Chapter 8: Analyzing Social Costs

8.1 Introduction

The goal of a benefit-cost analysis is to determine the net change in social welfare brought about by a new environmental policy, as measured by changes in the producer and consumer surpluses. In general, the economic effects of a new environmental policy result in many different people and firms being affected, both positively and negatively. The previous chapter looked at the positive effects (or social benefits). This chapter considers the negative effects (or social costs). It is the sum of these changes, when combined with the social benefits, that yield a measure of the net changes in social welfare.

As with social benefits, when computing the social cost of a policy (i.e., the negative impact on social welfare), monetary sums that measure changes in individuals' welfare are all weighted equally in benefit-cost analysis. Other methods for evaluating the welfare consequences of policies on particular individuals, groups, or sectors should be examined using either economic impact analysis, equity assessment techniques, or social welfare functions (all described in Chapter 9).

This chapter is organized into four major sections followed by a concluding section. Section 8.2 reviews the theoretical foundations of social cost estimation for environmental policies. Section 8.3 discusses how to estimate and model total social cost.[1] Next, four types of models for estimating social cost are examined in Section 8.4. Then the estimation of the costs of specific regulatory approaches is reviewed in Section 8.5. Finally, Section 8.6 provides a discussion of the choice of tools for each type of policy

.

8.2 The Theory of Social Cost Analysis

The total social cost is the *sum* of the opportunity costs incurred by society because of a new regulatory policy; the opportunity costs are the value of the goods and services lost by society resulting from the use of resources to comply with and implement the regulation, and from reductions in output. These costs, however, do not take into account any of the health, environmental, safety, or other benefits which offset the social welfare costs.

The five basic components of total social costs are listed here in the general order of relative ease of estimation, and hence inclusion, in most social cost analyses of environmental policies. They include:

- **Real-resource compliance costs:** These direct costs are the principal component of total social costs and are associated with: (1) purchasing, installing, and operating new pollution control equipment, (2) changing the production process by using different inputs or different mixtures of inputs, or (3) capturing the waste products and selling or reusing them. (The last two options can actually result in negative compliance costs.)

  These real-resource costs should also include unpriced resources that have opportunity costs associated with them, such as unpaid labor diverted from other productive uses, and extra administrative costs associated with compliance. However, the pre-tax compliance costs do not include any transfers, such as emissions taxes, licensing fees, or subsidies (which are included in the firm's private costs).

[1] Several texts on applied microeconomics and policy evaluation provide substantially more theoretical depth and examples than the overview presented in this chapter, such as Arnold (1995), Gramlich (1981), and Just et al. (1982).

- **Government regulatory costs:** These include the monitoring, administrative, and enforcement costs associated with new regulations. This also includes the cost of setting up a new market when incentive-based regulations are established, such as tradable permits.
- **Social welfare losses:** These are the losses in consumer and producer surpluses associated with the rise in the price (or decreases in the output) of goods and services that occurs as a result of an environmental policy.
- **Transitional costs:** These include the value of resources that are displaced because of regulation-induced reductions in production, and the private real-resource costs of reallocating those resources. Offsetting these costs, in theory, are regulation-induced increases in resource use in both primary and related markets (e.g., more workers and equipment are needed for pollution control).
- **Indirect costs:** These other costs include the adverse effects policies may have on product quality, productivity, innovation, and changes in markets indirectly affected by the environmental policy, all of which may have impacts on net levels of measured consumer and producer surplus.

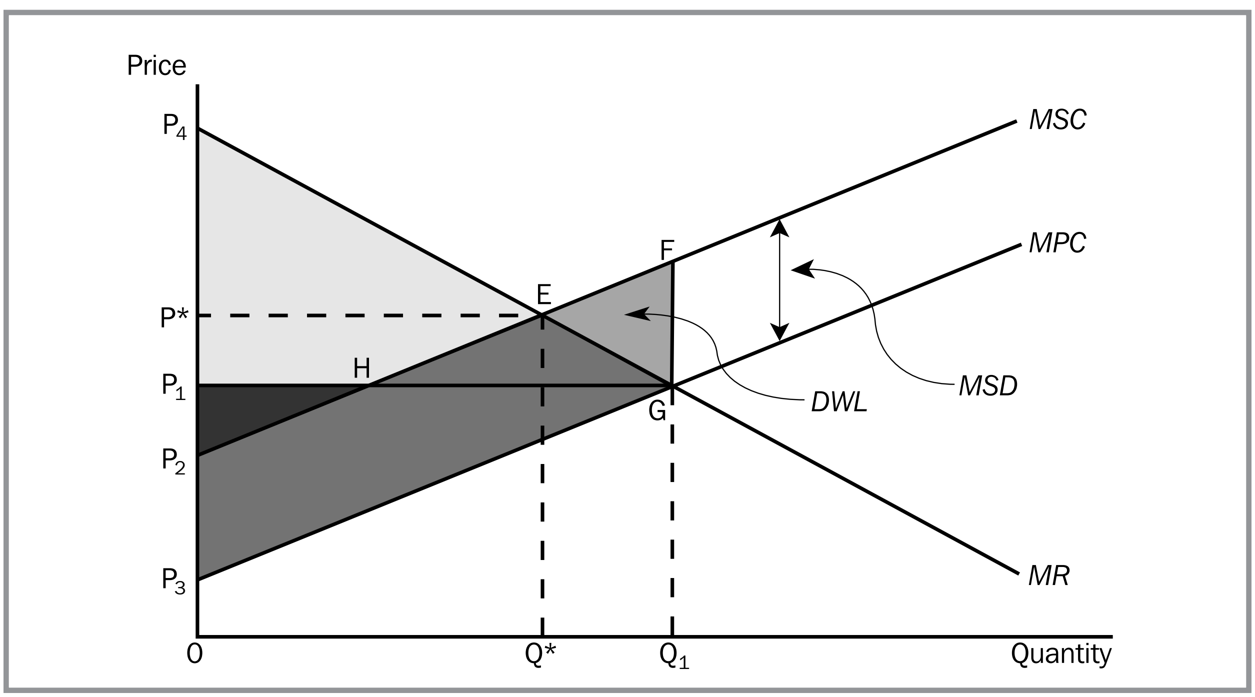
8.2.1 An Illustration of Social Costs and Externalities

Exhibit 8-1 illustrates an externality (pollution) associated with the production of a good or service (Q). In this figure:

- MR is marginal revenue from selling the good;
- MPC is the marginal private real-resource cost of production;
- MSD is the marginal social damage from pollution associated with production; and
- MSC is the total marginal social cost of supplying the good.

The producer operates where marginal revenue (MR) equals marginal private real-resource costs (MPC), so it produces Q_1 items at a price of P_1 per item. In this example, the producer also is assumed to impose a social cost on society due to pollution associated with its production of Q. Here the actual pre-policy total social cost of supplying the good is measured by the marginal private real-resource cost (MPC) plus the marginal social damage (MSD, also known as an externality) caused by pollution. Together the MPC plus the MSD gives the true marginal social cost (MSC) of supplying the good.

Exhibit 8-1 Producer and Consumer Surplus with an External Cost



The producer surplus is indicated by the area of triangle P_1GP_3 and the consumer surplus is measured as the area of triangle P_1GP_4, but the total social damage is indicated by the area of $P_3GF\ P_2$. Therefore, the deadweight loss to society (DWL) is equal to the area of triangle EFG. If producers have to pay for the damage caused by the pollution, their producer surplus is reduced to area of triangle P_2HP_1 minus the area of triangle HGF. In this case the firm would be making negative profits since the area of triangle HGF is larger than their producer surplus. Net social welfare in this case would be the area of triangle P_2EP_4 less the area of triangle EFG (the deadweight loss).

If, however, the optimal amount of the product is produced (i.e., where MR equals MSC), then the firm's output is Q* at a price of P*. In this case, consumer surplus is equal to the area of triangle P_4EP^* and producer surplus is the area of triangle P_2EP^*. Since there is no deadweight loss to society, net social welfare has increased and is equal to the area of triangle P_2EP_4.

Suppose that producers can do nothing to reduce the pollution damages other than decrease the amount of output supplied. If the government places a tax equal to the MSD on each unit of pollution, this would increase private production costs (but not private real-resource costs) by the amount of the MSD, which would cause a rise in consumer (taxpayer) welfare. This occurs because of the reduction in adverse health effects. Depending on the revenue policy of the government, it could lead to a possible reduction in consumer taxes, since producers are now paying an additional tax (the double-dividend hypothesis, which is described in greater detail later in this chapter). Although there is a decrease in the producer surplus (and the obvious consumer surplus), the overall social welfare has increased because of the reduction in the externality costs.[2] Adding all of these surplus changes together, and subtracting the transfers to the government (i.e., taxes), yields the net social cost of the policy.

If instead of an emissions tax, a firm is required to install pollution control devices, the private compliance costs will raise the firm's supply curve (or MPC) up by the amount spent on the new equipment. Under a permit system, where a set number of permits are issued for each unit of pollution, and firms are allowed to buy and sell these permits, then each firm will consider buying permits if the private cost of a permit is less than the unit cost of reducing pollution. Conversely, a firm that can reduce its pollution by less than the cost of a permit will consider selling its "extra" permits. In both cases, the firms' MPC curves will shift up by the price of the permits, just as it did in the case of an emissions tax.

8.3 A General Approach to Social Cost Analysis

The challenge in developing an estimate of the social cost of an environmental policy is to consider the market(s) being affected by the policy, assess the available data and analytic methods, and adopt an analytic approach that will yield an estimate suitable for use in the benefit-cost analysis. An important requirement in measuring social costs is to characterize the supply and demand equations of the regulated market or behavior. This section briefly reviews the estimation of supply and demand equations and their relevance to social cost, but concentrates on the variety of social costs that may be encountered from different types of environmental policies: (1) direct social costs, (2) transitional costs, and (3) indirect costs. Finally, some other issues that arise in characterizing and presenting social costs are examined, including discounting, difficulties in monetizing costs, consideration of sensitivity analyses, and simplifying market effects.

8.3.1 Estimating the Supply and Demand Equations of All the Affected Markets

Empirical estimates of the supply and demand curves for each market are usually needed to calculate the social costs of proposed regulations and policies. In addition to private sources, government reports and academic studies can provide useful information needed to estimate the

[2] If the regulation causes social costs to be greater than the MSD, then net social welfare may actually fall because of the new regulation; one cause being the diversion of investment capital to excess pollution control and away from its highest valued use.

supply and demand equations.[3] Solving these equations will yield equilibrium quantities and prices in each market that approximate the baseline figures.

In most situations, the supply and demand functions can be derived based on engineering cost estimates. For example, a step-function demand curve for a particular good can be computed based on the prices at which various segments of the market will turn to substitute goods. This technique is relatively more successful for products that are used as inputs to other processes and consumer goods that have well-defined alternatives. Similarly, an estimate of producer surplus can be derived based on the value of plant and equipment dedicated to supplying a particular good, and the ease or difficulty with which this capital can be deployed in other markets to supply different goods. In the long run, the supply curve is often assumed to be horizontal.

Information on the elasticity of demand is available for the aggregate output of most industries. When such information is unavailable, as is often the case for intermediate goods, the elasticity of demand may be quantitatively or qualitatively assessed. Econometric techniques, such as multiple regression, can be used to estimate a demand curve when sufficient data are available. For example, when dealing with intermediate products, econometric models can be constructed using engineering cost data to estimate both the supply and demand curves. In general, econometric tools are frequently used to estimate supply and demand equations and the factors that influence them.

Information on the availability of product or service substitutes, the impact of price increases on final goods (where the product or service is an intermediate good), the amount of a person's income devoted to the good or service, and the necessity of the final product or service can be used to qualitatively assess demand elasticities. The estimate selected for the point elasticity should be consistent with the equilibrium point (the time allowed for adjustments to occur) used in the analysis.

Estimating the equations that govern market supply and demand may be time and resource intensive, in addition to the formidable tasks of developing the means to structure and compute the considered models. While many types of markets have been researched in detail by the academic community, others may be too new to have much information available. It may be difficult to obtain data from the affected firms or industries because of confidentiality provisions or the proprietary nature of some data and models. Achieving sufficiently reliable results will often depend on the quality of the data, and overcoming problems with data will be a primary hurdle in many social cost analyses.

8.3.1.1 Definition of Elasticities

In general, economists use the term "elasticity" to refer to the sensitivity of one variable to changes in another variable.[4] The price elasticity of demand (or supply) refers to changes in the quantity demanded (or supplied) that would result from a change in the price of a good or service. Changes are measured assuming all other things, such as incomes and tastes, remain constant. Demand and supply elasticities are rarely constant and often change depending on the quantity of the good. Therefore, when calculating elasticities, it is important to state the price and quantity of the good.

"Elastic" demand (or supply) indicates that a small percentage increase in price results in a larger percentage decrease in quantity demanded (or supplied). How much of the price increase that will be passed on to consumers is determined by the elasticity of demand relative to supply (as well as the degree of competition within the industry and existing price controls). All other things equal, an industry facing a relatively elastic demand is less likely to pass on costs to the consumer because increasing prices will result in reduced revenues.

[3] Sources can include trade publications, financial studies, and data collected through surveys administered in support of the regulation (e.g., Section 308 surveys administered under the Clean Water Act for promulgation of effluent discharge limitations). Government agencies and the private sector also publish data and studies on the economic activity of the public and private sector and households. A more complete listing of examples is provided in Exhibit 9-3 on sources used to prepare economic profiles of industries. Additional illustrations can be found in existing EPA economic reports, several of which are referenced later in this chapter.

[4] *Own price elasticity of demand* is defined as the percentage change in quantity demanded divided by the percentage change in price. *Own price elasticity of supply* is defined as the ratio of the percentage change in quantity supplied divided by the percentage change in price.

8.3.1.2 Determinants of Demand Elasticity

Among the many variables that affect the elasticity of demand are: (1) the availability of close substitutes, (2) the percentage of income a consumer spends on the good, (3) how necessary the good is for the consumer, (4) the amount of time available to the consumer to locate substitutes, (5) the level of aggregation used in the study, and (6) the expected future price of the good. In this section, only the first four will be discussed.

- **The availability of close substitutes** is one of the most important factors that determine demand elasticities. A product with close substitutes tends to have an elastic demand, because consumers can readily switch to substitutes rather than paying a higher price. Therefore, a company is less likely to be able to pass through costs if there are many close substitutes for its product.
- **Whether the affected product represents a substantial or necessary portion of customers' costs or budgets** is another factor that affects demand elasticities. When price increases occur for products that represent a substantial portion of downstream producers' costs or consumers' budgets, these producers or consumers may be more likely to seek alternatives. Where the product subject to the price increase is less important in customers' budgets, customers may be less motivated to use substitutes (even if they are available) or to forego consumption entirely. A similar issue concerns the type of final good involved. Reductions in demand may be more likely to occur when prices increase for "luxuries" or optional purchases than for basic requirements.
- **The time frame considered** is a third important factor in determining elasticity. Elasticities tend to increase over time, as firms and customers have more time to respond to changes in prices. A company facing an inelastic demand curve in the short run may experience greater losses in demand in the long run, as customers have time to make adjustments that allow use of substitutes or as new substitutes are developed.

It is important to keep in mind that elasticities differ at the firm versus the industry level. For example, if twenty companies are producing pesticide formulations that are equally effective, each firm may face an elastic demand curve because of competition within the industry, although the industry as a whole may face an inelastic demand curve for its products as a group. In this example, it would not be appropriate to use an industry-level elasticity to estimate the ability of only one firm to pass on compliance costs when its competitors are not subject to the same costs.

8.3.1.3 Determinants of Supply Elasticities

The elasticity of supply depends, in part, on how quickly costs per unit rise as firms increase their output. Among the many variables that influence this rise in cost are:

- the availability of close input substitutes;
- the amount of time available to adjust production to changing conditions;
- the degree of market concentration among producers;
- the expected future price of the product;
- the price of related inputs and related outputs; and
- the speed of technological advances in production that can lower costs.

Supply elasticities will tend to increase over time as firms have more opportunities to renegotiate contracts and change production technologies.

Characteristics of supply in the industries affected by a regulation can be as important as demand characteristics in determining the economic impacts of a rule. For highly elastic supply curves, it is likely that costs will be passed through to consumers. The main determinants of industry supply curves are the structure of costs and the time period of the analysis. Industry supply curves are defined as the aggregation of the supply curves of individual firms within an industry.

If detailed financial profiles of individual establishments or categories of establishments and production data are available, they can be used to define an industry supply curve. Explicit information on the cost structure of an industry is very useful in predicting impacts more precisely than is possible using industry average data. A given firm may experience significant impacts if it is already a relatively high cost producer. Such firms would be more vulnerable to closure if subjected to high compliance costs.

8.3.1.4 Obtaining Supply and Demand Elasticities

Elasticity estimates may be obtained from existing literature or from original research. The use of published estimates avoids the time and expense of gathering the necessary data. Sources for published estimates include previous agency rule makings or relevant studies found in the economics literature. The analyst will have to employ careful judgement in deciding whether and how to use elasticity estimates from previous studies. Estimates should be drawn from studies based on:

- similar market structure and level of aggregation;
- sensitivity to potential differences in regional elasticity estimates;
- current economic conditions; and
- appropriate time horizon (i.e., short or long run).

This is not an exhaustive list of issues which must be considered in applying existing estimates to new analyses. There are a number of statistical and technical issues that may influence the quality of elasticity estimates. Relevant texts cited below should be consulted and technical assistance sought when necessary.

New or original estimates of elasticities are derived from demand and supply functions for goods or services that have been estimated using econometric methods. Econometrics is the use of statistical analysis in applied economic research. For example, the demand for a good or service is often estimated as a function of its price, the price of related goods (substitutes and complements), consumer demographic characteristics, as well as variables that may represent institutional or technological characteristics of a market. Supply and demand elasticities may be derived from a variety of functional forms that embody various assumptions about the relationships between the data. Methods of calculating elasticity estimates differ according to the specification of the function. The analyst should consult relevant texts and seek technical assistance.

The availability of sufficient data, both in terms of quantity and quality, is the first threshold that determines whether econometric tools can be used. Only with sufficient data can elasticity estimates be considered reliable. The analyst should carefully document data sources. Once the decision to employ econometrics is made, there are a number of issues which the analyst must address, including the choice of an appropriate modeling technique, proper functional form, and ensuring that the mathematical properties required for the chosen technique to yield proper results are achieved. For example, ordinary least squares (OLS) requires that:

- values of independent variables are *non-stochastic or fixed*;
- expected mean value of the error term is zero;
- expected value of the variance of the error term is constant;
- no correlation exists between error terms; and
- no correlation exists between error terms and independent variables.

If any of these conditions are violated, the analyst will have to make a corrective adjustment to the OLS or consider an alternative econometric technique. For example, if one of the independent variables is *endogenous*, the first and last condition will be violated, resulting in a biased and inefficient coefficient estimate. In the context of estimating a demand function, the price variable is likely to be endogenous, which would render the coefficient estimate and derived elasticity incorrect. A method known as two-stage least squares (TSLS) represents one means of accounting for endogeneity. The number of potential econometric approaches, mathematical requirements, and corrective measures is beyond the scope of this guidance document. Analysts should consult relevant texts for a more thorough discussion of all of these issues.[5]

[5] For detailed review of econometric modeling and technical issues see Greene (1996), Maddala (1992), or Pindyck and Rubinfeld (1991). Kennedy (1998) provides a more intuitive discussion in the main text with detailed technical notes provided in appendices.

8.3.1.5 Uses and Substitutes Analysis

A "Uses and Substitutes Analysis" may provide useful information on the characteristics of demand as a supplement to or substitute for elasticity estimates.[6] This is "...an in-depth examination of each significant use of the substance in question, and an assessment of the costs, performance, and useful life of substitutes, on a product-by-product basis."[7] A "Uses and Substitutes Analysis" includes four steps:

1) define markets and segments of markets that are relatively homogeneous;
2) assess the cost and performance characteristics of the products in question;
3) identify the most appropriate substitutes; and
4) estimate the incremental costs and performance characteristics of the substitutes in each specific application.

The results of the analysis can then be used to generate demand functions, based on the price at which substitute products become economical for different uses. This analysis can be time and information intensive and may produce relatively crude results. It is nonetheless a useful alternative to estimating demand functions when elasticities are not available.

8.3.2 Determining the Different Types of Social Costs

Having established measures of supply and demand, the analysis then considers how equilibrium price and quantities will change from measured baseline conditions. Social cost changes in each of the affected markets are assessed by examining the direct, indirect, and transitional effects that occur as a result of the new policy. The types of social costs that need to be examined to determine how the supply and demand equations change are summarized, with examples in Exhibit 8-2. A short description of direct costs, which include private and public compliance costs, government regulatory costs, and other types of social costs, is presented. Other social costs less routinely included in empirical analyses of social costs, including indirect costs and the transitional costs, are then reviewed.

8.3.2.1 Direct Social Costs

The direct social costs of a new environmental policy arise from: (1) changes in the private real-resource compliance costs, (2) additional government regulatory costs, (3) social welfare losses, and (4) transitional social costs. The largest fraction of direct social costs arises from the real-resource compliance costs due to the new regulation. These new compliance costs arise from the installation, operation, and maintenance of new capital equipment, or are a result of changes in the production process that raise the price of producing the good.

The additional compliance costs can be used to estimate the new equilibrium price and quantity in the affected markets which will change social welfare. However, these changes will affect other markets, resulting in further price and quantity changes in other goods, giving rise to additional changes in social welfare. The significance of the changes in other markets will influence the type of model necessary for the economic analysis (see Section 8.4, "Modeling Tools"). Changes in social welfare also result from increased government regulatory costs and transitional costs from plant closures and unemployment.

- **Private real-resource compliance costs** can arise from: (1) the capital costs associated with the purchase, installation, operation, and maintenance of new pollution control equipment, (2) changes in the inputs or mixtures used in the production process, or (3) the capture of waste products that can either be disposed of, sold, or reused.

  Real-resource costs are theoretically straightforward to calculate if they arise from the purchase of new pollution control equipment. For example, having information on the number of factories and the price of purchasing and operating new equipment required to meet a policy would provide a means of estimating the compliance costs for the industry. However, since all factories are not identical, costs may be estimated based on cost studies of representative factories

[6] Uses and substitutes analysis is described in Arnold (1995).

[7] Ibid., p. 21.

chosen by random sampling procedures, which can be extrapolated to the universe of affected factories.

Additional costs involve the operating expenses, maintenance, and training associated with the new equipment. Further costs may occur from maintenance changes in other equipment. Also, additional administrative costs may be associated with obtaining permits and preparing required monitoring reports.[8]

In the two other methods of compliance, the private costs may actually be negative and thus need to be included for an accurate estimate of social costs. When waste products are captured and then disposed of, sold, or reused, the cost calculation is also straightforward. Disposal charges are easily determined and the selling price of the waste product (if it is used as an input for other goods) can also be obtained. However, if the production process is changed so that different inputs are used or the mixture of the inputs is altered, the costs involved will be difficult to determine before the change takes place. In addition, the changes may be considered proprietary information.

- **Government regulatory costs** are incurred by federal, state, or local governments to administer and enforce new policies. Government regulatory costs include: administration, training, monitoring/reporting (if they are not included in compliance costs), enforcement, litigation, and the cost of developing and distributing permits. These incremental costs must be financed through additional taxation or other governmental financing mechanisms.

Because they are hard to translate into producer and consumer surplus terms, governmental administration and enforcement costs are typically examined in terms of their dollar costs and staffing requirements (expressed as full-time equivalent employment (FTEs)). Ultimately, these costs are borne by taxpayers unless other administrative costs are reduced to accommodate a new policy. Since government costs are usually small compared to the explicit compliance costs, they are not usually included in partial

Exhibit 8-2 Examples of Social Cost Categories

Social Cost Category	Examples
Real-resource Compliance Costs	• Capital costs of new equipment • Operation and maintenance of new equipment • Waste capture and disposal, selling, or reuse • Change in production processes or inputs • Maintenance changes in other equipment
Government Sector Regulatory Costs	• Training/administration • Monitoring/reporting • Enforcement/litigation • Permitting
Social Welfare Losses	• Higher consumer and producer prices • Legal/administrative costs
Transitional Social Costs	• Unemployment • Firm closings • Resource shifts to other markets • Transaction costs • Disrupted production
Source: Adapted from Harrington et al. (1999).	

[8] A good recent illustration of the measurement of compliance costs can be found in EPA (1997), *Economic Analysis for the NESHAPS for Source Categories: Pulp & Paper Production; Effluent Limitations Guidelines, Pretreatment Standards: Pulp, Paper, and Paperboard Category, Phase I*. For useful empirical presentations on engineering approaches, see Vatavuk (1990) for air pollution controls and EPA (1984) for a wider variety of pollution control technologies.

equilibrium models. However, if they are significant, they should be estimated separately and added to the surplus-based social cost estimates.

Monitoring and enforcement costs, incurred by the government, can be either (1) the opportunity costs of other activities that are discontinued because of fixed government budgets, or (2) the private costs imposed on taxpayers to support the increased government expenditure necessary for the program. The costs of government monitoring and enforcement efforts are normally based on the cost of necessary administrative activities.[9]

- **Social welfare losses** occur when real-resource compliance costs result in higher prices for the good or service and when additional government regulatory costs result in higher taxes passed on to the consumer. New regulations may lead to increased legal and administrative costs for the government, as well as for the regulated entities. The change in social welfare resulting from an increase in taxes or fees assessed in order to pay for government regulatory costs will typically be small relative to social welfare losses attributable to the real-resource compliance costs.

  If the imposition of real-resource compliance costs leads to an increase in the price of the good, this will lead consumers to either buy less or switch to substitutes, thereby leading to a fall in the consumer surplus. The amount of the private costs passed through to the consumer is determined by the market structure, and the elasticities of demand, supply, and income. Once the prices, quantities, and elasticities are known, the process of calculating changes in producer and consumer surpluses is also theoretically straightforward.[10]

- **Transitional effects** vary depending on the length of the time period examined; therefore, social cost analyses should be explicit about the time frame being studied. In the short run, the private annualized costs of compliance, both for consumers and producers, will be higher relative to the annualized long-run costs. This is because the short-run analysis will not provide for possible adjustments in the production process, or allow consumers to find substitutes. Some workers may become unemployed in the short run, but will almost certainly find other jobs in the long run.

  However, over time the impact of a policy can easily spread out to a variety of markets and result in a number of unanticipated adverse effects. Therefore, it is not always appropriate to assume that social costs arising in the short run as a consequence of transitional effects will be resolved in the long run. For EPA economic analyses, the four transitional effects most frequently considered include: (1) plant closings and resultant unemployment, (2) resources shifting to other markets, (3) transactions costs associated with setting up incentive-based programs, and (4) disruptions in production.

  Firm closings and unemployment: In the simplest static models, the time frame is assumed to be a period of time in the near future (e.g., the first year after a new policy is promulgated). Surplus-based measures of social cost are therefore short-run estimates. But as time passes, adjustments are likely to occur. Workers who suffer transitional unemployment will usually find new jobs, and new plant and equipment installed in the future might require relatively less costly pollution control. These long-run changes should be considered as the yearly social costs of a policy are calculated into the future.

  In most cases, involuntary unemployment and plant closings are consequences that are difficult to model using a conventional partial equilibrium framework (which will be discussed in the following section on modeling tools). Predicting these specific consequences would require far more detailed analysis and data than are usually available for practical assessments. Unemployment rates for each group of workers, the duration of unemployment, and the cost of job training programs are just some of the factors that

[9] A useful illustration of the measure of government regulatory costs for a rule can by found in EPA (1995a), *Economic Analysis of the Title IV Requirements of the Clean Air Act Amendments*.

[10] An example of the steps taken to estimate the measurement of social welfare losses from a rule is EPA (1998), *Economic Analysis of Effluent Limitation Guidelines and Standards for the Centralized Waste Treatment Industry*.

need to be taken into account when estimating how the transitional costs decline over time.

These temporary effects are typically assessed and reported as part of an "economic impact" of the policy, and are incorporated into the development of the social cost section of an economic analysis. Chapter 9 of this document reviews such methods to assist in detecting situations in which a policy's private costs are sufficiently large to induce social costs from occurring as a consequence of business closures, reduced employment, or other such impacts.

Shifts of resources to other markets: These shifts occur when the payments to factors of production (labor, land, and capital) are reduced. These shifts are partly responsible for the decreased output level of the product or service. Those that remain earn less than before, at least in the short run, which is reflected in the lower net price received by producers for the good or service. Some of the resources no longer employed in producing this good or service might even become unemployed for a while, such as labor, or be permanently and prematurely scrapped, such as plant and equipment. These and other real-world phenomena can change the position and slope of the supply functions in other markets. Likewise, consumers of the product either pay more for the same good or purchase substitutes that are less suitable or more costly, which can change the position and slope of several demand functions. The analysis of these types of effects is also treated more fully in Chapter 9.

Transaction costs: These costs are encountered with incentive-based policies, such as with a tradable permits program. A market must be established so that the efficiency gains from trading permits are maximized, and rules for trading are developed that enable the market to function under the rules of perfect competition. Therefore, initial short-run costs associated with setting up the market will be high, but are expected to diminish over time as the created market begins to function with less government oversight. The private cost of buying and selling permits will then become similar to the purchase of any other resource needed to produce a good or service.

Disruptions in production: This may take place when new equipment is installed or new production processes or inputs are applied. These costs can be estimated as the amount of time the production line is stopped or slowed down to allow for the necessary changes to comply with the new policy regulations. However, if the changes are made during previously scheduled down-time or required maintenance, then downward adjustments should be made to the estimated costs to reflect this.

To conclude, in many cases transitional costs are considered to be small enough that their inclusion in the overall social cost estimate would not appreciably alter the quantitative conclusions. However, when these are expected to be significant, the costs should be estimated. For example, lost wages and job search costs during the time workers are unemployed can be used as a proxy for this transitional social cost. Similarly, the value of prematurely retired plant and equipment can be calculated and added to the surplus-based social cost estimates to capture this transitional effect, as long as this is not reflected already in the supply and demand framework.

8.3.2.2 General Equilibrium (Indirect) Effects

Other possible components of social costs, such as effects on product quality, productivity, innovation, and market structure, can require fairly complex dynamic models to quantify. Although most individual regulatory policies will not have such dramatic effects, these costs can be quite significant in certain instances, such as when a policy's requirements delay industrial projects or affect new product development. Such policy effects have implications for future social costs but are difficult to measure and express in social cost terms. However, an effort should be made to qualitatively describe these factors and look at approaches that can quantify these effects when data and resources can support this level of detailed analysis of social costs.

- **Changes in market structure** may occur if the expense of pollution control is sufficiently high that it drives out enough firms to cause changes in the market concentration and competitiveness of firms remaining in the industry. Such a change often results in shifts of both firm and industry supply curves, which can lead to changes in output and prices in several markets affecting both producer and consumer surpluses.

- **Labor and capital productivity** may decrease under new regulations. For example, the administrative costs of monitoring emissions and filing reports with regulatory agencies may require firms to hire more workers whose labor does not increase productivity (as measured by labor employed relative to produced output). Pollution control devices or restrictions on the use of products may cause lower levels of output relative to unconstrained production processes. For example, placing restrictions on pesticide use may reduce the yield of crops susceptible to pest damage, holding other factors of production (e.g., labor, fertilizer) constant. In each case, however, private costs are captured by changes in the supply and demand curves of the product, and therefore care should be taken to insure that social costs associated with productivity losses are not double counted with other social cost estimates.

- **Discouraged investment** may occur if research and development funds are reallocated to meet additional compliance costs. This may result in decreases in technological innovation and product quality. The latter can be modeled as the reduced amount consumers are willing to pay for the low quality good, relative to what they were willing to pay for the original, higher quality good. In practice, changes in technological innovations are not commonly analyzed in most economic models used in benefit-cost analyses of individual regulations and policies.

8.3.3 Other Issues Arising in Presentation of Social Costs

Four additional issues to note arise in the organization and presentation of social costs, several of which have also been raised earlier in this document in connection with the measurement of social benefits. These issues discussed here on social costs include: (1) discounting, (2) difficulties valuing some social cost categories, (3) conducting sensitivity analyses, and (4) simplifying market effects.

- **Discounting:** Social discounting procedures for economic analyses are reviewed in considerable detail in Chapter 6. For purposes of computing the social costs of environmental policies, costs should be discounted using the methods and social discount rates discussed in that chapter. This is the case regardless of the methods used to estimate social costs. Social costs can be estimated in detail year-by-year, or estimated using growth rates, or merely assumed to be constant. These streams of social costs can then be adjusted to yield: (1) discounted present value, (2) future value, or (3) the annualized cost of the policy. All three approaches are different ways to express the same concept and choosing which method to present the results will depend on the method that most effectively allows comparisons among the options and the measurement of net benefits.[11]

- **Difficulties of valuing social costs:** Some consequences of environmental policies are difficult to represent in the definitive, quantitative terms of conventional social cost analysis. Irreversible environmental impacts, substantial changes in economic opportunities for certain segments of the population, social costs that span very long time horizons, socioeconomic effects on communities, and poorly understood effects on large-scale ecosystems are difficult to summarize in a quantitative benefit-cost analysis. Some alternative techniques for measuring and presenting these effects to policy makers are reviewed in section 7.6.3 of the benefits chapter that discusses measuring ecological benefits. The relative significance of social cost categories that are not quantified—or are quantified but not valued—should be described in the analysis.

- **Sensitivity analysis:** The estimates in the social cost analysis will not be known with certainty. In fact, some data and models will likely introduce substantial uncertainties into the estimations of social costs. Numerous assumptions are made in regard to

[11] Many EPA analyses typically prepare an annualized cost estimate, since this measure is one of several used to determine whether rules require additional review and oversight, and is used to help establish the scope of the economic analysis to be conducted (e.g., the social cost threshold of $100 million in annual costs is used to identify rules that require a benefit-cost analysis under the provisions of EO 12866).

the baseline, predicting responses to policy, and the number of affected markets. Therefore, the conclusions drawn in the benefit-cost analysis will be sensitive to the degree of uncertainty present and the assumptions that were made. Reporting the uncertainty of the data, the assumptions used, and how the uncertainty and assumptions affect the results are important components of the presentation of social cost. Section 5.5 outlines the process of analyzing and presenting uncertainty.

- **Simplifying market effects:** Given the complexity of modern economies, measuring and predicting all of the consequences of a particular action would involve a significant effort. The central question explored in this section is whether some or all markets indirectly affected by a policy must be analyzed to obtain a measure of social costs suitable for a benefit-cost analysis, or whether the calculation of social costs can be limited to an assessment of the directly affected markets without introducing unacceptable biases and errors into the analysis.

In general, the social cost of a policy can be measured exclusively by changes that occur in the markets directly targeted by a policy, as long as significant net changes in social welfare are not generated in indirectly affected markets. If price changes in other markets generate both gainers and losers among the producers and consumers, then they may offset each other in a social cost analysis as transfers.[12] However, if there are strong reasons to believe that conditions in other related markets might generate important net social welfare consequences, these should be examined. If a policy indirectly increases or decreases the quantity of a good that is consumed, whose production or consumption involves an externality, then this results in net social welfare effects that may be worth considering when calculating total social costs (and benefits).

8.4 Modeling Tools

The following section first focuses on the basic framework common to all models used to estimate social costs, while the remaining sections examine the models commonly used: (1) direct compliance cost methods, (2) partial equilibrium models, (3) multi-market models, and (4) computable general equilibrium models.

8.4.1 The Basic Framework

Benefit-cost models must predict what actions firms are likely to choose when attempting to comply with a new policy and what the compliance costs of those actions will be. Normally, these are based on engineering or process cost models that examine firms' alternative compliance methods. Engineering cost estimates typically specify the capital, operating, and maintenance costs that are likely to occur in adopting different pollution control strategies. When possible, these initial engineering cost estimates should include the expected level of compliance costs, as well as reasonable lower and upper bounds for purposes of sensitivity analysis.

In addition to the preliminary engineering or other estimates of the social costs of various compliance strategies, other costs may be significant. As noted earlier, for some market-based approaches, transaction costs can often be substantial. For example, when setting up the market for a permit trading system, determining how many permits to purchase or sell can involve detailed cost modeling and forecasting, in addition to the social costs associated with operating the trading system. When these costs are likely to be significant, they should be estimated in addition to the basic private real-resource costs of capital and the operating costs of alternative compliance methods.

8.4.2 The Direct Compliance Cost Method

In some cases, social costs are estimated using the *direct compliance cost* method. This is the simplest approach used in estimating social costs. Under this approach, the social cost for a policy is simply set equal to the initial engineering or other compliance cost estimates for the compliance options the firms are likely to adopt; no additional modeling is undertaken. If only compliance costs are calculated, the private (compliance) costs are likely to

[12] This conclusion regarding the net social welfare implications of price changes in related markets requires some qualification. Even when non-zero welfare effects are produced by price changes in related markets, they are likely to be small relative to the estimated producer and consumer welfare effects in the directly affected markets. See Arnold (1995) for more discussion of related markets and welfare measurement.

be overestimated. This is because private costs are computed for the pre-policy level of output under the implicit assumption that there is no substitution away from the affected products or activities into other relatively less expensive ones. That is, firms do not make any capital or labor adjustments in their production processes. In addition, when the resulting changes in consumer surplus are calculated at the new higher prices, consumer welfare losses are also likely to be overestimated since changes in consumer behavior will not be taken into account.

Nevertheless, using direct compliance costs as an approximation of actual social costs may be reasonable for a policy when price and quantity changes are small, and there are few indirect effects. However, if consumers can easily switch to substitute goods, this adjustment will make the actual social cost of the policy significantly less than indicated by the direct compliance cost estimates. Likewise, if firms can find less costly substitutes for their inputs or production processes, which have been made more expensive by the new regulations, then compliance costs will be an overestimate of the actual social costs.

8.4.3 Partial Equilibrium Analysis

Because of the limitations of using direct compliance costs as a measure of social costs, an alternative approach is to model the economic effects of these compliance costs on producers and consumers using a *partial equilibrium* supply and demand model of the affected markets. This allows for a more complete analysis of social costs and their incidence. "Partial" equilibrium refers to the fact that the supply and demand functions are modeled for just one or a few isolated markets and that conditions in other markets are assumed either to be unaffected by a policy or unimportant for social cost estimation.

For example, if using a partial equilibrium supply and demand framework, a new environmental policy that increases production costs will cause a change in the supply function. The demand function, the old and new supply functions, prices, and quantities can then be used to compute changes in producer and consumer surpluses. If the relevant markets are evolving over time, this technique can be applied in each future time period using new supply and demand functions. This makes it possible to estimate the changing distribution of social costs over time.

The practical difference between the results of the partial equilibrium supply and demand-based modeling and the direct compliance costs approach depends on the nature of the policy and the magnitude of its effects. For small compliance costs, price and quantity movements are likely to be minimal, so the social cost estimates derived from the partial equilibrium model framework will not be significantly different from the results obtained from the direct compliance cost method.

For policies with larger compliance costs, price and quantity movements could be more substantial. The estimated social costs using the supply and demand framework in these cases may be considerably less than those suggested by the simpler direct compliance cost approach. Moreover, policies that effectively ban products or activities cause the loss of all producer and consumer surpluses in these markets. Therefore, it is difficult to calculate social costs of these policies without an explicit supply and demand framework.

Analyzing the effects of a policy using a partial equilibrium model of the directly affected markets is appropriate when the ramifications in indirectly affected markets do not generate net social costs. It is also a reasonable framework as long as the social costs imposed by a policy are small and do not significantly alter other markets or produce measurable macroeconomic effects (e.g., changes in national unemployment levels).

In most cases, a conventional partial equilibrium framework comparing the pre-policy baseline with the expected results of a new environmental policy will suffice for an economic analysis. For analyzing environmental policies that pose very large consequences for the economy, computable general equilibrium modeling is an alternative technique that is particularly useful and is discussed later in this chapter.[13]

The partial equilibrium framework is a commonly used theoretical tool for modeling and measuring the social costs of environmental policies. In theory, a variety of

[13] Useful recent illustrations of partial equilibrium analyses prepared in support of environmental policies include EPA (1998) *Economic Analysis of Effluent Guidelines and Standards for the Centralized Waste Treatment Industry*, and EPA (1996) *Economic Impact Analysis of Proposed NESHAP for Flexible Polyurethane Foam*.

social costs can be observed and calculated using this technique. Even transitional effects that result in short-run social costs, such as premature capital equipment retirement and relatively brief spells of involuntary unemployment, can be modeled and estimated using this framework. Thus, the approach offers a theoretically sound, if limited, method for conceptualizing the consequences of an environmental policy and measuring their social costs.

Deriving the supply and demand functions is the foundation of benefit-cost analysis and is necessary in all economic models used to analyze social costs and benefits. However, because of its importance and the uncertainties associated with estimating supply and demand functions, it may be useful to evaluate key assumptions with sensitivity analyses and develop a range of estimated social costs.

The typical analysis is performed assuming a competitive market, although unusual circumstances may require relaxing this assumption. Even should competitive market conditions fail to hold, partial equilibrium analysis can be adapted to analyze varying market conditions that may more closely reflect real-world conditions. It is useful to indicate when social benefits or social costs have been overestimated or underestimated because of biases caused by market distortions. However, the principles underlying partial equilibrium analysis can serve as a useful model to evaluate the real-resource costs of many of EPA's regulations and policies.

As previously discussed in Section 5.6, "Emerging Cross-Cutting Issues," environmental policies usually can be analyzed assuming a first-best regulatory setting, although actual conditions reflect a second-best world in light of taxes placed on a variety of goods and services. Therefore, it is conceivable that a regulatory policy in one sector may have effects in labor markets and other sectors of the economy. Thus, examining costs in only the final goods market may cause costs (or even benefits) to be underestimated.

The scope of the regulatory program is likely to be proportional to the effects experienced in other sectors of the economy. Therefore, the larger the program, the more important it is to examine several markets to accurately estimate costs and determine (1) tax interaction effects, (2) changes in technology, and (3) the effects on firms' research and development decisions. Thus, multi-market models are needed for regulatory policies that may have large economic effects on several sectors of the economy.

8.4.4 Multi-Market Models

Multi-market models go beyond partial equilibrium analysis by extending the inquiry to more than just a single market. Multi-market analysis attempts to capture at least some of the interactions between markets. However, unlike the general equilibrium models discussed in the next section, multi-market models do not attempt to incorporate a representation of the entire economy.

An example of the use of a multi-market model for environmental policy analysis is contained in a report prepared for EPA on the regulatory impact of controls on asbestos and asbestos products (EPA 1989). The model developed for the study describes the interactions between the asbestos fiber market and markets for the goods that use the fiber as an intermediate input. The collective demands for final goods that use asbestos create a derived demand for asbestos fiber. The price of the fiber is determined through the interaction between the demand and supply schedules for asbestos. Changes in this price in turn influence the prices and demands for the downstream goods. The specification of the links between the input and output markets is especially important for simulating alternative regulatory policies, including interventions in both the input market (caps on the usage of asbestos fiber) and in the output market (bans on some of the goods that use asbestos as an input), as well as combinations of the two. The model was then used to compare the efficiency losses under various regulatory scenarios.

8.4.5 General Equilibrium Analysis

Although the use of a partial equilibrium or multi-market model may be appropriate when policies are likely to affect a limited number of markets, they are not able to capture interactions between a large number of sectors. Many environmental policies, such as energy taxes, can be expected to impact a large number of sectors both directly where the policy is applied, and indirectly through spillover and feedback effects on those and other sectors. A strength of general equilibrium models is their ability to account consistently for the linkages between all sectors of the economy. Three types of general equilibrium models that have been used for the analysis of social costs are input-output models, linear programming models, and computable general equilibrium (CGE) models.

8.4.5.1 Input-Output (I/O) Models

The central idea underlying I/O analysis is that in modern economies, production activities are closely interrelated. An input-output table represents the flow of goods and services through the economy, usually measured as transactions occurring over the course of a year. In addition to the primary factors of capital, labor, and land, most productive sectors use many different intermediate inputs. In an I/O table, the column associated with a particular sector lists the value of the individual intermediate and primary inputs consumed by that sector. The row associated with an individual sector lists the value of that sector's output purchased as both intermediate inputs and final demand. For each sector in a table, the column sum represents the total costs of production and the row sum represents total expenditure on that sector's output. A key feature of I/O tables is that, by definition, for every sector, total costs must equal total expenditures during the year.[14]

An I/O table can be turned into a simple linear model through a series of matrix operations. The intermediate inputs matrix defines a matrix of technical coefficients, based on the assumption that inputs to production are consumed in fixed proportions to output and that there are constant returns to scale. The model is manipulated by making exogenous changes to the vector of final demands. The model will then calculate how much of each of the intermediate goods is required to produce the new final demand vector. The sum of the intermediate inputs required plus final demand is equal to total output for the year.

I/O models have a long history in environmental policy analysis. Leontief (1970) showed how it was possible to augment the basic I/O model with an additional set of coefficients for pollution generation and/or abatement. When a set of pollution coefficients has been defined, an I/O model can then produce an estimate of the quantity of pollution that would be generated along with a given amount of final demand or total output. The quantity of pollution generated may be specified in either monetary terms (as damages) or in physical units.

Some economic research firms use I/O models to provide upper bound estimates on price effects. Others use I/O models to look at the related markets and their potential significance prior to adopting a partial or general equilibrium model. The I/O approach has also been extended further to include non-market, ecological commodities such as ecosystem services.[15]

Although I/O models can be a useful as a consistency check or a first-order approximation, they have a number of shortcomings that limit their applicability as a predictive tool:

- Given that prices are normally assumed to be fixed and do not adjust to indicate scarcity, there is nothing to ensure that the total demands generated by manipulation of the model are consistent with the actual productive capacity of the economy.
- The fixed coefficients assumption leaves no scope for substitution of inputs in production.
- Since there is no producer or consumer behavior built into I/O models, simulation of policy interventions that would affect those agents is of limited value.
- Because the construction of an input-output table is a costly and time-consuming process, usually requiring a specialized survey, the application of input-output analysis to environmental policy making will normally only be possible when an appropriate table already exists. More importantly, since input-output tables are used in linear programming and computable general equilibrium models, this last shortcoming is shared by these models as well.

[14] A general reference on input-output models is Miller and Blair (1985).

[15] A discussion of the application of input-output models to environmental policy analysis, with a number of examples, is provided in Chapter 7 of Miller and Blair (1985). Another example applied to the environmental protection industry is EPA (1995b), *The U.S. Environmental Protection Industry: A Proposed Framework for Assessment*.

8.4.5.2 Linear Programming (LP) Models

I/O models are driven by exogenous changes in final demand. Since they do not contain an objective function, I/O models are difficult to use for decision making among multiple alternatives. However, it is possible to extend the basic I/O model into a LP model by incorporating an explicit objective function and a set of inequality constraints.[16]

In addition to the usual economic variables, the objective function may be specified to include a number of environmental variables, such as the discharge of air or water pollutants. The specification of multiple inequality constraints allows for a great deal of flexibility in the application of LP model (because of this flexibility, EPA's Office of Air and Radiation has used linear programming models for many years). Shadow prices generated in the dual form of LP models have a limited relationship to market prices and may sometimes be useful as indicators of the importance of the individual constraints. Sensitivity analysis can be conducted by varying key parameters in the model.[17]

The flexibility in the specification of LP models is also something of a liability of the approach. The problem is that the selection of the constraints used is often *ad hoc* and may influence the model solution. As with many linear models, there is often a tendency towards unrealistic solutions, such as excessive specialization in production or trade. Finally, the lack of realistic consumer and producer behavior is carried over from I/O models.

8.4.5.3 Computable General Equilibrium (CGE) Models

As discussed in the previous sections on I/O and LP models, these approaches have shortcomings that make them less than ideal tools for policy analysis in modern market economies. In particular, in both I/O and LP models, the behavior of producers and consumers does not reflect the independent optimizing behavior that is usually assumed to be a characteristic of agents in a market economy. Without the specification of realistic producer and consumer behavior, model-based policy simulations will be unable to correctly account for the reactions agents may have to policies that impact them. Computable general equilibrium (CGE) models incorporate more realistic behavioral specifications of the agents into the model and are thus able to provide a better laboratory for many types of policy analysis. CGE models have been used to analyze a wide variety of policy interventions, including issues in public finance, international trade, development, and increasingly, the environment.[18]

Most policies meant to protect the environment, ranging from those relying on market-based instruments, such as effluent taxes, to command and control regulations, induce changes in the behavior of consumers and producers. These changes may occur directly where the intervention takes place or indirectly as the effects of the intervention are passed through the economy. Because they focus on both trying to model more accurately the expected reactions of consumers and producers to policy interventions and on the interactions between various actors in the economy, for some problems CGE models may be the most appropriate tool for the analysis of social costs. CGE models are particularly good at examining questions of static resource allocation, such as the effects the imposition of a tax may have on sectoral output, income, and employment. Under certain specifications, CGE models may also be useful for assessing impacts on overall measures of economic performance, such as aggregate output, employment, and various measures of welfare.

In almost all cases, CGE models start from the framework and data of an input-output table, which provides a basic set of accounting identities for the production sectors. Producers are assumed to maximize their profits through their choice of productive inputs, typically labor, capital, and intermediate goods, and sometimes land. Consumers,

---

[16] The term linear programming actually refers to any applied mathematical programming exercise where an objective function is either maximized or minimized subject to a set of inequality constraints and where all of the equations are linear. In this section, only general equilibrium applications (i.e., those based on an input-output table) are discussed.

[17] Linear programming models are discussed in Dervis et al. (1982). A number of examples of the application of linear programming models to environmental problems are given in Hufschmidt et al. (1983).

[18] General references on CGE models include Dervis et al. (1982) and Ginsburgh and Keyser (1997). Applications to environmental policy are discussed in Wajsman (1995).

or in many cases a representative consumer, are assumed to maximize their utility by choosing their consumption bundles, subject to a budget constraint. Although not usually specified as an optimizing agent, most CGE models also include a government sector that collects a variety of taxes to pay for its purchases of goods and services. The domestic demand for imports and the supply of exports are determined based on the relative prices of domestic and foreign goods.

CGE models may be categorized across a number of dimensions. These can include (1) the method by which the parameters of the model are specified (through calibration or econometric estimation), (2) the time horizon of the model (static or dynamic), and (3) the scope of the model (single- or multi-country). Most CGE models are calibrated to a single base year, which is assumed to be in equilibrium. After the specification of a subset of elasticities and other data obtained through a literature search (or using informed judgments) the rest of the parameters can be determined by working backward from a social accounting matrix (SAM) for the base year.[19] An alternative to the calibration approach is econometric estimation.[20] General equilibrium econometric estimation allows models to incorporate the representation of more sophisticated producer and consumer behavior than would normally be possible through calibration. However, econometric estimation requires a consistent set of multi-sector time-series data and this data is usually not available for developing countries.

CGE models can also be differentiated by the time horizon of the analysis. The majority of CGE models are "static," meaning that no explicit dynamics are incorporated and the time frame for the attainment of a new equilibrium following a policy or external shock is indeterminate. In conducting simulations, an exogenous shock is introduced or a variable, such as a tax rate, is altered. The model is then allowed to search for a solution until a new set of prices is found which again equilibrates the system. The new prices in turn determine a new set of factor demands, outputs, and incomes. The values from this new solution are then compared with the values from the original equilibrium. Dynamic models, on the other hand, incorporate an explicit updating of time dependent variables, such as the labor supply, capital stock, technology, and demand patterns. In conducting a simulation, a baseline case is first run with a given set of assumptions about the time-dependent variables. Next, an alternative or counterfactual simulation is run with the same set of assumptions, but with a policy or external shock. The values resulting from the alternative solution are then compared with the original baseline. These values may be compared at different points in time or discounted to estimate present values, or to evaluate changes in welfare.

Another dimension along which CGE models may be classified is by scope: (1) single country or single region models, (2) multi-country or multi-region models, and (3) global models encompassing all countries and regions. Although models representing a single country or region are the most common, multi-country or multi-region models are being developed in increasing numbers. Because trade is inherently a multi-country phenomenon, multi-country models are generally the best suited for examining issues that involve the flow of goods, services, and capital across national boundaries.

CGE models have been applied to an expanding array of environmental policy issues. Most recently, they have been used for the analysis of policies designed to avert or slow global climate change, such as those proposed in the Kyoto Protocol. Both single country and multi-country CGE models have been used for these simulations, with multi-country models able to assess policies like global emissions trading. Because they are able to incorporate taxes and other existing distortions, CGE models have been used to explore the potential for a "double dividend"—a reduction in pollution plus a reduction in the inefficiencies of the tax system—from substituting taxes on pollutants for pre-existing taxes on output, income, or wages. In addition, CGE models have been used to perform retrospective analyses of the economic costs of a number of environmental regulations.[21]

---

[19] References on social accounting matrices include Pyatt and Round (1985) and Chapter 10 of Sadoulet and de Janvry (1995).

[20] This approach has been pioneered by Dale Jorgenson and a number of his collaborators. See in particular the papers collected in Jorgenson (1998a, 1998b). Another example of the use of the econometric approach is Hazilla and Kopp (1990).

[21] For example, the Jorgenson-Wilcoxen dynamic CGE model of the U.S. was used to estimate compliance costs between 1970 and 1990 for EPA's retrospective study of the benefits and costs of the Clean Air Act (EPA, 1997b). A previous CGE-based study by Hazilla and Kopp (1990) looked at the costs of both the Clean Air and Clean Water Acts.

While CGE models have a number of advantages as tools for policy analysis, they also have serious drawbacks:

- Although the costs have been reduced in recent years, the construction of a CGE model can be still be time consuming and expensive.
- In addition to an appropriate input-output table, a considerable amount of data on national accounts, trade, elasticities, and environmental externalities must be collected and made consistent with the sectors chosen to be part of the analysis.
- Dynamic models also require that forecasts be made for many exogenous variables.
- Many environmental policies only affect a small part of what may be a highly aggregated sector in an input-output table. Sometimes it will be possible to separate these smaller sectors out, but sufficient data is often not available at that level of detail.

8.5 Estimating the Social Costs of Alternative Policy Approaches

This section discusses the methods of estimating the social costs for several alternative regulatory and nonregulatory policy approaches, which are divided into three categories: (1) direct controls, (2) incentive-based controls, and (3) voluntary actions taken to reduce environmental risks. The discussion focuses on the significant features of each regulatory approach that must be examined in either partial equilibrium, multi-market, or CGE models. In addition to the private compliance costs, transactions costs may be significant. Therefore, the associated changes in the prices of goods and services will alter producer and consumer surplus and must be calculated to estimate the total social costs.

Independent of the method used, the social cost analysis should explain how the uncertainties and assumptions in the data and models affect the results. Since much of the data used is not known with certainty and many assumptions must be made to develop the necessary analytical models, social cost estimates can never be known with total certainty. Another difficulty is that private (compliance) cost bounds in one project may be based on the intuition of a single engineer, but the private cost bounds in another sector may be developed based on adequate data permitting the estimation of confidence intervals. Aggregating these into a single study may conceal important uncertainties rather than enlightening the decision making process.[22]

8.5.1 Direct (or Standards-Based) Controls

In general, direct or standards-based controls rely on different types of standards that mandate a level of performance intended to acheive an environmental objective.

8.5.1.1 Technology Standards

Estimating the private compliance costs of standards-based regulations is relatively straightforward compared to incentive-based approaches. Technology standards often require Best Available Technology (BAT) or Best Practicable Technology (BPT). Since these technologies already exist, their costs and the number of firms required to use them are often well documented. Additional compliance costs include expenditures on maintenance and training costs associated with installing and operating the equipment. However, estimating the private compliance costs is not always simple, especially for proposed regulations. For example, unanticipated scaling effects, as well as unforeseen bottlenecks in construction and implementation may occur, resulting in differences between the anticipated bids for a project, the bids received, and the actual construction cost.

The private real-resource costs, when discounted over time, correspond to the sum of investment costs and discounted annual costs (operating and maintenance and other annual regulatory costs) that will be incurred by firms to comply with the regulation. Thus, the real-resource costs of regulation can be approximated, in most instances, by methodologies routinely used by other EPA

[22] Another reason for variability of the compliance cost estimates for pollution control may be due to the way emission rates are characterized, their method of transport, and chemical transformation rather than variations in the price of pollution control equipment and labor costs.

program offices to evaluate compliance costs. Furthermore, the supply and demand curves that implicitly lie behind such calculations need not be formally estimated unless the effects of the regulation on price and output are expected to be significant.

8.5.1.2 Emission Standards

Regulations that limit emissions are usually targeted at particular point sources or geographic regions, but there also exist national standards such as ambient air and water quality standards. For point sources, private compliance cost estimates are usually based on the cost to purchase and operate regulatory equipment needed to comply with the regulations. This equipment will be similar to that needed to meet technology standards. Since it may be prohibitive to examine in detail each area and all its pollution sources, private social and compliance cost estimates can be based upon random samples of representative areas and industries. The survey should accurately reflect the expected compliance costs for different categories and sizes of industries in each area. In each of the three cases, additional social costs are involved with monitoring and enforcement of the regulations.

8.5.1.3 Production Bans

The prohibition of a product or service results in shutdowns, causing short- and, sometimes, long-term unemployment, as well as the loss or premature retirement of capital equipment. Therefore, adjustment costs should include: (1) the value of wages temporarily or permanently foregone because of reductions in production levels in the directly affected markets[23] and (2) the social cost of re-employing displaced workers (including the administrative cost for transfer payment programs, but excluding the payment itself). Moreover, policies that effectively ban products or activities cause the loss of all producer and consumer surpluses in these markets. Regulations also may substantially affect secondary or linked markets. CGE and multi-market models will account for these effects, but partial equilibrium models will not do so unless a separate model is used.

Some policies, although not explicitly banning production, may be so stringent that the effect on production is the same. In this case, the concept of compliance cost is less applicable. For example, if the mandated environmental protection controls would be so costly that the new equilibrium level of output is zero (because the consumers of the good shift completely to substitutes and producers of the good exit this market to produce other outputs), then it is not possible to use compliance costs as an estimate of social costs. A ban on producing this good would produce a similar result.

In the case of an effective ban on production, the social cost of the new policy is measured by the complete loss of all producer and consumer surpluses in this market. The real-resource cost in this case might be conceptualized as the welfare change associated with the additional expense and lower quality of the other goods that consumers purchase as substitutes for their previous use of the product.

8.5.2 Incentive-Based Controls

The appeal of incentive-based approaches is their potential ability to achieve environmental improvement goals more cost effectively than traditional standards-based methods. The approaches examined here include: marketable permits, emission taxes, bubbles and offsets, user charges, product charges, subsidies for pollution reduction, government cost sharing, refundable deposits, pollution indemnity, and information and labeling rules. In many cases, significant transfers will occur between private parties and the government, but in most cases, these policies achieve their greater economic efficiency through mechanisms that encourage private parties to use information known to them but not to the environmental authorities. Such information may include differences in emission control costs among different firms. Analyses of the social costs of incentive-based approaches may require different information and tools than those used to analyze more traditional

[23] Lost wages, rather than lost production, is suggested as a proxy for the value of displaced resources. In most cases, lost wages will capture most of the value of displaced resources because it is likely that inputs other than labor will be reallocated to other sectors of the economy fairly quickly and at little cost.

policies. The task of calculating the exact compliance costs of these policies is therefore more difficult.[24]

8.5.2.1 Marketable Permits

Permits are usually denominated in the amount of emissions allowed and the number and denomination of permits issued determines the aggregate amount of emissions.[25] Marketable permits establish the aggregate quantity of pollution allowed and allow the price of those entitlements to vary. Since different polluters incur different private costs to control emissions, they will be willing to pay different amounts for permits. The price of permits, in theory, will be established by the unit cost of control of the marginal polluter. Marketable permits are traded between emission sources, giving rise to a transfer among private parties but not social costs.

In contrast to technology standards, incentive-based approaches (taxes or permits) do not require any particular firm to install particular pollution control devices. Therefore, it is usually necessary to predict what technology will be used by the firms to meet the new regulations to estimate costs. Under a marketable permit system, the private costs of pollution control are estimated following a three-step process:

- Calculate the demand and supply functions for the permits (these demand and supply functions are based on the costs of different sources' pollution control options). Polluters will be willing to pay prices for the permits up to the unit cost of reducing emissions.
- Estimate the equilibrium price for permits. This price will determine which firms will install pollution control measures and those which will purchase additional permits.
- Calculate the real-resource cost of the regulation by summing the investment costs and the present value of operating and maintenance costs incurred to reduce emissions. (The cost of the permits purchased by firms is classified as an income transfer between firms, not a social cost.)

Marketable permits may be sold at auction initially, in which case the prices bid for the newly issued permits again represent income transfers to the government. Alternatively, permits may be allocated to sources by some rule, in which case no private costs are imposed at the outset. In neither case is the private cost of a permit counted as part of the social cost, since it is not a real-resource cost, but rather a transfer from one firm to another or a transfer from a firm to the government. The act of establishing the permit system and assigning property rights to the distributed permits may result in some type of "wealth transfer" taking place, which should be accounted for in the equity assessment of the benefit-cost analysis.

As described earlier, the marketable permit systems requires the creation of a functioning market. This results in administrative costs and also additional enforcement costs since it is necessary to ensure that emissions do not exceed the levels for which permits are held. Both need to be added to the social cost estimate.

8.5.2.2 Emission Taxes

Estimates of the social costs of pollution control under emissions taxes are virtually the same as those under marketable permits. Here however, the unit price of pollution will be known (since it is set by the regulation) and does not have to be calculated. Because the private cost of pollution control varies among firms, firms with the highest private costs of pollution control are expected to cut back production and pay the tax on the remaining emissions, rather than install required pollution control equipment. Most often, firms will choose some combination of cutbacks in production, installation of pollution control equipment, and payment of the tax. However, as in the case of most regulations, real-world limitations may reduce the possible selection of cost-minimizing alternatives chosen or firms may simply decide to engage in litigation to delay the regulation, which adds an additional cost.

[24] However, after the policy is passed, compliance costs are much easier to calculate. In the case of emission taxes, cost-minimizing polluters, in theory, will reduce emissions up to the point where the marginal cost of control equals the tax. Of course, these conclusions rest upon the assumptions of perfectly competitive markets, low transactions costs, and complete information.

[25] Permits may also be weighted based on the impact the pollutant has on air or water quality.

After the supply (or abatement cost) function for each firm is estimated, then the equilibrium amount of pollution generated can be determined. The new production levels can then be calculated for each firm along with how much pollution control equipment will be installed. Finally, the real-resource costs and private costs are calculated as is done above for marketable permits. However, here the pollution taxes or charges may involve transfers of tax revenues from the private sector to the government, but because such fees accrue to the government, they are again income transfers and should not be included in total social costs.

8.5.2.3 Bubbles and Offsets

Bubbles and offsets allow emissions to be averaged among specific regions or among different sources within a particular facility. The resulting level of emission control must be equivalent to or better than that required by existing regulations. If "banking" is allowed, pollution credits can be traded across time—with potential offsets created in one period to be used in later periods. Bubbles and offsets create incentives to reduce emissions in firms where the private costs of control are relatively low. Compared with direct controls, bubbles and offsets usually result in lower compliance costs (relative to costs incurred under technology and emission standards).

Additional social costs associated with bubbles and offsets are similar to those encountered with marketable permits. Initial administrative costs may be significant and some additional enforcement costs for monitoring emission levels also may be incurred. The private cost of the offsets traded in a formal market are transfers between the creator and the user of the offset and are not social costs. However, the transactions costs incurred to arrange the trade, both private and public, are part of total social costs.

8.5.2.4 User Charges

Charges may be imposed directly on users of publicly operated facilities. Such charges have been imposed on firms that discharge waste to municipal wastewater treatment facilities and on non-hazardous solid wastes disposed of in publicly operated landfills. User charges are usually set at a level sufficient to recover the private costs of operating the public system, rather than to create incentives for reducing pollution. Measuring the total social cost imposed by user charges is similar in concept to measuring the social costs of emission charges, but is not always based on a per unit charge of the pollutant.

8.5.2.5 Product Charges

Charges may be imposed on intermediate or final products whose use or disposal pollutes the environment. The private and social costs imposed by product charges depend on the extent to which users switch to substitutes, reduce the rate at which the product is used by recycling or other process changes, or continue to use the regulated products. Predicting responses and estimating compliance costs is difficult and requires analysis of the social costs and effectiveness of substitute products as well as the social costs of recycling and reuse. Any charges paid as a result of continuing use represent private costs, but are not social costs because these are borne by the consumer who buys less of the more expensive product.

8.5.2.6 Subsidies for Pollution Reduction

Subsidies paid to polluters based on their reductions in pollution have the same general effect on behavior as charges on pollution. Sources may reduce pollution up to the point where the private costs of control equal the subsidy. Using subsidies instead of charges shifts private costs to the government. This may result in more sources continuing to operate than if a charge system were used. Thus, subsidies and charges may not have the same aggregate social costs or the same degree of pollution control.

Measuring the social costs resulting from a system of pollution subsidies is similar in concept to measuring the social costs resulting from pollution charges, except that private costs are reduced by the amount of the subsidy, rather than being increased by the amount of the fee. Again, the subsidies themselves are income transfers and do not constitute a social cost. Therefore, private real-resource costs should be computed excluding the subsidies.

8.5.2.7 Government Cost-Sharing

In addition to issuing the regulations described above, the government may take actions to lower the private costs of specific actions—most notably, by subsidizing investments in pollution control equipment. These subsidies may take the form of reduced interest rates, accelerated depreciation, direct capital grants, and loan assistance or guarantees for pollution control investments. Such policies may not by themselves induce changes in private behavior. However, in conjunction with direct controls, pollution fees, or other regulatory mechanisms, they may influence the nature of private responses and the distribution of the cost burden. In particular, such subsidies may encourage investment in pollution control equipment, rather than other responses that do not require capital investments (e.g., changes in operating practices or recycling and reuse).

Government cost-sharing subsidies reduce the private costs associated with the resulting private investments. However, social costs may arise if cost-sharing programs lead to resource misallocations. Additional social costs will result from administration of the subsidy program, but are likely to be minor if the incentives are provided through the existing tax system. However, they may be significant if new administrative structures are required.

8.5.2.8 Refundable Deposits

Refundable deposits create economic incentives to return a product for reuse or for proper disposal, providing that the deposit exceeds the private cost of returning the product. Therefore, to predict the rates of return, the private cost of returning products must be estimated.

Under a refundable deposit system, compliance costs consist of the resources (labor, equipment, and transportation) required to return the regulated product, and the private cost of preparing products for reuse (if required), less the cost of new products replaced by recycled products. The private administrative costs of a deposit system vary, depending on where in the production-consumption cycle they occur and from whom the deposits are collected. Record-keeping requirements may also be a cost component. For those that participate in a recycling/refund program, the opportunity cost of the time spent sorting trash is an important component, and the analysis must address whether other behavior changes may be expected to take place (e.g., whether consumers may adjust their consumption of products marketed in recyclable containers). The deposits themselves represent transfers from one point in the production-consumption cycle to another and, hence, are not social costs. These transfers are temporary if the deposit is reclaimed, but permanent if it is not. Enforcement costs are minimal since no standards have been set and no laws are broken if the product is not returned.

A government "buy-back" constitutes another type of refundable deposit. Under this system, the government either directly pays a fee for the return of a product or subsidizes firms that purchase recycled materials. They are equivalent to product deposits, except that the government, rather than the purchaser, provides the deposit. The government subsidy represents a transfer from the government to the private sector, which offsets the private costs of recycling products.

8.5.2.9 Pollution Indemnity

Regulations that impose stricter liability on polluters for the health and environmental damage caused by their pollution may reduce the transaction costs of legal actions brought by affected parties. Such regulations do not impose additional social costs, but only shift the costs from one party to another. However, this may induce polluters to alter their behavior and expend real resources to reduce their probability of being required to reimburse other parties for pollution damages. For example, they may reduce pollution, dispose of waste products more safely, install pollution control devices, reduce output, or invest in added legal counsel.

Other regulations may require firms to demonstrate financial ability to compensate damaged parties by posting performance bonds that are forfeited in the event of damages, by obtaining liability insurance, or by contributing to a pool of funds to compensate victims. The administrative and enforcement costs imposed by such requirements represent the use of economic resources but are not counted as part of the social costs because the funds used to pay damages do not represent a use of resources, but are transfers among private parties (between polluters, insurers, and victims of pollution). Again, however, these requirements are likely to alter private behavior and lead to increased outlays of real resources to reduce the probability of accidents, or reduce the probability of having to pay using any of the methods cited above.

8.5.2.10 Information and Labeling Rules

Information or labeling rules may be applied to specific substances or to certain contaminated locations. For example, warning labels may be required for hazardous substances that describe safe-handling procedures or describe the risks posed by the product. Purchasers may then switch to less damaging substitutes for some or all uses or handlers of hazardous substances may be better able to prevent damages. Posting information on contaminated locations gives potentially exposed parties the opportunity to avoid hazards—for example, contaminated dump sites or drinking water aquifers.

Calculating the private costs of complying with information and labeling requirements for particular cases is straightforward. Compliance costs include the cost of developing the required information (analyzing the composition of substances, monitoring and testing of sites, testing for health damages, etc.) and the cost of disseminating information (printing and applying labels, maintaining and publishing information on sites).

Similarly, the direct costs of enforcing and administering the requirements (including government review and approval of labels) can be calculated directly. Calculating aggregate private costs may be more difficult, however, if the number of containers requiring labels or the number of facilities affected is unknown. In addition, it is difficult to predict responses by the recipients of the information and, hence, the social cost of avoidance.

8.5.3 Voluntary Actions

While there can be social costs associated with voluntary actions taken to mitigate environmental polluting behavior, it may be difficult to establish the relation between decisions made by firms or individuals and the role EPA and other regulatory agencies may play in inducing or contributing to the adoption of these practices. EPA and other regulatory agencies are looking to alternative nonregulatory approaches in an effort to change behavior that contributes to health and environmental risks. Examples of EPA programs of this type include the 33/50 program for reduction of toxic pollutant discharges and energy conservation and greenhouse gas mitigation measures, such as ENERGY STAR and Climate Wise programs.[26]

A basic premise underlying social cost analyses is the assumption that profit-maximizing firms undertake investment decisions, voluntary or otherwise, when it is in their private interests to do so (i.e., where private benefits are greater than private costs). If actions would not have occurred absent EPA's involvement in these programs, then there may be social costs (beyond those costs incurred by EPA) that are associated with actions taken by participants in the programs. Social costs may arise, for example, from firms exhibiting strategic behavior in their investment decision that incorporates expectations that voluntarily participating in nonregulatory programs may serve to reduce or delay promulgation of future, potentially more stringent enforceable compliance standards. Without some assessment of costs, it is difficult to establish whether a particular voluntary program is cost-effective in comparison with other policy actions. As a consequence, it is useful to investigate the social costs associated with nonregulatory programs—quantifying how they affect economic markets, and evaluating the relative economic efficiency of these approaches as compared with regulatory policies.

8.6 Summary and Conclusions

This chapter has reviewed the theoretical foundations of social cost assessments as well as practical methods for measuring the social costs of environmental policies. Several key conclusions reached in this discussion are worth reiterating.

First, in most cases, the social costs of an environmental policy or other action can be measured with sufficient accuracy by limiting the analysis to the directly affected markets. This allows the analysis to focus on the sectors that must comply with a policy. In these cases, the disturbances that ripple outward from the directly affected markets to numerous other markets should have a minimal effect on the estimation of social costs.

[26] More information on the operations and objectives of these types of programs can be found in publications prepared by EPA's Office of Reinvention and at the following website http://www.epa.gov/reinvent/ (accessed 8/28/2000).

Second, a conventional partial equilibrium depiction and modeling of the directly affected markets will often be sufficient to measure social costs. The detail and precision of applying this approach in practice will depend on the availability of information, the resources devoted to the evaluation, and the value to policy makers of improved accuracy of the results.

Finally, other modeling techniques, such as CGE, are often used to measure a variety of indirect costs, the many transitional effects of environmental policies, and, when they are significant, transactions costs borne by private sector entities. Nevertheless, the majority of the economic analysis of environmental policies can employ the conventional partial equilibrium modeling approach to evaluate social costs of EPA policies and programs.

8.7 References

Arnold, F.S. 1995. *Economic Analysis of Environmental Policy and Regulation*. New York, NY: John Wiley and Sons, Inc.

Dervis, K., J. de Melo, and S. Robinson. 1982. *General Equilibrium Models for Development Policy*. New York, NY: Cambridge University Press.

Friedman, L. E. 1984. *Microeconomic Policy Analysis*.: New York, NY: McGraw-Hill.

Ginsburgh, V. and M. Keyser. 1997. *The Structure of Applied General Equilibrium Models*. Cambridge, MA: MIT Press.

Goulder, L. H. 1995. Effects of Carbon Taxes in an Economy with Prior Tax Distortions: An Intertemporal General Equilibrium Analysis. *Journal of Environmental Economics and Management* 29: 271-297.

Gramlich, E. M. 1981. *Cost-Benefit Analysis of Government Programs*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Greene, W. H. *Econometric Analysis*. 1996. 3rd edition. New York, NY: Macmillian.

Harrington, W., R. Morgenstern and P. Nelson. 1999. *On the Accuracy of Regulatory Cost Estimates*, Discussion Paper 99-18. Resources for the Future, Washington, D.C.

Hazilla, M. and R. J. Kopp. 1990. Social cost of environmental quality regulations: a general equilibrium analysis. *Journal of Political Economy*, 98 (4): 853-873.

Hufschmidt, M. M., D. E. James, A. D. Meister, B. T. Bower, and J. A. Dixon. 1983. *Environment, Natural Systems, and Development*. Baltimore, MD: The Johns Hopkins University Press.

Jorgenson, D. W. 1998a. *Growth, Volume 1: Econometric General Equilibrium Modeling*. Cambridge, MA.: MIT Press.

Jorgenson, D. W. 1998b. *Growth, Volume 2: Energy, the Environment, and Economic Growth*. Cambridge, MA: MIT Press.

Just, R. E., D. L. Hueth, and A. Schmitz. 1982. *Applied Welfare Economics and Public Policy*, Englewood Cliffs, NJ: Prentice-Hall, Inc.

Kennedy, P. 1998. *A Guide to Econometrics*. 4th edition. Cambridge, MA: MIT Press.

Leontief, W. 1970. Environmental Repercussions and the Economic Structure: An Input-Output Approach. *Review of Economics and Statistics*, (52)3.

Maddala, G. J. 1992. *Introduction to Econometrics*. 2nd ed. Englewood Cliffs, NJ: Prentice Hall.

McKibbin, W. J. and P .J. Wilcoxen. 1995. The Theoretical and Empirical Structure of the G-Cubed Model. *Brookings Discussion Papers in International Economics*, no. 118 (December).

Miller, R. E. and P. D. Blair. 1985. *Input-Output Analysis: Foundations and Extensions*. Englewood Cliffs, NJ: Prentice-Hall.

Morgenstern, R. D. 1997. *Economic Analysis at EPA: Assessing Regulatory Impact*. Resources for the Future, Washington, D.C.

Nestor, D. V., and C. A. Pasurka, Jr. 1995. CGE Model of Pollution Abatement Processes for Assessing the Economics Effects of Environmental Policy, *Economic Modeling* 12(1): 53-59.

Pyatt, G. and J. I. Round (eds.) 1985. *Social Accounting Matrices: A Basis for Planning*. World Bank, Washington, D.C.

Pindyck, R. S. and D. L. Rubinfeld. 1991. *Econometric Methods and Economic Forecasts*. 3rd edition. New York, NY: McGraw Hill.

Sadoulet, E., and A. de Janvry. 1995. *Quantitative Development Policy Analysis*. Baltimore, MD: The Johns Hopkins University Press.

U.S. Environmental Protection Agency. 1984. *The Cost Digest: Cost Summaries of Selected Environmental Control Technologies*. EPA/600/8-84-010, Office of Research and Development.

U.S. Environmental Protection Agency. 1989. *Regulatory Impact Analysis of Controls on Asbestos and Asbestos Products: Final Report*. Prepared by the Office of Pesticides and Toxic Substances.

U.S. Environmental Protection Agency. 1995a. *Economic Analysis of the Title IV Requirements of the Clean Air Act Amendments*. Prepared by the Office of Air and Radiation.

U.S. Environmental Protection Agency. 1995b. *The U.S. Environmental Protection Industry: A Proposed Framework for Assessment*. EPA/230/R-95-011, Office of Policy, Planning and Evaluation.

U.S. Environmental Protection Agency. 1996. *Economic Impact Analysis of Proposed NESHAP for Flexible Polyurethane Foam*. Prepared by the Office of Air and Radiation.

U.S. Environmental Protection Agency. 1997a. *Economic Analysis for the NESHAPS for Source Categories: Pulp & Paper Production; Effluent Limitations Guidelines, Pretreatment Standards: Pulp, Paper, and Paperboard Category, Phase I*. EPA/821/R-97-012, Office of Water.

U.S. Environmental Protection Agency. 1997b. *The Benefits and Costs of the Clean Air Act*. Prepared for U.S. Congress by the Office of Air and Radiation and Office of Policy, Planning and Evaluation.

U.S. Environmental Protection Agency. 1998. *Economic Analysis of Effluent Guidelines and Standards for the Centralized Waste Treatment Industry*. EPA/821/R-98-019, Office of Water.

Vatavuk, W. M. 1990. *Estimating Costs of Air Pollution Control*. Chelsea, MI: Lewis Publishers, Inc.

Wajsman, N. 1995. The Use of Computable General Equilibrium Models in Evaluating Environmental Policy, *Journal of Environmental Management* 44: 127-143.

Zerbe, R. O. and D.D. Dively. 1994. *Benefit-Cost Analysis: In Theory and Practice*. New York, NY: Harper Collins.