as expression (11). When $dA_i=0$ for $i \neq 1$, and by using (12), they obtain:

$$\frac{dY}{dQ_1} = \sum_{i=1}^{n} A_i \frac{dP_i}{dQ_1} - \frac{\partial U/\partial Q_1}{\partial U/\partial X} \tag{13}$$

This represents the additional income that in the face of an environmental quality change would make the individual feel no worse off. Considering only the total differential of (11), while continuing to assume that $dQ_i=0$ for $i \neq 1$, they obtain another expression for dY/dQ_1:

$$\frac{dY}{dQ_1} = \sum_{i=1}^{n} A_i \frac{dP_i}{dQ_1} + \sum_{i=1}^{n} P_i \frac{dA_i}{dQ_1} + \frac{dX}{dQ_1} \tag{14}$$

When one equates (13) and (14), and cancels similar terms, the result is:

$$\sum_{i=1}^{n} P_i \frac{dA_1}{dQ_1} + \frac{dX}{dQ_1} = \frac{-\partial U/\partial Q_1}{\partial U/\partial X} < 0 \tag{15}$$

In short, the last two terms in (14) are negative.

Schulze, et al. suggest that (14) and (15) provide a common and easily grasped basis for interpreting the substantive analytical content and the data requirements of alternative economic methodologies for assessing marginal willingnesses-to-pay for changes in environmental quality. Consider, for example, an air pollutant which reduces the yield of an agricultural crop. One expedient method to assess the economic value of a quality improvement is simply to ask individual producers and consumers what their magnitudes of dY/dQ_1 are. This approach, probably because of the ready availability of price, yield, and location data, has not to our knowledge vet been used to assess agricultural damages from air pollution. Under the label of "bidding games" or "contingent valuations" it has been widely used to value environmental quality improvements where there is little or no historical experience with the potential improvement and where directly observable price and quantity data are unavailable to either the researcher or the individual producer and consumer. These circumstances aptly describe many aesthetic and health effects of air pollution. Schulze et al. thoroughly review and evaluate several of the existing contingent valuation studies, and provide a listing of many more. Brookshire and Crocker (forthcoming) provide further discussion of the real-world circumstances under which contingent valuation approaches are especially appropriate. Although the natural science informational requirements of these methods might appear to be minimal or nonexistent, all commentaries insist that great care must be taken in describing the state-of-the-world to which the interviewee is to be asked to respond. Otherwise, biases can be introduced that make interviewee responses uninterpretable. Thus, although natural science information is not an integral part of the analytical exercise involved in contingent valuation methods, it does play an important role in establishing the scenario that is to be valued.

If agricultural settings have seen but infrequent application of the contingent valuation methods that capture the right-hand-side of (14), they have experienced numerous applications of methods that focus on no more than the middle term, $\Sigma P_i(dA_i/dQ_1)$ on its left-hand-side. Examples are Benedict, et al. (1973) and Millecan (1976). When the P_i are readily observable, the role the economist need play is minimal; the role of the natural scientist dominates because, by assumption, only the activities change in response to changes in environmental quality. Thus the natural scientist must translate alternative air pollution states into changes in plant growth, and changes in this growth into changes in useful yield. Given that crops and crop varieties display different tolerances to pollution, numerous dose-response functions similar to those established for alfalfa by Oshima and his colleagues (1976) may be required. Having obtained these dose-response functions for the list of activities in question, the determination of dY/dQ_1 is a simple matter of multiplying the changes in yields by the observed or inferred market prices.

If the scope of the analysis extends beyond yield effects upon existing cropping and location patterns, the role of the economist for evaluating $P_i(dA_i/dQ_1)$ need not be quite so limited as the previous paragraph implies. In particular, a change in pollution may make alternative cropping and location patterns more appealing. Economic contributions are then useful in specifying those among the set of feasible grower alternatives that are worthy of detailed investigation. Nevertheless, the core of the exercise remains the estimation by natural scientists of the yield responses of individual crops to pollution under a variety of environmental conditions and in a variety of locations.

Two terms remain on the right-hand-side of (5) that we have not yet discussed: $\Sigma A_i dP_i/dQ_1$, the change in the price of the ith activity due to a change in the environmental quality parameter; and dX/dQi, the change in expenditures on the composite commodity due to a change in the quality parameter. Here the relative importance of the roles of the natural scientist and the economist is reversed from the earlier discussion. Cropping and location patterns are treated as being utterly unresponsive to changes in the quality parameter. All adjustments to variations in the quality parameter are reflected in inferred or market prices alone. Thus, for example, as Johnson and Hough (1970) and Crocker (1971) have done, one might estimate dY/dQ_1 by holding the levels of all agricultural activities constant, the prices of all other commodities except land constant, and the magnitude of expenditures on other goods constant, and then estimate the effect of variations in the quality parameter upon the market prices of agricultural sites. In this extreme case, the only role of the natural scientist would be to identify the sites that are subjected to a variety of levels of pollution. If the number of activities whose price responsivenesses to pollution was of interest were to be expanded for study purposes, the natural scientist's role would continue to be limited to specifying the existing levels of these activities. Just as with contingent valuation methods, the natural scientist's expertise on the behavior of organisms under stress has no role to play.

The importance of considering these dP_i/dQ_1 and dX/dQ_1 terms is readily perceived by considering a simple analytical model of price determination frequently used by agricultural economists. Specifically, the equilibrium price of agricultural commodities, in the aggregate or individually, may be derived from the intersection of the relevant supply and demand curves. The effects of air pollution may be viewed as a supply phenomenon, shifting the supply curve. Given the generally inelastic demand for agricultural commodities, the supply-demand model indicates that shifts in the supply curve will translate into rather large shifts in the equilibrium price of food. Thus, following from the nature of the demand-supply relationships, one may hypothesize changes in commodity prices if air pollution affects the position of the supply curve.

The significance of these price movements is that agricultural prices cannot necessarily be assumed to be static or stable. Further, changes in agricultural prices do not occur in isolation but rather work their way through the system, affecting the welfare of consumers, producers, input suppliers, resource owners, and other parties. For example, given the generally inelastic demand for agricultural commodities, reductions in supply may actually increase farmers total net revenue, as the attendant price rise may be greater than the percentage reduction in quantity supplied or produced. Conversely, the increase in prices from a supply reduction will reduce consumers' welfare. Thus, if air pollution alters yield of a substantial proportion of a given crop or causes a reduction in planted acreage of that crop, then the overall change in supply may result in changes in the price at the farm level which will ultimately be felt at the consumer level. Alternatively, if farmers employ mitigative measures to adjust for the presence of air pollution, then any additional costs of such measures may also affect consumers through shifts in supply caused by changes in producers' cost functions.

Fortunately, the alternative methods available to assess the benefits of controlling pollution such as acid precipitation are not limited only to those which ask hypothetical questions of supposedly knowledgeable interviewees, consider the activity effects but not the price effects, or consider the price effects but not the activity effects, of a pollution change. Consider the following quadratic programming model, with which Adams, et al. (1979) have recently assessed the economic impact of air pollution upon southern California agriculture, as an example of the ability of many economic methodologies to capture both the price and the activity effects of pollution-induced damages. Again, however, the viability of the methodology is utterly dependent upon the availability of accurate dose-response functions.

Assume that the effect of acid precipitation upon a set of annual agricultural crops in a number of regions is of concern. The markets for each of the included crops in each region operate so as to solve the following problem:

$$\text{Max:} \quad \pi = C^T Q + 1/2\, Q^T D Q - H^T Q \tag{16}$$

$$\text{Subject to:} \quad AQ \leq b$$

$$Q \geq 0$$

The symmetric matrix D in the objective function is negative definite, and the constraints are convex. The terms of (16) are defined as follows.

A is a m x n matrix of production coefficients indicating the invariant amount of each of a variety of inputs required to produce any single unit of a particular output.

Q is a n x 1 column vector of crop outputs.

D is a m x m matrix representing slope values of the linear demand structure for the fourteen included crops.

H is a n. x 1 column vector of invariant unit costs of production for the included crops.

C is a n x 1 column vector of constants.

b is a m x 1. column vector of inputs.

As advocated by Harberger (1971.), π is the sum of ordinary consumer surpluses and producer quasi-rents. The supply functions for all producer inputs purchased in the current period (seeds, labor, fertilizer, etc.) can be assumed to be perfectly price-elastic. In addition, one can invoke Willig's (1976) results and presume any differences between ordinary and compensated consumer surpluses to be trivial. Since neither income elasticizes nor ordinary consumer surpluses or expenditures as a percentage of incomes are likely to be large for most crops or other entities affected by acid precipitation, this invocation seems reasonable.

The left-hand-side of the objective function in (16) can be stated in terms of observable by introducing a price forecasting expression:

$$P = C + 1/2\ DQ, \tag{17}$$

where P is a n x 1 vector of farm level crop prices. In matrix form, the objective function may then be expressed as:

$$P^TQ - H^TQ = C^TQ + 1/2\ Q^TDQ - H^TQ \tag{18}$$

In order to capture the impact of acid precipitation upon crop yields, we define a variable. Z* ($0<Z^*<1$) for each included crop in each region. The Q terms in (16), (17), and (18) can then be stated as:

$$Q^* = (1 - Z)\ L^TY \tag{19}$$

where:

Q* is a n x 1 column vector of yields of the n crops in the presence of acid precipitation.

Z^* is a n x 1 column vector of indicies of yield reduction for the n crops.

I is a n x 1 column vector of unity.

L is a n x 1 column vector of the land acreage used for cultivating the n crops. The total land area available for all crops can be assumed to be fixed.

Y is a n x 1 column vector of yields per acre of the n crops in the absence of acid precipitation.

Given L and Y constant, the value of Q^* varies inversely with the value of z^*. Thus regions with higher acid precipitation will have higher values of Z^* and consequently lower values for Q^*. The yield price effects of these reductions in O^* are then predicted by (17), the price forecasting expression. Impacts of these predicted price changes upon consumer surpluses, producer quasi-rents, and cropping patterns within and across regions can then be calculated by solving the quadratic programming problem.

The immediately preceding formulation is meant to be illustrative of what economic analysis can do in assessing the benefits of controlling acid precipitation. It by no means exhausts the techniques that might be applied to the various aspects of the acid precipitation issue, although it is representative of the most robust and economically meaningful of the available techniques. With the sole exception of contingent valuation techniques which employ stated answers to hypothetical questions as data, all these techniques use observed decisionmaker behavior as data. The economic interpretation of these data on observed behavior is generally unable to proceed unless believable and useful dose-response functions can be provided by the natural scientist.[2] In the last chapter, we shall have a great deal to say about what a dose-response function must include if it is to be useful to the economist. For the next two chapters, we try to employ the knowledge the natural scientist has thus far accumulated on dose-response functions to gain some insights into the economic benefits of controlling acid precipitation.

REFERENCES

1/ This is adapted from Hamlen (1978), bearing in mind that emissions are generated in I only.

2/ Note that this formulation deals with deposition of sulfur or NO_x, as such, rather than. acidity. The United States - Canada Research Consultation Group (undated, p.11) states that this is common to all models in the area.

3/ See Freeman (1979) and Maler (1974) for additional treatments grounded upon an internally consistent theoretical framework.

4/ Further generality can be easily obtained by introducing a time constraint. At the level of abstraction used in this section, no additional insights would be gained by doing so.

5/ It should be mentioned that, at least in principle, the duality between cost and production (dose-response) functions that the envelope theorem provides means that the economist, without any dose-response data whatsoever, can use data on observed behavior to perform analyses of the benefits of controlling acid precipitation. For a clear treatment of the envelope theorem, see Silberberg (1978, pp. 309-312). Most interestingly perhaps, the theorem implies that one could estimate dose-response functions using only data on cost function parameters. This would permit the services of the natural scientist to be dispensed with entirely! However, given the somewhat disturbing findings of Appelbaum (1978) and others on the empirical reality of this dualism, we prefer to refrain, for now, from stating that the research of the natural sciences into dose-response functions is irrelevant. Nevertheless, a careful inventory of practical opportunities for empirical applications of duality principles to the valuation of pollution impacts would be worthwhile.

BIBLIOGRAPHY

Adams, R.M., and T.D. Crocker, "Analytical Issues in Economic Assessments of Vegetation Damages," Crop Toss Assessment, University of Minnesota Press, 1980. (forthcoming).

Adams, R.M., T.D. Crocker, and N. Thanavibulchai, An Economic Assessment of Air Pollution Damages to Selected Crops in Southern California, A report to the U.S. Environmental Protection Agency for Grant #R805059010, Resource and Environmental Economics Laboratory, University of Wyoming Laramie, Wyoming, (October 1979).

Appelbaum, E., "Testing Neoclassical Production Theory," Journal of Econometrics 7(1978), 87-102.

Benedict, H.M., C.J. Miller, and J.S. Smith, Assessment of Economic Impact of Air Pollutants on Vegetation in the United States, Washington, D.C.: National Technical Information Service Publication Number PB-224-818, (1973).

Brookshire, D.S., and T.D. Crocker, "The Advantages of Contingent Valuation Methods for Benefit-Cost Analysis," Public Choice (forthcoming).

Crocker, T.D., "Externalities, Property Rights, and Transaction Costs: An Empirical Study," Journal of Law and Economics 14(October 1971), 451-464.

Forster, B.A., "Optimal Pollution Control with a Non-Constant Exponential Decay Rate," Journal of Environmental Economics and Management 2 (September 1975), 186-194.

Freeman, A.M. III, The Benefits of Environmental Improvement, Baltimore: Johns Hopkins University Press, (1979).

Galloway, J.N., et al. "Acid Precipitation: Measurement of pH and Acidity," Limnology and Oceanography 2(1979), 1161-1165.

Hamlen, W.A. Jr., "The Optimality and Feasibility of Uniform Air Pollution

Controls," Journal of Environmental Economics and Management 5(December 1978), 301-312.

Harberger, A.C., "Three Basic Postulates for Applied Welfare Economics: An Interpretative Essay," Journal of Economic Literature 9(September 1971), .785-797. . . .

Johnson, S.R. and P.A. Hough, "Agricultural Price Differentials and Their Relationship to Potentially Modifiable Aspects of the Climate." Review of Economics and Statistics 52(May 1970),' 173-180.

Lotka, A.J., Elements of Physical Biology, Baltimore: Williams and Wilkens.

Maler, K.G., Environmental Economics: A Theoretical Inquiry, Baltimore: The Johns Hopkins University Press (1974).

Millecan, A.A., A Survey and Assessment of Air Pollution Damage to California Vegetation, 1.970 through 1974, Sacramento, California: California Department of Food and Agriculture (April 1976).

Oshima, R.J., M.P. Poe, R.K. Braegelmann, D.W. Baldwin, and V.W. Way, "Ozone Dosage-Crop Loss Function for Alfalfa: A Standardized Method for Assessing Crop Losses from Air Pollutants," Journal of the Air Pollution Control Association 26(September 1976), 861-865.

Perhac, R.M., Transcript of testimony before the National Commission on Air Quality, Washington, D.C., (October 5, 1979).

Schulze, W.D., R.C. d'Arge, and D.S. Brookshire, "Valuing Environmental Commodities: Some Recent Experiments," Land Economics (forthcoming).

Silberberg, E. The Structure of Economics, New York: The McGraw-Hill Book Company (1978).

United States - Canada Research Consultation Group on the Long-Range Transport of Air Pollutants, The LRTAP Problem in North America: A Preliminary Overview, A Report from meetings held in Research Triangle park, North Carolina, on July 26-27, 1?78, and Downsview, Ontario, on March 6-7, 1979 (undated).

Willig, R.D., "Consumers' Surplus Without Apology," The American Economic Review 66(September 1976), 589-597.