Introduction

The effects of an air pollutant may include increased illness and earlier death, deterioration of materials, reduced agricultural productivity, reduced visibility, increased soiling, and annoying odors. Air-pollution control can benefit society by reducing these damages, but control programs require resources that could be used to produce other goods and services. The choice of an appropriate air-pollution-control policy requires comparison of the benefits and the costs of alternative policies in order to determine the net impact of each policy on social well-being.

The benefits and costs of an air-pollution-control policy may take many different forms, occur at different times, involve different degrees of uncertainty, and affect different individuals. The economic theory of benefit-cost analysis provides a framework for taking such diversity into account. This book discusses the theoretical and practical issues involved in using benefitcost analysis to evaluate air-pollution-control policies.

The importance of making the correct policy choices is suggested by the magnitude of the benefits and costs of air-pollution control. Recent estimates of the total annual benefits and costs of air-pollution control in the United States are shown in table 1-1. The figures for benefits are Freeman's (1979a) estimates of the reduction in each type of damages between 1970 and 1978. Freeman emphasizes the uncertainty underlying these estimates and suggests that, although the most reasonable point estimate of total benefits is $21.4, billion, the actual value may be as low as $4.6 billion or as high as $51.2 billion. The estimate of $16.7 billion for annual costs is calculated from survey and census data for 1977 (Rutledge 1979; Rutledge and O'Connor 1979).

Because the estimates of benefits and costs in table I -I do not distinguish between geographic areas, are neither complete nor fully comparable, and do not indicate the benefits and costs of alternative degrees of control, they are not sufficient to evaluate the desirability of existing air-pollutioncontrol policies.' The determination of the optimal degree of control, and the question of whether government action is required to attain it, are discussed in the following section.

Table 1-1
Estimated Annual Benefits and Costs of Air-Pollution Control in the United States

	Stationary Sources	*Motor Vehicles*	*Total*
Benefits			
Human health	$16.8	$0.2	$17.0
Vegetation	0.0	0.7	0.7
Materials	0.7	0.2	0.9
Soiling and aesthetics[a]	n.a.[b]	n.a.	2.8
Total benefits			$21.4
Costs			
Capital expenditures	4.2	3.5	7.7
Operating and maintenance[c]	3.4	4.6	8.0
Regulation and monitoring	n.a.	n.a.	0.2
Research and development	n.a.	n.a.	0.8
Total costs			$16.7

Source: Benefits: Adapted from A. Myrick Freeman III, *The Benefits of Air and Water Pollution Control: A Review and Synthesis of Recent Estimates* (U.S. Council on Environmental Quality, 1979). Costs: Adapted from Gary L. Rutledge, Pollution abatement and control expenditures in constant and current dollars, 1972–77, *Survey of Current Business* 59, no. 2 (1979):13–20; and Gary L. Rutledge and Betsy O'Connor, Capital expenditures by business for pollution abatement, 1977, 1978, and planned 1979, *Survey of Current Business* 59, no. 6 (1979):20–22.

Note: Benefits are for 1978 and costs are for 1977. Both are expressed in billions of 1978 dollars.

[a]Does not include visibility.

[b]n.a. indicates data not available.

[c]Includes depreciation. Does not include credit for recovery of product or byproducts.

Optimal Degree of Air-Pollution Control

The benefits of an air-pollution-control policy are the resulting reductions in air-pollution damages, and the costs are the resources necessary to implement the policy. Figure 1-1(a) illustrates typical relationships between the degree of control of an air pollutant and total benefits and costs. Both total benefits and total costs can be expected to increase as the percentage of the pollutant controlled increases, with total costs increasing at an increasing rate and total benefits increasing at a decreasing rate. The net benefits of control are equal to the difference between total benefits and total costs. In figure I-I(a) the maximum net benefit is distance AB, and L* is the optimal degree of control.

The optimal degree of control also can be determined from the increments to total benefits and total costs as the degree of control increases. The increment to total benefits when control increases by one unit is

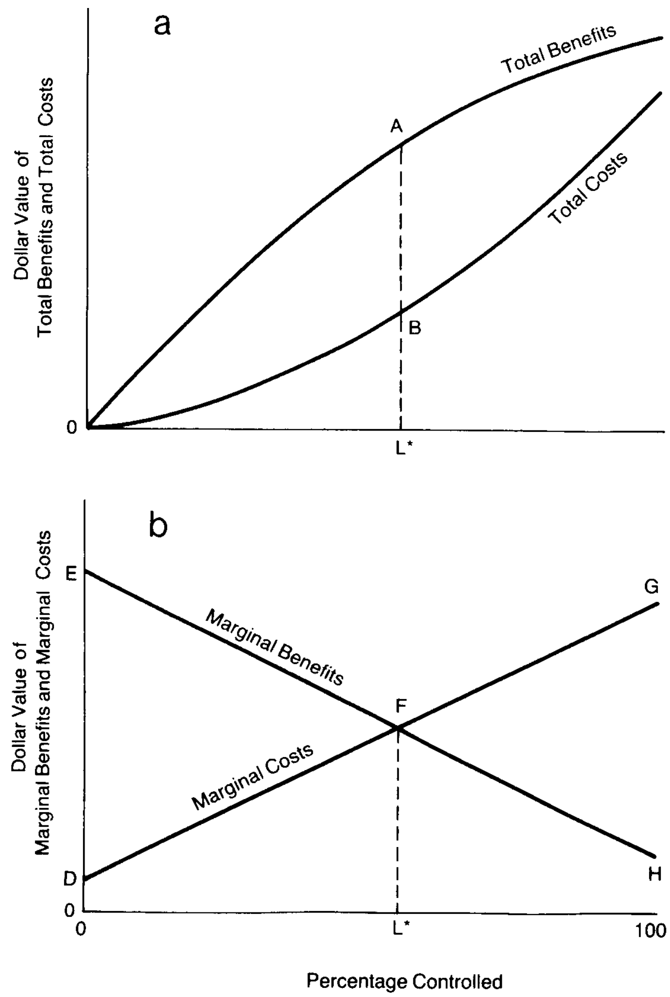

Figure 1-1. Optimal Degree of Air-Pollution Control

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Referred to as the *marginal benefit*, and the increment to total costs is referred to as the *marginal cost*. As shown in figure 1-1(b), marginal benefits are greater than marginal costs to the left of L^* and are greater than marginal costs to the right of L^*. Therefore, increases in control up to L^* increase total benefits more than total costs, whereas increases in control beyond L^* increase total costs more than total benefits. Thus the optimal degree of control is that for which marginal benefits are equal to marginal costs.[2]

For the case illustrated in figure 1-1, and in most actual pollutioncontrol situations, the optimal degree of control is less than 100 percent because marginal costs increase, and marginal benefits decrease, as the degree of control increases. Thus attainment of the optimal degree of control does not imply the total elimination of air-pollution damages; and, conversely, the existence of air-pollution damages does not imply that the degree of control is less than optimal. Therefore, the observation that private markets result in substantial air-pollution damages does not in itself imply that government policies to increase the degree of air-pollution control are desirable. However, consideration of the way private markets operate does indicate that government action generally is required to attain the optimal degree of pollution control.

In considering the operation of private markets, it is convenient to think of pollution control as a productive activity the output of which is environmental quality. Like other productive activities, pollution control will be undertaken up to the point where the marginal benefit to the individual performing it is equal to his marginal cost. Therefore, if the benefits and costs accrued to the same individual, the optimal degree of pollution control would result.

The marginal benefits of a productive activity will accrue to the individual performing it if he uses the output himself, or if he sells the output for a price equal to its marginal benefit to the person using it. The latter condition will be satisfied for most types of output, because each consumer will be willing to pay a price equal to his marginal benefit. However, the output of pollution control generally can not be sold for a price equal to its marginal benefit because environmental quality is a *public good.* That is, each unit of environmental quality is available equally to all individuals in the relevant area whether they pay for it or not.'

Coase (1960) argued that private negotiations nevertheless would result in the optimal level of pollution control if contracts could be negotiated and enforced without cost (that is, if there were no transactions costs). Coase's argument can be illustrated using figure I-I(b). Assume for simplicity that all damages of air pollution are incurred by individuals other than the polluter. Then, in the absence of negotiations, the percentage of control would be 0 because control would result in costs but no benefits for the polluter. However, the potential would exist for negotiations that made both the polluter and those damaged by the pollution better off, because marginal benefits from control (OE in figure I-I(b)) would be greater than the marginal costs of control (OD). If those damaged by pollution paid the polluters an amount less than OE but greater than OD to undertake one unit of control, both would be better off. The potential for such mutually beneficial increases in pollution control exists up to the optimal degree of control, L*, at which point marginal benefits are equal to marginal costs.

The total potential gain from increasing control from 0 percent to L* is the area EDF.'

The conclusion that the optimal degree of pollution control can be obtained through private negotiations has come to be known as the *Coase theorem.* Despite its importance in the development of the economic theory of pollution control, the Coase theorem provides little basis for complacency concerning most actual air-pollution-control situations. Because transactions costs are not in fact equal to zero, the type of negotiations he envisaged are likely to occur only when small numbers of individuals are involved.' Since most important pollution problems involve large numbers of individuals, the optimal degree of pollution control is unlikely to be attained by private actions.

It should also be emphasized that the term *optimal* in this context implies only that no potential mutually beneficial exchanges remain unexploited. Issues such as the equity or fairness of pollution-control decisions are not considered, although they may be very important in society's overall evaluation of the desirability of alternative outcomes. For example, a situation in which a poor person had to make substantial payments to a rich polluter in order to reduce the damage imposed on him by the polluter might be considered socially undesirable, even if it resulted in the "optimal" level of pollution.

The conclusion that private markets generally will not result in optimal air-pollution control implies that government intervention in this area has the potential to increase social well-being. However, for this potential to be realized it is necessary both that the appropriate degree of pollution control be determined and that appropriate policy instruments be chosen for achieving this degree of control. The choice of policy instruments has received considerable attention in the economics literature and will not be discussed here.' Instead, this book concentrates on the use of benefit-cost analysis to determine the optimal degree of control.

Benefit-Cost Analysis

Benefit-cost analysis of an air-pollution-control policy requires a prediction of the direct and indirect effects of the policy, expression of these effects in terms of common units, and a determination of the net impact on social well-being. The benefit-cost-analysis process is illustrated schematically in figure 1-2.

The first step in the analysis (labeled I in figure 1-2) is an evaluation of the effects of the policy on the decisions of the pollutant sources. For example, if the policy imposes a specific limitation on the emission rate of pollutants for a factory, it must be determined what control equipment or

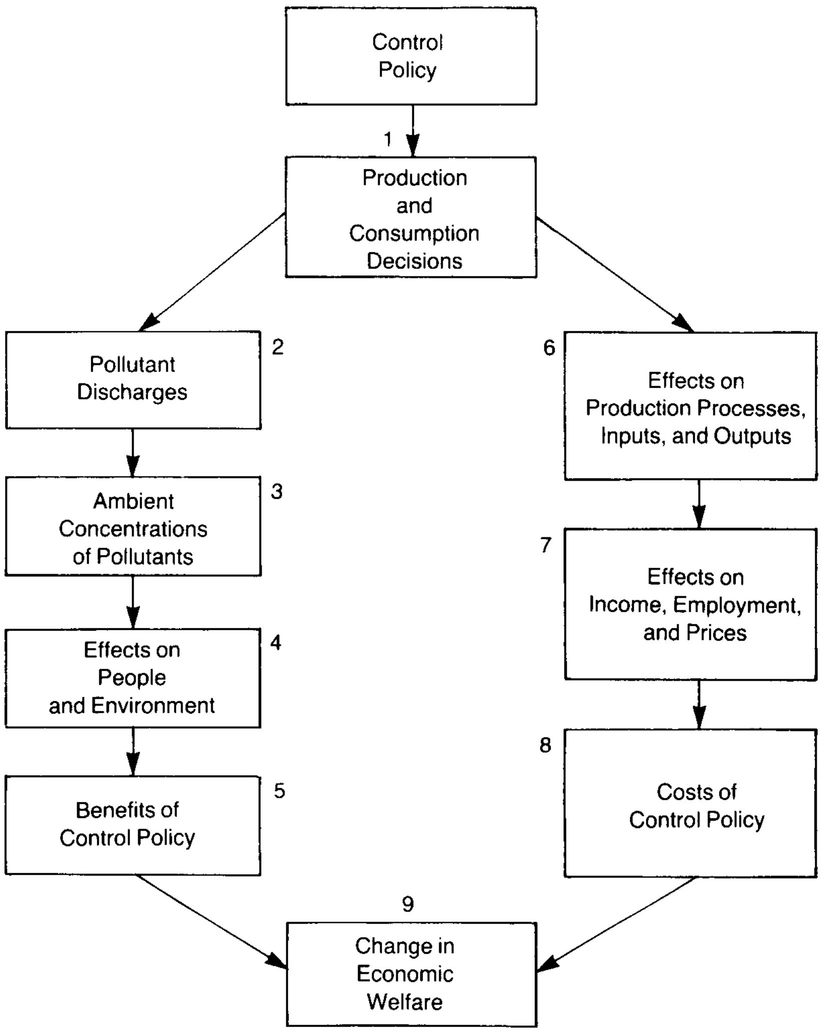

Figure 1-2. Steps in Benefit-Cost Analysis

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changes in the production process will be chosen to satisfy the new requirement. If the policy affects the characteristics of a final product, such as automobiles, the effect on consumption decisions has to be determined.

The responses of pollutant sources to the control policy will affect both pollutant discharges and the use of resources. The effects on pollutant discharges give rise to the policy's benefits and are evaluated in steps 2 through 5. The effects on the use of resources give rise to the costs of the policy and are evaluated in steps 6 through 8. It should be noted that these definitions of benefits and costs are not synonymous with, respectively, positive and negative effects on social well-being. Thus some effects on pollutant discharges may be adverse (for example, if land or water pollution is increased as a result of an air-pollution policy) and some effects on resource use may increase well-being (for example, if the policy offsets a preexisting market distortion such as monopoly).

Analysis of the effects of production and consumption decisions on pollutant discharges (step 2) and of pollutant discharges on ambient concentrations (step 3) requires knowledge of the physical processes involved in the generation, transportation, dispersion, and transformation of the pollutants.

Analysis of the effects of the ambient concentrations on the exposed individuals and portions of the environment (step 4) requires knowledge both of physical and biological processes and of the economic responses to these effects. For example, determination of the effects of changes in pollutant concentrations on agricultural productivity requires knowledge of the effects of pollutants on the yields of various crops and of the responses of farmers in choosing which crops to plant. The failure adequately to account for economic responses has been a serious flaw in past studies of the effects of pollution.

Step 6, analysis of the effects of production and consumption decisions on production processes and the choices of inputs and outputs, requires procedures for estimating the resources required to implement these decisions. The effects of these changes on income, employment, and prices, evaluated in step 7, requires knowledge of the economic responses of the affected individuals and firms, including the possibility that a firm would prefer to shut down rather than modify its operations to satisfy the requirements of a policy.

The fifth and eight steps of a benefit-cost analysis involve the expression of the effects of a policy in terms of common units that reflect the value of these effects to the affected individuals. Although these values generally are expressed in dollar terms, this does not imply that a benefit-cost analysis is concerned only with the financial effects of a policy.

The final step in a benefit-cost analysis is the determination of the net impact of the benefits and costs on social well-being. This requires both a criterion for determining what constitutes an increase in social well-being, and procedures for aggregating effects that occur at different times, involve different degrees of uncertainty, and affect different individuals.

Several published benefit-cost analyses illustrate the application of the techniques discussed in this book to actual air-pollution-control problems. Finklea et al. (1975), Harrison (1975), and Schwing et al. (1980) have estimated the benefits and costs of motor-vehicle-emissions controls. Cohen, Fishelson, and Gardner (1974) examined the benefits and costs of regulating residential-heating fuels. North and Merkhofer (1975) and Cohen (1977) analyzed emissions regulations for electric-power plants. Loehman et al. (1979) considered the geographic and socioeconomic distribution of the receiving population. Mendelsohn (1980) introduced the location of the emission source as a control variable.

Criticisms of Benefit-Cost Analysis

The recent dramatic growth in interest in the use of benefit-cost analysis to evaluate public policies has generated a number of critical reviews of the theoretical basis and techniques for application of benefit-cost analysis.

The principal focus of a critique of benefit-cost analysis presented by a committee of the U.S. House of Representatives (1976a) is the difficulty inherent in estimating the direct effects of a policy and translating these into economic terms. The committee argued that such estimates seldom can be made with any accuracy because of the poor quality or nonexistence of objective measurements. This can provide substantial opportunities for the agency or analyst to bias the result by a subjective selection of critical values, which may not be apparent to a reviewer. The committee cited an example of a U.S. Department of Agriculture study that predicted that a U.S. Environmental Protection Agency (EPA) rule would result in 5,200 head of cattle being destroyed at a cost of $2.6 million. The rule was adopted, with 3 head eventually destroyed at a cost of $1,500. The committee further argued that analyses tend to emphasize the immediate, intended effects of the policy and to neglect longer-term undesirable or unintended effects that may be more difficult to quantify.'

Baram (1980) argued that "monetization of environmental and health amenities constitutes an inappropriate treatment of factors that transcend economics." He expressed concern for the evaluation of the distribution of the costs and benefits among social groups and concluded that distributional decisions cannot be made by "unaccountable analysts" who are outside the proper and traditional arenas for adjudicating the constitutional guaranties of due process, equal protection, and property rights.

The primary concerns of these and other critics may be summarized as follows:

1. Sufficiently great uncertainty exists in the estimates of the different components of the analysis that the results are frequently misleading and provide opportunities for mischief by less-than-objective analysts.
2. The selection of values for some variables and the analysis of distributional implications is best left to elected representatives and the courts rather than being buried within the results presented by the benefit-cost analyst.

The first point clearly represents a real problem for benefit-cost analysis, but it is at least equally relevant for other possible ways of evaluating public policies. As Williams (1972) pointed out, a major advantage of benefit-cost analysis is that it provides a formal and explicit framework within which the effects of a policy can be compared, thereby making it possible to evaluate the effects of possible errors on the final decision. This virtue is not shared by such alternatives to benefit-cost analysis as simply leaving the decision to the political process. Similarly, it is true that value judgments on such issues as the desirability of the distributional consequences of a policy should not be implicitly imposed by the analyst; however, this is less of a problem for benefit-cost analyses than for lessexplicit decision-making processes.

Plan of the Book

The economic theory underlying benefit-cost analysis is discussed in part 1. Chapter 2 discusses the derivation of criteria for evaluating the net impact of a policy on social well-being. Chapters 3 and 4 discuss appropriate rules to use in aggregating benefits and costs over individuals and over time, respectively. Chapter 5 considers the evaluation of uncertain benefits and costs, and chapter 6 discusses the use of market data to assign dollar values to the effects of a policy.

Part II discusses the application of benefit-cost analysis to airpollution-control problems. Chapter 7 discusses procedures for quantifying air-pollution effects. Chapters 8 through I I discuss specific estimation procedures and existing empirical results for health, vegetation, materials, and aesthetics benefits, respectively. Chapters 12 and 13 discuss estimation procedures and existing empirical results for determination of control costs.

Appendix A discusses briefly the sources, measurement, and effects of the major air pollutants. Appendix B discusses the principal types of control equipment. Estimation results for order-of-magnitude cost functions are presented in appendix C.

Notes

1. However, the estimates do suggest that the total costs of existing control policies for motor vehicles are greater than the total benefits on a national scale.

2. In mathematical terms the marginal benefit is the derivative of total benefits with respect to the degree of control, and the marginal cost is the derivative of total cost. The condition that marginal benefit equal marginal

cost is thus the first-order condition for maximization of the difference between total benefits and total costs.

3. Samuelson (1955) discusses the distinguishing characteristics of public goods and the reasons that private markets generally will not result in the production of the optimal quantity of a public good.

4. Similarly, if no pollution could occur without the permission of those damaged by it, the degree of control in the absence of negotiations would be 100 percent. However, since the marginal cost of control would be greater than the marginal benefit, the potential for mutually beneficial reductions in control would exist until point L* was reached.

5. An interesting example of negotiations occurring when a small number of individuals was affected, but not When many were, is cited by Baumol and Oates (1975). A Swedish refinery discharged corrosive materials into the air when lower-quality petroleum was refined. A nearby automobile plant negotiated with the refinery, which agreed to undertake the corrosive activities only when the wind was blowing away from the automobile plant and toward a large number of households, who did not participate in the negotiations.

6. Economists have tended to favor the use of incentives, such as pollution taxes, rather than direct regulations. See, for example, Baumol and Oates (1975) and Kneese and Schultze (1975). Some of the complications involved in the use of such incentives are discussed by Rose-Ackerman (1973) and Tietenberg (1978). Weitzman (1974) discusses the possible superiority of direct regulation under conditions of uncertainty.

7. When very long-term effects are involved, intergenerational equity becomes an important consideration. This issue is discussed by Mishan (1977) and Page (1977).