Chapter 8

Analyzing Costs

The previous chapter discussed the process of estimating the benefits of environmental regulations and policies. This chapter discusses the estimation of costs, with a primary focus on estimating costs for use in benefit-cost analyses (BCA). While often portrayed as being relatively straightforward — particularly compared to the estimation of benefits — the estimation of costs presents a number of challenges in its own right.

The first challenge is to identify an appropriate measure of cost for a particular application. A number of concepts of cost exist, with some overlap of ideas. In conducting a BCA, the correct measure to use is the social cost. Social cost represents the total burden that a regulation will impose on the economy. It is defined as the sum of all opportunity costs incurred as a result of a regulation where an opportunity cost is the value lost to society of any goods and services that will not be produced and consumed as a result of a regulation.

A second challenge involves choosing an economic framework for the analysis. Depending on the scope of the regulation or policy, either a partial or general equilibrium framework is employed. Partial equilibrium analysis is usually appropriate when the scope of a regulation is limited to a single sector, or to a small number of sectors. General equilibrium analysis may be more appropriate if the analyst expects a large number of sectors to be impacted and that the effects will be spread more broadly throughout the economy.

The third challenge is choosing one or more models to use in an analysis. Factors to consider in selecting a model include the types of costs being investigated, the geographic and sectoral scope of the likely impacts, and the expected magnitude of the impacts. For some analyses, it may be necessary to use more than one model.

This chapter discusses social cost and its underlying economic theory as well as several alternative concepts of cost. In addition, the chapter discusses several additional issues in cost estimation and presents a number of the models that can be employed in the estimation and analysis of costs.

8.1 The Economics of Social Cost

The most comprehensive measure of the costs of a regulation — and thus the appropriate measure to use in a BCA — is "social cost." Social cost represents the total burden a regulation will impose on the economy; it can be defined as the sum of all opportunity costs incurred as a result of the regulation. These opportunity costs consist of the value lost to society of all the goods and services that will not be produced and consumed if firms comply with the regulation and reallocate resources away from production activities and towards pollution abatement. To be complete, an estimate of social cost should include both the opportunity costs of current consumption that will be foregone as a result of the regulation, and the losses that may result if the regulation reduces capital investment and thus future consumption.[1]

The purpose of estimating social cost is to have a reference point for comparing the costs of a regulation with the estimated benefits. Social cost is not a particularly meaningful concept unless it is used as part of a net social welfare calculation, or perhaps compared to other (less comprehensive) cost measures.[2] Conceptually, it should be noted that the social cost of a regulation is generally not the same as a change in gross domestic product (GDP), or another broad measure of economic activity, that may result from its imposition. Expenditures on inputs into pollution abatement, such as equipment, materials, and labor, are counted as part of social cost. All or part of their consumption will at the same time be included positively in the calculation of GDP. Thus, if a regulation has the effect of lowering GDP, this decline will in general be less than the social cost of the regulation.

Two broad analytical paradigms are used in the analysis of social cost: partial equilibrium and general equilibrium. A partial equilibrium approach is appropriate when it is assumed that the effects of a regulation will primarily be confined to a single or small number of closely related markets. If this is not the case, and the regulation is expected to cause significant impacts across the economy, it is more appropriate to use general equilibrium analysis to estimate social cost. The use of these two analytical paradigms is explored in the following sections.

8.1.1 Partial Equilibrium Analysis

When the analyst expects that the effects of a regulation will be confined primarily to a single market or a small number of markets, partial equilibrium analysis is the preferred approach for estimation of social cost. The use of partial equilibrium analysis assumes that the effects of the regulation on all other markets will be minimal and can either be ignored or estimated without employing a model of the entire economy. This section presents some simple diagrams to show how social cost can be defined in a partial equilibrium framework.

Figure 8.1 shows a competitive market before the imposition of an environmental regulation. The intersection of the supply (S_0) and demand (D) curves determines the equilibrium price (P_0) and quantity (Q_0). The shaded area below the demand curve and above the equilibrium price line is the consumer surplus. The area above the supply curve and below the price line is producer surplus. The sum of these two areas defines the total welfare generated in this market: the net benefits to society from producing and consuming the good or service represented in this market.[3]

In this market, the imposition of a new environmental regulation raises firms' production costs. Each unit of output is now more costly to produce because of expenditures incurred to comply with the regulation. As a result, firms will respond by reducing their level of output. For the industry, this will appear as an upward shift in the supply curve. This is shown in Figure 8.2 as a movement from S_0 to S_1. The effect on the market of the shift in the supply curve is to increase the equilibrium price to P_1 and to decrease the equilibrium output to Q_1, holding all else constant.

1 This section discusses the prospective estimation of social cost for regulations that have not yet been implemented. However, the same principles apply to estimating costs retrospectively for regulations already in place. Likewise, while the text refers to the social cost of "a regulation" the same principles apply to the estimation of the social cost for each alternative in a set of regulatory alternatives. For a more rigorous and detailed treatment of the material in this section, see Pizer and Kopp (2005).

2 For example, comparing the social cost of different regulations may provide some sense of the relative burden they impose on the economy, but this exercise alone would not indicate which, if any, of the regulations may be worthwhile from a public policy standpoint. However, the accurate measurement of social cost would be an essential component in attempting to make such a determination.

3 It should be noted that total welfare as depicted ignores the negative pollution externality arising in this market, which the environmental regulation is designed to correct. Appendix A presents a graphical description of how to account for this externality. Reduction of this negative externality would be quantified in the benefits portion of an analysis. The supply curve in Figure 8.1 corresponds to the marginal private cost (MPC) curve described in Figure A.5 of Appendix A.

Figure 8.1 - Competitive Market Before Regulation

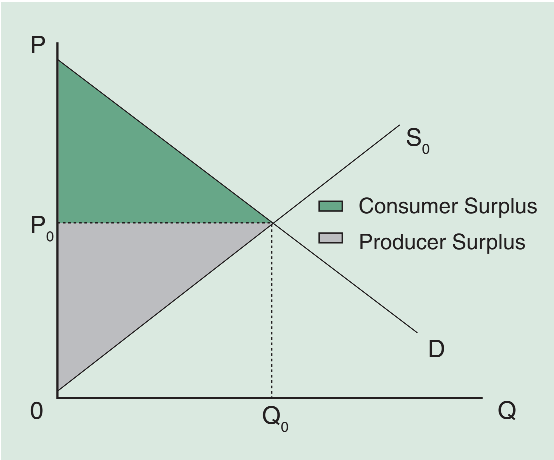
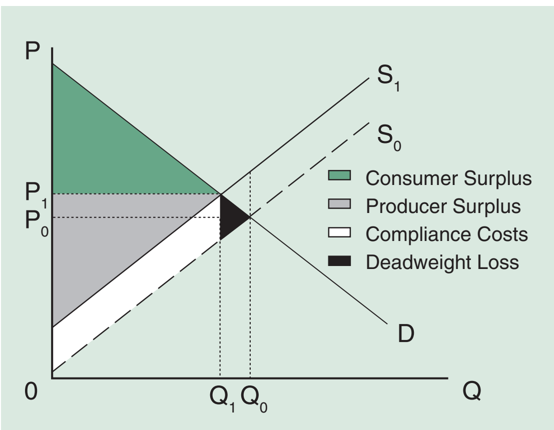


Figure 8.2 - Competitive Market After Regulation



As seen by comparing Figures 8.1 and 8.2, the overall effect on welfare is a decline in both producer and consumer surplus.[4]

Compliance costs in this market are equal to the area between the old and new supply curves, bounded by the new equilibrium output, Q_1.[5] Noting this, a number of useful insights about the total costs of the regulation can be derived from Figures 8.1 and 8.2. First, when consumers are price sensitive — as reflected in the downward sloping demand curve — a higher price causes them to reduce consumption of the good. If costs are estimated ex ante and this price sensitive behavior is not taken into account (i.e., the estimate is based on the original level of output (Q_0) compliance costs will be overstated. Extending the vertical dotted line in Figure 8.2 from the original equilibrium to the new supply curve (S_1) illustrates this point.[6]

A second insight derived from Figures 8.1 and 8.2 is that compliance costs are usually only part of the total costs of a regulation. The "deadweight loss" (DWL) shown in Figure 8.2 is an additional, real cost arising from the regulation. It reflects the foregone net benefit due to the reduction in output.[7] Moreover, unlike many one-time compliance costs, DWL will be a component of social cost in future periods.

Under the assumption that impacts outside this market are not significant, then the social cost of the regulation is equal to the sum of the compliance costs and the deadweight loss (shown in Figure 8.2). This is exactly equal to the reduction in producer and consumer surplus from the pre-regulation equilibrium (shown in Figure 8.1). This estimate of social cost would be the appropriate measure to use in a BCA of the regulation. As noted above, if some of the compliance costs are spent on other goods and services or on hiring additional labor, any fall in GDP attributable to the imposition of the regulation will be less than the social cost.

The preceding discussion describes the use of partial equilibrium analysis when the regulated

4 The figure depicts an equal distribution of welfare between consumers and producers, in both the old and new equilibria. Depending on the elasticities of supply and demand, this may not be the case. The elasticities will determine the magnitude of the price and quantity changes induced by the cost increase, as well as the distribution of costs.

5 Here distinctions between the fixed and variable costs of abatement are abstracted and it is assumed that all of the costs are represented in the movement of the supply curve. See Tietenberg (2002).

6 In the extreme, if the regulation raised production costs so much that firms decided to halt production altogether, or if an outright ban on the product was issued, a strict compliance cost analysis would yield zero cost as no direct expenditures on abatement would be made. Clearly this would constitute an underestimate of the loss in consumer welfare.

7 Typically, in a market already distorted with pollution externalities, the DWL triangle shown in Figure 8.2 will serve to offset (at least in part) the existing DWL in the market that results when the real costs of production (including the pollution damages) are not considered in the production decision. Of course, if the regulatory action is too stringent and "over controls" the pollution problem, the optimal outcome will not be achieved and additional DWL will be created. Figure 8.2 is silent on where the optimal solution is achieved. See Appendix A for more detail.

market is perfectly competitive. In many cases, however, some form of imperfect competition, such as monopolistic competition, oligopoly, or monopoly, may better characterize the regulated market. Firms in imperfectly competitive markets will adjust differently to the imposition of a new regulation and this can alter the estimate of social cost.[8] If the regulated market is imperfectly competitive, the market structure can and should be reflected in the analysis.

In certain situations, when the effects of a regulation are expected to impact a limited number of markets beyond the regulated sector, it still may be possible to use a partial equilibrium framework to estimate social cost. Multi-market analysis extends a single-market, partial equilibrium analysis of the directly regulated sector to include closely related markets. These may include the upstream suppliers of major inputs to the regulated sector, downstream producers who use the regulated sector's output as an input, and producers of substitute or complimentary products. Vertically or horizontally related markets will be affected by changes in the equilibrium price and quantity in the regulated sector. As a consequence, they will experience equilibrium adjustments of their own that can be analyzed in a similar fashion.[9]

8.1.2 General Equilibrium Analysis

In some cases, the imposition of an environmental regulation will have significant effects in markets beyond those that are directly subject to the regulation. As the number of affected markets grows, it becomes less and less likely that partial equilibrium analysis can provide an accurate estimate of social cost. Similarly, it may not be possible to accurately model a large change in a single regulated market using partial equilibrium analysis. In such cases, a general equilibrium framework, which captures linkages between markets across the entire economy, may be a more appropriate choice for the analysis.

For example, the imposition of an environmental regulation on emissions from the electric utility sector may cause the price of electricity to rise. As electricity is an important intermediate input in the production of most goods, the prices of these products will most likely also rise. Households will be affected as both consumers of these goods and as consumers of electricity. The increase in prices may cause them to alter their relative consumption of a variety of goods and services. The increase in the price of electricity may also cause feedback effects that result in a reduction in the total consumption of electricity.

General equilibrium analysis is built around the assumption that for some discrete period of time, an economy can be characterized by a set of equilibrium conditions in which supply equals demand in all markets. When the imposition of a regulation alters conditions in one market, a general equilibrium model will determine a new set of prices for all markets that will return the economy to equilibrium. These prices in turn determine the outputs and consumption of goods and services in the new equilibrium. In addition, the model will determine a new set of prices and demands for the factors of production (labor, capital, and land), the returns to which compose the income of businesses and households. Changes in aggregate economic activity, such as GDP, household consumption, and other variables, also can be calculated in the model.

The previous section shows how the social cost of a regulation can be estimated in a single market using partial equilibrium analysis. The example demonstrates how a regulation causes

8 The opportunity costs of lost production from the regulation will be less for a monopoly than a perfectly competitive industry, even if they face the same market demand curve. This result may seem counterintuitive, but the monopolist operates on a more elastic, or price sensitive, portion of the demand curve. As a result, it will have lower profits if it tries to increase price (and lower output) by as much as the competitive industry.

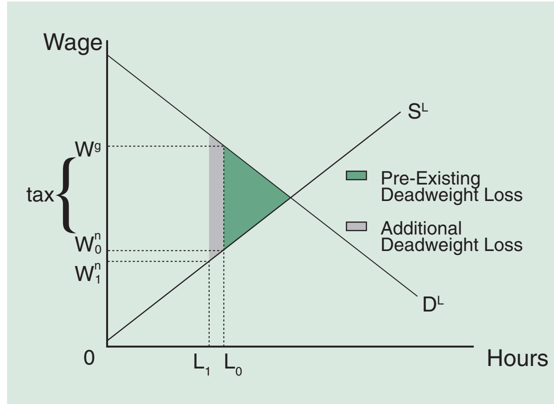
9 In theory, impacts in undistorted related markets are "pecuniary" and do not need to be included if the social costs have been correctly measured in the primary market, but pecuniary effects are important in inefficient related markets and should be considered (Boardman et al. 2006). Just et al. (2005) provide a detailed treatment of multi-market analysis. Kokoski and Smith (1987) demonstrate, however, that one must use caution when using these methods.

a DWL in that market, reflecting a decline in economic welfare as measured by consumer and producer surplus. In reality, DWL already exists in many, if not most, markets as a result of taxes, regulations, and other distortions. When the imposition of a regulation causes a new distortion in one market, it may interact with pre-existing distortions in other markets and this may cause additional impacts on welfare.

An important example of how a regulation can interact with pre-existing distortions can be found in the labor market, depicted in Figure 8.3. Here, a pre-existing tax on wages causes the net, after-tax wage (W_0^n) to be lower than the gross, pre-tax wage (W^g) by the amount of the tax. With this tax distortion, the quantity of labor supplied is L_0 and there is a DWL. When a new regulation is imposed in another market, raising production costs, one of the indirect effects may be an increase in the price level as those costs are passed through the economy. This increase in the price level will reduce the real wage and, given an upward sloping labor supply curve, the amount of labor supplied.[10] This is shown in Figure 8.3 as a decrease in the net wage to W_1^n and a decrease in the amount of labor supplied to L_1.

The interaction between new and pre-existing distortions is especially pronounced in the labor market because pre-existing distortions there are large. As shown in Figure 8.3, even a small reduction in the amount of labor supplied will result in a large increase in DWL.[11] Similar interactions are likely to occur in other markets with pre-existing distortions. In cases where they are likely to have a significant impact, analysts should incorporate these distortions into models used to estimate social cost.[12]

Figure 8.3 - Labor Market with Pre-Existing Distortions



In a general equilibrium analysis, the social cost of a regulation is estimated using a computable general equilibrium (CGE) model. CGE models simulate the workings of a market economy and can include representations of the distortions caused by taxes and regulations. As described above, they are used to calculate a set of price and quantity variables that will return the simulated economy to equilibrium after the imposition of a regulation. The social cost of the regulation can then be estimated by comparing the value of variables in the pre-regulation, "baseline" equilibrium with those in the post-regulation, simulated equilibrium.[13]

10 In general equilibrium analysis, all prices and wages are real, i.e., they are measured relative to a *numéraire*, a specific single price or weighted average of prices, such as the GDP deflator. Here, the consumer price level rises relative to the *numéraire*. The result is a fall in the real wage — the nominal wage divided by the consumer price level.

11 The labor tax distortion affects individual labor supply decisions at the margin. Thus, a full-time worker may not change (or be able to change) her hours worked in response to a fall in the real wage. However, part-time workers, workers in households with more than one full-time worker, or potential retirees, may be more likely to adjust the number of hours they work or whether they work at all. A discussion of the theoretical and empirical basis for this depiction of the labor market can be found in Parry (2003).

12 Economists have long recognized these interaction effects (Ballard and Fullerton 1992). A more recent body of work has focused on them in the context of environmental regulation. In this literature, these interactions are known as the "tax-interaction effect." If an environmental regulation raises revenue through a tax on pollution or other revenue raising provision, and the revenue is used to reduce pre-existing distortions such as taxes on wages, the tax-interaction effect may be offset. This is known as the "revenue recycling effect." The offset may be partial, complete, or in some cases, the overall efficiency of the tax system may actually be improved. The net result is an empirical matter, depending on the nature of the full set of interactions across the economy and how the revenue is raised. Some of the early papers in this literature include Bovenberg and de Moojii (1994), Parry (1995), and Bovenberg and Goulder (1996). Goulder (2000) provides an accessible summary of the early literature. More recent papers include Parry and Bento (2000); Murray, Keeler, and Thurman (2005); and Bento and Jacobsen (2007).

13 CGE models are discussed in more detail in the modeling section of this chapter. Applications of CGE models to the estimation of the social cost of environmental regulation include Hazilla and Kopp (1990) and Jorgenson and Wilcoxen (1990). A version of the Jorgenson and Wilcoxen model was used as part of EPA's retrospective study of the benefits and costs of the Clean Air Act for the period 1970 to 1990 (U.S. EPA 1997a).

Even in a general equilibrium analysis, analysts must take care in selecting an appropriate measure of social cost. Calculating social cost by adding together estimates of the costs in individual sectors can lead to double counting. For example, counting both the increased costs of production to firms resulting from a regulation and the attendant increases in prices paid by consumers for affected goods would mean counting the same costs twice, leading to an overestimate of social cost. Instead, focusing on measures of changes in final demand, so that intermediate goods are not counted, can avoid the double-counting problem.[14]

While it is theoretically possible to estimate social cost by adding up the net change in consumer and producer surplus in all affected markets, the measures most commonly used in practice are consumer's equivalent variation (EV) and compensating variation (CV). Both are monetary measures of the change in utility brought about by changes in prices and incomes resulting from the imposition of a regulation. As households are the ultimate beneficiaries of government and investment expenditures, the EV and CV measures focus on changes in consumer welfare, rather than on changes in total final demand.

8.1.3 Dynamics

In most cases, a regulation will continue to have economic impacts for a number of years after its initial implementation. If these intertemporal impacts are likely to be significant, they should be included in the estimation of social cost. For example, if a regulation requires firms in the electric utility sector to invest in pollution control equipment, they may not invest as much in electric generation capacity as they would have in the absence of the regulation. This may result in slower growth in electricity output and reduce the overall growth rate of the economy. In some cases, the effect of a regulation on long-term growth may be much more significant than the effect on the regulated sector alone.

14 Final demand consists of household purchases, investment, government spending, and net exports (exports minus imports).

When conducting a BCA in which the analyst expects intertemporal effects of a regulation to be confined to the regulated sector, it may be appropriate to simply apply partial equilibrium analysis to multiple periods. Relevant conditions, like expected changes in market demand and supply over time, should be taken into account in the analysis. The costs in individual years can then be discounted back to the initial year for consistency.

If the intertemporal effects of a regulation on non-regulated sectors are expected to be significant, analysts can estimate social cost using a dynamic CGE model. Dynamic CGE models can capture the effects of a regulation on affected sectors throughout the economy. They can also address the long-term impacts of changes in labor supply, savings, factor accumulation, and factor productivity on the process of economic growth.[15] In a dynamic CGE model social cost is estimated by comparing values in the simulated baseline (i.e., in the simulated trajectory of the economy without the regulation) with values from a simulation with the regulation in place.

8.1.4 Social Cost and Employment Effects

At times of recession, questions arise about whether jobs lost as a result of a regulation should be counted as an additional cost of the regulation. However, counting the number of jobs lost (or gained) as a result of a regulation generally has no meaning in the context of BCA as these are typically categorized as transitional job losses.[16] BCA requires monetized values of both the social benefits and costs associated with the regulation. The social cost of a regulation already includes the value

15 In addition to affecting the growth of the capital stock, an environmental regulation may also negatively affect the supply of labor through the interaction effects discussed above, thus increasing social cost. However, there may also be a positive effect on labor supply if improved environmental quality confers health benefits that make the work force more productive.

16 In very rare cases in which a regulation contributes additional job losses to a sector exhibiting structural unemployment, analysts should consider including job losses as a separate cost category. See Appendix C for more detail.

of lost output associated with the reallocation of resources (including labor) away from production of output and towards pollution abatement. This does not mean, of course, that specific individual workers are not harmed by a policy if they lose their jobs. EPA estimates the magnitude of such losses as part of an Economic Impact Analysis (EIA). See Chapter 9 for more details on this topic.

8.2 A Typology of Costs

The previous section defined social cost as the sum of the opportunity costs incurred as the result of the imposition of a regulation, and introduced the basic economic theory used in its estimation. Conceptually, social cost is the most comprehensive measure of cost, and is thus the appropriate measure to use in BCA. In addition to social cost, a number of other concepts of cost exist and are often used to describe the effects of a regulation. This section discusses these alternative concepts and introduces a number of additional terms. This section also provides a discussion of measures that define temporary costs or define how costs are distributed across different entities.

8.2.1 Alternative Concepts of Cost

Three alternative concepts of cost, each of which is composed of two components, are: explicit and implicit costs, direct and indirect costs, and private sector and public sector costs. Like social cost, all of these concepts are comprehensive in nature. An important distinction is that while social cost is a measure derived from economic theory, these three alternative concepts are in general only descriptive.[17]

Consideration of these alternative concepts can provide insights into the full range of the costs of a regulation. They may also be useful in determining the appropriate framework and modeling methodology for an analysis. Several executive and legislative mandates require that a number of different types of costs be included in a regulatory impact analysis (RIA).[18]

8.2.1.1 Explicit and Implicit Costs

The total costs of a regulation can include both explicit and implicit costs.[19] Explicit costs are those costs for which an explicit monetary payment is made, or for which it is straightforward to infer a value. For firms, the explicit costs of environmental regulation normally include the costs of purchase and operation of pollution control equipment. This includes payments for inputs (such as electricity) and wages for time spent on pollution control activities. For households, explicit costs may include the costs of periodic inspections of pollution control equipment on vehicles. For government regulatory agencies, wages paid to employees for developing a regulation and then for administration, monitoring, and enforcement are included in explicit costs. Implicit costs are costs for which monetary values do not readily exist and are thus likely more difficult to quantify. Implicit costs may include the value of current output lost because inputs are shifted to pollution control activities from other uses, as well as lost future output due to shifts in the composition of capital investment. Implicit costs may also include the lost value of product variety as a result of bans on certain goods, time costs of searching for substitutes, and reduced flexibility of response to changes in market conditions.

8.2.1.2 Direct and Indirect Costs

Direct costs are those costs that fall directly on regulated entities as the result of the imposition of a regulation. These entities may include firms, households, and government agencies. Indirect costs are the costs incurred in related markets or experienced by consumers or government agencies

17 In certain cases, a single component, such as direct cost, may provide a reasonable estimate of social cost.

18 EO 12866 specifies that an assessment of the costs of a regulation should include "any adverse effects on the efficient functioning of the economy and private sector (including productivity, employment, and competitiveness)" in addition to compliance costs. The UMRA of 1995 requires that cost estimates take into account both indirect and implicit costs on state and local governments.

19 The term "total cost" is used here when discussing alternative concepts of cost in order to reinforce the distinction between these concepts and social cost.

not under the direct scope of the regulation. These indirect costs are usually transmitted through changes in the prices of the goods or services produced in the regulated sector. Changes in these prices then ripple through the rest of the economy, causing prices in other sectors to rise or fall and ultimately affecting the incomes of consumers. Government entities can also incur indirect costs. For example, if the tax base changes due to the exit of firms from an industry, revenues from taxes or fees may decline. In some cases, the indirect costs of a regulation may be considerably greater than the direct costs.

8.2.1.3 Private Sector and Public Sector Costs

The total costs of a regulation can also be divided between private sector and public sector costs. Private sector costs include all of the costs of a regulation borne by households and firms. Public sector costs consist of the costs borne by various government entities.

8.2.2 Additional Cost Terminology

In addition to the conceptual categories and their components discussed above, a variety of other terms are often used in describing the costs of environmental regulation. A number of these terms are defined here. It should be noted that there are numerous overlaps between these concepts, and analysts must take care to avoid double counting.[20]

8.2.2.1 Incremental Costs

Incremental costs are the additional costs associated with a new environmental regulation or policy. Incremental costs are determined by subtracting the total costs of environmental regulations and policies already in place from the total costs after a new regulation or policy has been imposed.

20 References that provide definitions of cost terminology include U.S. CBO (1988), and Callan and Thomas (1999).

8.2.2.2 Compliance Costs

Compliance costs (also known as *abatement costs*) are the costs firms incur to reduce or prevent pollution to comply with a regulation. They are usually composed of two main components: capital costs and operating costs. Compliance costs can be further defined to include any or all of the following:

- Treatment/Capture — The cost of any method, technique, or process designed to remove pollutants, after their generation in the production process, from air emissions, water discharges, or solid waste.
- Recycling — The cost of postproduction on-site or off-site processing of waste for an alternative use.
- Disposal — The cost involving the final placement, destruction, or disposition of waste after pollution treatment/capture and/or recycling has occurred.
- Prevention — The cost of any method, technique, or process that reduces the amount of pollution generated during the production process.

8.2.2.3 Capital Costs

Capital costs include expenditures on installation or retrofit of structures or equipment with the primary purpose of treating, capturing, recycling, disposing, and/or preventing pollutants. These expenditures are sometimes referred to as "one-time costs" and include expenditures for equipment installation and startup. Once equipment is installed, capital costs generally do not change with the level of abatement and are thus functionally equivalent to "fixed costs." In BCA, capital costs are usually "annualized" over the period of the useful life of the equipment.

8.2.2.4 Operating and Maintenance Costs

Operating and maintenance costs are annual expenditures on salaries and wages, energy inputs, materials and supplies, purchased services, and maintenance of equipment associated with pollution abatement. In general, they are directly related to the level of abatement. Operating costs are functionally equivalent to "variable costs."

8.2.2.5 Industry Costs

Industry costs are the costs of a regulation to an industry, including the effects of actual or expected market reactions. They often differ from compliance costs because compliance costs do not normally account for market reactions. Market reactions may include plant closures, reduced industry output, or the passing on of some costs directly to consumers.

8.2.2.6 Transactions Costs

Transactions costs are those costs that are incurred in making an economic exchange beyond the cost of production of a good or service. They may include the costs of searching out a buyer or seller, bargaining, and enforcing contracts. Transactions costs may be important when setting up a new market, such as those markets designed to be used for market-based regulations.

8.2.2.7 Government Regulatory Costs

Government regulatory costs are those borne by various government entities in the course of researching, enacting, and enforcing a policy or regulation.[21]

8.2.3 Transitional and Distributional Costs

In addition to the concepts and terms defined above, several other types of cost exist. Two qualitatively different types of cost from those above are transitional and distributional costs.

8.2.3.1 Transitional Costs

At some point in time after the imposition of a new environmental regulation, the economy can be expected to adjust to a new equilibrium. While many costs are likely to be permanent additions to the costs of production, others will be short term in nature, being incurred only during the adjustment to the new equilibrium. These are known as transitional costs. Transitional costs may include the costs of training workers in the use of new pollution control equipment. After workers receive their initial training, the time they spend on pollution control activities would be counted as operating costs.

8.2.3.2 Distributional Costs

Distributional costs are those costs that relate to how certain entities or societal groups are impacted by the imposition of a policy or regulation. While BCA is by definition concerned only with the net benefits, it is likely that most policies or regulations will result in winners and losers. In some cases, the models described later in this chapter can be used for distributional analysis as well as BCA. Distributional costs are covered in detail in Chapter 10.

8.3 Measurement Issues in Estimating Social Cost

A number of issues may arise when estimating the expected social cost of a proposed regulation, or when measuring costs incurred as a result of an existing regulation. These issues can be divided into two broad categories: (1) those that arise when estimating costs over time; and (2) those associated with difficulties in developing numeric values for estimating social cost. This section discusses both these issues in turn. It concludes with a short analysis of how estimates of Title IV of the Clean Air Act's costs evolved over time, illustrating the importance of accurately accounting for these issues when estimating the costs of a regulation.

8.3.1 Evaluating Costs Over Time

Most regulations cause permanent changes in production and consumption activities, leading to permanent (ongoing) social costs. As a result, regulations are often phased in gradually over time in an effort to limit any disruptions created

21 Government entities may themselves be polluters and therefore subject to regulation. Compliance costs under this scenario would be captured as such.

by their imposition. When measuring costs over time, assumptions related to the time horizon of the analysis, the use of a static versus a dynamic framework, discounting, and technical change are extremely important. These assumptions are each discussed in more detail in the paragraphs that follow.

8.3.1.1 Time Horizon

Irrespective of the method used for the estimation of social cost, the time horizon for calculating producer and consumer adjustments to a new regulation should be considered carefully. Ideally, the analyst estimates the value of all future costs of a regulation discounted to its present value. If the analyst is only able to estimate a regulation's costs for one or a few representative future years, she must take great care to ensure that the year(s) selected are truly representative, that no important transitional costs are effectively dismissed by assumption, and that no one-time costs are assumed to be on-going.

In the short term, at least some factors of production are fixed. If costs are evaluated over a short period of time, then contractual or technological constraints prevent firms from responding quickly to increased compliance costs by adjusting their input mix or output decisions. In the long term, by contrast, all factors of production are variable. Firms can adjust any of their factors of production in response to changes in costs due to a new regulation. A longer time horizon affords greater opportunities for affected entities to change their production processes (for instance, to innovate). It is important to select a time horizon that captures any flexibility the regulation provides firms in the way they choose to comply.

8.3.1.2 Choosing Between a Static and Dynamic Framework

In many cases, costs are evaluated in a static framework. That is, costs are estimated at a given point in time or for a selection of distinct points in time. Such estimates provide snapshots of costs faced by firms, government, and households but do not allow for behavioral changes from one time period to affect responses in another time period.

In addition to the capital-induced growth effects discussed in Section 8.2.3, the evaluation of costs in a dynamic framework may be important when a proposed regulation is expected to affect product quality, productivity, innovation, and changes in markets indirectly affected by the environmental policy.[22] These may have impacts on net levels of measured consumer and producer surplus over time.

8.3.1.3 Discounting

Social discounting procedures for economic analyses are reviewed in considerable detail in Chapter 6. Benefits and costs that occur over time must be properly and consistently discounted if any comparisons between them are to be legitimate.[23]

There is one application of discounting that is unique to cost analysis. When calculating firms' private costs (e.g., the internal cost of capital used for pollution abatement), the analyst should use a discount rate that reflects the industry's cost of capital, just as a firm would. The social cost of the regulation, on the other hand, would be calculated using the social discount rate, the same discount rate used for the benefits of the regulation.

8.3.1.4 Technical Change and Learning

Estimating the costs of a given environmental regulation frequently entails estimating future technical change. Despite its importance as a determinant of economic welfare, the process of technical change is not well understood. Different approaches to environmental regulation present widely differing incentives for technological innovation. As a result, the same environmental end may be achieved at significantly different costs, depending on the pace and direction of technical change. Recent empirical work supports this hypothesis. Most notably, the realized costs of Title IV of the 1990 Clean Air Act Amendment's SO_2 Allowance Trading program are considerably lower than initial predictions, in part due to unanticipated technical change (see Text Box 8.1).

22 See Section 8.1.3 for a discussion of dynamics.

23 In a CEA, it is equally important to properly discount cost estimates of different regulatory approaches to facilitate valid comparisons.

Text Box 8.1 - The Sulfur Dioxide Cap-and-Trade Program — A Case Study[24]

Under Title IV of the 1990 Clean Air Act Amendments (CAAA), coal fired power plants are required to hold one sulfur dioxide (SO_2) allowance for each ton of SO_2 they emit during the year. Utilities are allowed to buy, sell and bank unused allowances to cover future SO_2 emissions (see Chapter 4 for additional detail). Title IV was subject to intensive ex ante and ex post analysis. The evolution of these analyses illustrates the importance of complete and thorough estimation of social costs and highlights the difference some of the issues discussed above (e.g., discounting or uncertainties) can make to actual cost estimates.

Estimates of Title IV's compliance costs have declined over time, particularly so once the program was launched and researchers were able to observe the behavior of electric utilities. Title IV proved less costly than originally estimated due to behavior responses, indirect effects, technological improvements, market structure, and prices that changed over time. Table 8.1 provides a comparison of some of the program's cost estimates over time. Rows that report ex ante estimates are shaded gray.

Table 8.1 - Estimates of Compliance Costs for the SO_2 Program*

Study	*Annual Costs (Billions)*	*Marginal Costs per ton SO_2*	*Average costs per ton of SO_2*
Carlson et al. (2000)	$1.1	$291	$174
Ellerman et al. (2000)	1.4	350	137
Burtraw et al. (1998)	0.9	n/a	239
Goulder et al. (1997)	1.09	n/a	n/a
White (1997)	n/a	436	n/a
ICF (1995)	2.3	532	252
White et al. (1995)	1.4-2.9	543	286-334
GAO (1994)	2.2-3.3	n/a	230-374
Van Horn Consulting et al. (1993)	2.4-3.3	520	314-405
ICF (1990)	2.3-5.9	579-760	348-499

*Based on Table 2-1, Burtraw and Palmer (2004); n/a — not reported.

Most of the early estimates of Title IV's compliance costs were based on engineering models, which do not fully capture the concepts of consumer and producer surplus. In addition, many of these studies relied on the data and methodologies used to evaluate traditional command-and-control environmental policies, adjusted to estimate the efficiency gains of a permit trading system. Later studies that included more extensive examinations of both the regulatory impacts as well as outside economic pressures on the industry came up with significantly smaller compliance cost estimates for the regulation.

Several developments occurred around the time of Title IV that helped reduce the program's ex post cost estimates. For example, reductions in the price of low-sulfur coal, along with technological improvements that lowered the cost of fuel switching, allowed utilities in the East to reduce compliance costs by using low-sulfur coal from the Powder River Basin in Wyoming (Carlson et al. 2000, and Burtraw and Palmer 2004). Furthermore Popp (2003) concluded that Title IV-induced R&D led to technological innovations that improved the efficiency of scrubbers, thereby leading to lower operating costs.

The varying cost estimates also show the importance of accounting for changing implementation costs and uncertainty over time. The ability of facilities to "bank" SO_2 allowances allowed flexibility in implementation and thus reduced compliance costs. Cost estimates by Carlson et al. (2000) and Ellerman et al. (2000) factor in the discounted savings from banking. According to the latter study, costs savings are a relatively minor source of overall savings, but are important in developing a picture of the program's total effectiveness. This is because firms were able to "avoid the much larger losses associated with meeting fixed targets in an uncertain world" (Ellerman et al. 2000, p. 285).

24 This example is taken from Burtraw and Palmer (2004).

Organizations are able to learn with experience, which permits them to produce a given good or service at lower cost as their cumulative experience increases. While there are many different explanations for this phenomenon (e.g., labor forces learn from mistakes and learn shortcuts; ad hoc processes become standardized) its existence has been borne out by experiences in many sectors. Indeed, OMB now requires cost analyses to consider possible learning effects among the cost-saving innovations.[25] Recent EPA Advisory Council guidance recommends that default learning effects be applied even when sector- or process-specific empirical data are not available (U.S. EPA 2007b).

The decrease in unit cost as the number of units produced increases is referred to as an experience or learning curve. A useful description of the calculations used to identify a learning curve can be found in van der Zwaan and Rabl (2004). Learning rates for 26 energy technologies are described in McDonald and Schrattenholzer (2001). Dutton and Thomas (1984) summarize more than 100 studies, including some dealing with the energy and manufacturing sectors. Note that the empirical estimates in the literature represent a biased sample, since they only represent technology that has been successfully deployed (Sagar and van der Zwaan 2006).[26]

8.3.2 Other Issues in Estimating Social Cost

Difficulties in measuring social cost generally fall into two categories: (1) difficulties in developing a numeric value for some social cost categories; and (2) for social cost categories where numeric values have been successfully developed, accounting for uncertainty in these values.

25 OMB's *Circular A-4* asserts that a cost analysis should incorporate credible changes in technology over time, stating that "...retrospective studies may provide evidence that 'learning' will likely reduce the cost of regulation in future years" (OMB 2003). Other cost-saving innovations to consider include those resulting from a shift to regulatory performance standards and incentive-based policies.

26 Note that cost decreases associated with technological change and learning may not always be free but may have additional costs associated with them such as training costs. See Section 8.2.3.1 for a discussion of transitional costs.

8.3.2.1 Difficulties in Developing Numeric Values

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 populations, and poorly-understood effects on large-scale ecosystems are difficult to capture in a quantitative BCA. Some alternative techniques for measuring and presenting these effects to policy makers are reviewed in Section 7.6.3. The relative significance of social cost categories that are not quantified — or are quantified but not valued — should be described in the social cost analysis.

8.3.2.2 Uncertainty

The values of various costs in the social cost analysis can be estimated, but cannot be known with certainty. In fact, some data and models will likely introduce substantial uncertainties into these estimates. Numerous assumptions are made regarding the baseline, predictions of responses to policy, and the number of affected markets. The conclusions drawn in the social cost analysis are sensitive to the degree of uncertainty regarding these assumptions. The uncertainty associated with the data and methods, the assumptions made, and how the uncertainty and assumptions affect the results are all-important components of the presentation of social cost, and should be carefully reported.

8.3.2.3 Estimating Costs Under Different Statutory Criteria

Some statutes require EPA to choose a regulatory option that is demonstrably affordable. One way for a decision maker to ensure that a regulatory option is affordable is to estimate an upper bound of the compliance cost associated with the chosen option and then to show that it is affordable. However, this approach is inconsistent with the practice of producing the best central estimate of the cost of a regulation for the RIA and will cause the net benefits of the regulation to be biased

Table 8.2 - Major Attributes of Models Used in the Estimation of Costs

	Compliance Cost	Partial Equilibrium	Linear Programming	Input-Output	Input-Output Econometric	CGE
Can be used to measure direct compliance costs	•		•			
Can be used to measure transitional costs	•	•	•	•	•	
Can be used to measure distributional impacts	•	•		•	•	•
Can capture indirect effects				•	•	•
Can capture feedback and interaction effects						•

downward. Furthermore, using solely an upper bound estimate of the cost of a regulation could result in artificially low levels of regulation in situations where EPA must determine whether or not the benefits of the regulation justify the costs. It is thus very important that analysts rely on the best central estimate of the cost of a regulation for the RIA.

8.3.3 Use of Externally-Produced Cost Estimates

At various times EPA depends on externally (e.g., contractor, industry association, or advocacy group) generated cost estimates for use in its internal analyses. Any cost estimate produced by an external source and used by EPA in its internal analysis should be vetted by EPA to ensure that: (1) the information is relevant for its intended use; (2) the scientific and technical procedures, measures, methods and/or models employed to generate the information are reasonable for, and consistent with, the intended application; and (3) the data, assumptions, methods, quality assurance, sponsoring organizations, and analyses employed to generate the information are well documented.

8.4 Models Used in Estimating the Costs of Environmental Regulation

A number of different types of models have been used in the estimation the costs of environmental regulation. They range from models that estimate costs in a single industry (or part of an industry), to models that estimate costs for the entire economy. In practice, implementation of some of the models can be simple enough to be calculated in a spreadsheet. Others may be complex systems of thousands of equations that require highly specialized software.[27]

Table 8.2 summarizes some of the major attributes of the models discussed in this section. Each has strengths and weaknesses in analyzing different types of economic costs. When estimating social cost, there will be some cases where a single model is enough to provide a reasonable approximation. In other cases the use of more than one model is required. For example, a compliance cost model can be used to estimate the direct costs of a regulation in the affected sector. These direct cost estimates could then be used in a partial equilibrium model to estimate social cost. While most of the models discussed in this section can be used in some form in the estimation of social cost, many of them also have particular strengths in the estimation of transitional and/or distributional costs, as may be required as part of an RIA.

Selecting the most appropriate model (or models) to use in an analysis can be difficult. Below are a number of factors that may be helpful in making a choice.[28]

27 Data requirements for these models vary. Refer to Chapter 9 for a discussion of the process of conducting an industry profile and details on a range of public and private data sources that can be used for cost estimation.

28 This list of factors is derived from Industrial Economics, Inc. (2005). Proprietary models discussed in this section are examples only and no endorsement by EPA is given or implied.

- **Types of impacts being investigated.** Model selection should take into account the types of impacts that are important in the analysis being performed because models differ in their abilities to estimate different types of costs.
- **Geographic scope of expected impacts.** While some models may be well suited for the analysis of impacts on a national scale, it may not be possible to narrow their resolution to focus on regional or local impacts. Similarly, models that are well suited for examining regional or local impacts may not capture the full range of impacts at the national level.
- **Sectoral scope of expected impacts.** Some models are highly aggregated, and while proficient at capturing major impacts and interactions between sectors, are not well suited for focusing on a single or small number of specialized sectors. Likewise, models that are highly specialized for capturing impacts in a particular sector will usually be inappropriate for examining impacts on a broader set of sectors.
- **Expected magnitude of impacts.** A model that is well suited for capturing the impacts of a regulation that is expected to have large effects may have difficulty estimating the impacts of a regulation with relatively smaller expected effects, and vice versa.
- **Expected importance of indirect effects.** For a regulation that is expected to have substantial indirect effects beyond the regulated sector it is important to choose a model that can capture those effects.

Usually, some combination of the above factors will determine the most appropriate model for a particular application. Finally, it should be noted that advances in computing power, data availability, and more user-friendly software packages continually reduce the barriers to sophisticated model-based analysis.

8.4.1 Compliance Cost Models

Compliance cost models are used to estimate an industry's direct costs of compliance with a regulation. Estimates by engineers and other experts are used to produce algorithms that characterize the changes in costs resulting from the adoption of various compliance options. The particular parameters are usually determined for a number of individual plants with varying baseline characteristics. To estimate the control costs of a regulation for an entire industry, disaggregated data that reflects the industry's heterogeneity is input into the model. The disaggregated cost estimates are then aggregated to the industry level.

Compliance cost models may include capital costs, operating and maintenance expenditures, and costs of administration. Some compliance cost models are designed to allow the integrated estimation of control costs for multiple pollutants and multiple regulations. Some models are able to account for cost changes over time, including technical change and learning. Compliance cost models often are implemented in a spreadsheet; in general, they are relatively easy to modify and interpret.

While precise estimates of compliance costs are an important component of any analysis, it is only in cases where the regulation is not expected to significantly impact the behavior of producers and consumers that compliance costs can be considered a reasonable approximation of social cost. As discussed in Section 8.2.1, estimating social cost often requires knowledge of both supply and demand conditions. Compliance cost models focus on the supply side, and in circumstances where producer and consumer behavior is appreciably affected, these models are not able to provide estimates of changes in industry prices and output resulting from the imposition of a regulation. However, in these cases, estimates from compliance cost models can be used as inputs to other models that estimate social cost.

One example of a compliance cost model or tool is AirControlNET (ACN). ACN is a database tool for conducting pollutant emissions control strategy and costing analysis. It overlays a detailed control measure database of EPA emissions inventories to compute source- and pollutant-specific emission reductions and associated costs at various geographic levels (national, regional, local) and for many industries.

ACN contains a database of control measures and cost information that can be used to assess the impact of strategies to reduce criteria pollutants [e.g., NO_X, SO_2, volatile organic compounds (VOCs), PM_{10}, $PM_{2.5}$, or Ammonia (NH_3)] as well as carbon monoxide (CO) and mercury (Hg) from point (utility and non-utility), area, nonroad, and mobile sources as provided in EPA's National Emission Inventory (NEI). ACN is strictly a compliance cost model, because it does not account for changes in the behavior of consumers and producers.

Advantages:

- Compliance cost models often contain significant industry detail and provide relatively precise estimates of the direct costs of a regulation. This is particularly true for regulations with minor cost impacts.
- Once constructed, compliance cost models require a minimum of resources to implement and are relatively straightforward to use and easy to interpret.

Limitations:

- As they are focused exclusively on the supply side, compliance cost models can only provide estimates of social cost in certain limited cases.
- Compliance cost models are usually limited to estimating costs for a single industry.

8.4.2 Partial Equilibrium Models

While compliance cost models may provide reasonable estimates of the compliance costs of a regulation, they do not incorporate the likely behavioral responses of producers and consumers. As shown in Section 8.2.1, if these responses are not taken into account, estimates of social cost are likely to be inaccurate. In cases where the effects of a regulation are confined to a single market, partial equilibrium models, which incorporate the behavioral responses of producers and consumers, can be used to estimate social cost.

Inputs into an analysis employing a partial equilibrium model may include regulatory costs estimated using a compliance cost model and the supply and demand elasticities for the affected market. The model then can be used to estimate the change in market price and output. Changes in producer and consumer surplus reflect the social cost of the regulation. The relative changes between producer and consumer surplus provide an estimate of the distribution of regulatory costs between producers and consumers.

In a partial equilibrium model, the magnitude of the impacts of a regulation on the price and quantity in the affected market depends on the shapes of the supply and demand curves. The shapes of these curves reflect the underlying elasticities of supply and demand. These elasticities can be either estimated from industry and consumer data or taken from previous studies.[29]

If the elasticities used in an analysis are drawn from previous studies, they should be consistent with the following conditions:

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

In some cases, if the effects of a regulation are expected to spill over into adjoining markets (e.g., suppliers of major inputs or consumers of major outputs), partial equilibrium analysis can be extended into these additional markets as well. These "multi-market models" have been used in the analysis of a number of EPA regulations.[30]

29 Because of the widespread use of elasticity estimates, the Air Benefit and Cost (ABC) Group in EPA's Office of Air and Radiation maintains an elasticity database. This Elasticity Databank serves as a searchable database of elasticity parameters across economic sectors/product markets and a variety of types including demand and supply elasticities, substitution elasticities, income elasticities, and trade elasticities. An online submittal form allows users to provide elasticity estimates for consideration as part of this databank. The Elasticity Databank is available online at http://www.epa.gov/ttn/ecas/Elasticity.htm (U.S. EPA 2007d).

30 See, for example, U.S. EPA (1989) *Regulatory Impact Analysis of Controls on Asbestos and Asbestos Products: Final Report.*

Advantages:

- Because they usually simulate only a single market, partial equilibrium models generally have fairly limited data requirements and are relatively simple to construct.
- Partial equilibrium models are comparatively easy to use and interpret.

Limitations:

- Partial equilibrium models are limited to cost estimation in a single or small number of markets and do not capture indirect or feedback effects.
- Because partial equilibrium models are generally data driven and specific to a particular application, they are usually not available "off-the-shelf" for use in a variety of analyses.

8.4.3 Linear Programming Models

Although linear programming models can be employed in a variety of applications, their use in the analysis of EPA regulations occurs most frequently in the estimation of compliance costs.[31] Linear programming models minimize (or maximize) an objective function by choosing a set of decision variables, subject to a set of constraints. In EPA's regulatory context, the objective function is usually direct compliance costs, which are minimized. The decision variables represent the choices available to the regulated entities. The constraints may include available technologies, productive capacities, fuel supplies, and regulations on emissions.

Although linear programming models can be constructed to examine multiple sectors or economy-wide effects, they are more commonly focused on a single sector. For the regulated sector, a linear programming model can incorporate a large number of technologies and compliance options, such as end-of-pipe controls, fuel switching, and changes in plant operations. Similarly, the model's constraints can include multiple regulations that require simultaneous compliance. The objective function usually includes the fixed and variable costs of each compliance option. The program then chooses a set of decision variables that minimize the total costs of compliance. In addition to compliance costs, the outputs from the model may include other related variables, such as projected fuel use, output and input prices, emissions, and demand for new capacity in the regulated industry.

An example of a linear programming model used by EPA is the Integrated Planning Model (IPM). The IPM is a model of the electric power sector in the 48 contiguous states and the District of Columbia. It can provide long-term (10-20 year) estimates of the control costs of complying with proposed regulations, while meeting the projected demand for electricity. In the model, nearly 13,000 existing and planned electrical generating units are mapped to approximately 1,700 representative plants. Results are differentiated into 40 distinct demand and supply regions. IPM can be used to estimate the impacts on costs for policies to limit emissions of SO_2, NO_x, CO_2, and Hg.

Advantages:

- Compared to compliance cost models, linear programming models are better able to incorporate and systematically analyze a wide range of technologies and multiple compliance options.
- Linear programming models allow for a considerable amount of flexibility in the specification of constraints. This permits an existing model to be used in a range of applications.

Limitations:

- Linear programming models normally do not estimate costs beyond a single sector and are thus unable to estimate indirect or distributional costs.

31 An introduction to linear programming is provided in Chiang (1984). The "linear" in the name refers to the linear specification of the objective function and constraint equations. Similar, eponymous model types include non-linear, integer, and mixed integer programming models.

Table 8.3 - Input-Output Table for the United States, 1999 (bil. $)

	1 Agriculture	2 Manufacturing	3 Services	**Total Intermediate Outputs**	Final Demand	**Total Outputs**
1 Agriculture	70	150	30	**250**	30	**280**
2 Manufacturing	50	1,930	840	**2,820**	2,470	**5,290**
3 Services	60	1,070	2,810	**3,940**	6,780	**10,720**
Total Intermediate Inputs	**180**	**3,150**	**3,680**	**7,010**	**9,280**	**16,290**
Value Added	100	2,140	7,040	**9,280**		
Total Inputs	**280**	**5,290**	**10,720**	**16,290**		

Source: Adapted from Bureau of Economic Analysis (BEA) 10-sector table.

- A linear programming model designed for estimating sectoral compliance costs will likely be quite complex and have heavy input requirements. If an existing model is not available, the time and effort to construct one may be prohibitive.
- Linear programming models minimize aggregate control costs for the entire industry simultaneously, whereas the regulated entities actually do so individually. This may result in an underestimation of total compliance costs.

8.4.4 Input-Output Models

While input-output models have been used in many environmental applications, their primary use in a regulatory context is for estimating the distributional and short-term transitional impacts that may result from the implementation of a policy. For example, an input-output model could be used to estimate the regional economic effects of a regulation that would ban a particular pesticide. In this case, an input-output model could provide estimates of the effects on output and employment in the affected region. A key feature of input-output models is their ability to capture both the effects on sectors directly affected by a regulation and the indirect effects that occur through spillovers onto other sectors.[32]

An input-output model is based on an input-output table. The input-output table assembles data in a tabular format that describes the interrelated flows of goods and factors of production over the course of a year. An input-output table may consist of hundreds of sectors or may be aggregated into as few as two or three sectors. Table 8.3 is an example of a highly aggregated input-output table for the United States for the year 1999. The columns for the individual sectors denote how much of each commodity is used in the production of that sector's output. These intermediate inputs are combined with factors of production — labor, capital, and land — whose payments as wages, profits, and rents, compose sectoral value added. For the agricultural sector, total inputs consist of $70 billion of agricultural inputs, $50 billion of manufactured inputs, $60 billion of service inputs, and $100 billion of value added, for a total of $280 billion in inputs. The row for each sector shows how that sector's output is consumed. In the case of the agricultural sector, $250 billion is consumed as intermediate inputs, while the remainder, $30 billion, is consumed as final demand, which is composed of household consumption, government purchases, and investment.

An input-output table can be turned into a simple linear model through a series of matrix operations. The model relates changes in final demand to changes in the total amount of goods and services, including intermediate inputs, required to meet that demand. The model can also relate the change in final demand to changes in employment of factors of production, such as the demand for labor. In the case of the banned pesticide, if a separate analysis determines that there will be a

32 Miller and Blair (1985) is a standard reference on input-output analysis.

decline in the output of cotton, the input-output model could be used to determine the effect on those sectors that supply inputs to the cotton sector, as well as on industries that are users of cotton, such as the producers of textiles and clothing. Declines in the output of these industries will have further effects on the demand for other intermediate inputs, like electricity, which are also estimated by the model.

Input-output models are relatively simple to use and interpret and are often the most accessible tool for analyzing the short-term impacts of a regulation on regional output and income.[33] However, they embody a number of assumptions that make them inappropriate for long-term analysis or the analysis of social cost. Although their specifications can sometimes be partially relaxed, input-output models embody the assumptions of fixed prices and technology, which do not allow for the substitution that normally occurs when goods become more or less scarce. Similarly, input-output models are demand driven and not constrained by limits on supply, which would normally be transmitted through increases in prices. While the rigidities in the models may be reasonable assumptions in the short run or for regional analysis, they limit the applicability of input-output models for long-run or national issues. Because input-output models do not include flexible supply-demand relationships or the ability to estimate changes in producer and consumer surpluses, they are not appropriate for estimating social cost.

Advantages:

- Particularly in a regional context, input-output models are often well suited for estimating distributional and short-term transitional impacts.
- Input-output models are relatively transparent and easy to interpret.
- Some input-output models have a great deal of sectoral and regional disaggregation and can be readily applied to issues that require a high degree of resolution.

Limitations:

- Input-output models are not appropriate for estimating social cost.
- Because of their lack of endogenous substitution possibilities in production, input-output models are not appropriate for dealing with long-run issues.
- Because of their fixed prices and lack of realistic behavioral reactions by producers and consumers, input-output models are not well suited for dealing with issues that are likely to have large effects on prices.

8.4.5 Input-Output Econometric Models

Input-output econometric models are economy-wide models that integrate the structural detail of conventional input-output models with the forecasting properties of econometrically estimated macroeconomic models. Input-output econometric models are often constructed with a considerable amount of regional detail, including the disaggregation of regional economies at the state and county level. At EPA, input-output econometric models, like conventional input-output models, are often used to examine the regional impacts of policies and regulations. However, unlike conventional input-output models, input-output econometric models are also able to estimate long-run impacts.

When used for policy simulations, a major limitation of conventional input-output models is that the policy under consideration must be translated into changes in final demand. Furthermore, because they do not include resource constraints, the resulting solution may not be consistent with the actual supply-demand conditions in the economy. Input-output econometric models, in contrast, are driven by econometrically estimated macroeconomic

33 An off-the-shelf input-output model often used in the analysis of the impacts of environmental regulation is Impact Analysis for Planning (IMPLAN). IMPLAN is based on data for the United States that covers more than 500 sectors and can be disaggregated down to the county level.

relationships that more accurately account for these conditions. However, unlike standard macro-econometric models, input-output econometric models integrate input-output data and structure into the specification of production. This allows them to estimate changes in the demand for and the production of intermediate goods. The macroeconomic component enables the models to be used for long-run forecasting, including accounting for business cycles and involuntary unemployment. This makes input-output econometric models particularly useful for estimating transitional costs arising from the implementation of a regulation.

An example of an input-output econometric model that has been used for policy analysis at EPA is the Regional Economic Models, Inc. (REMI) Policy Insight. The standard REMI model includes 70 production sectors and 25 final demand sectors and can provide output on changes in income and consumption for more than 800 separate demographic groups. The model is both national in scope and can be specially tailored to individual regions. The REMI model has been applied to a wide range of regional environmental policy issues, including extensive analysis of air quality regulation in the greater Los Angeles area.

Advantages:

- Input-output econometric models can be used to estimate both long- and short-run transitional costs.
- Input-output econometric models can be used to estimate distributional costs.

Limitations:

- Because input-output econometric models combine elements of both macro and micro theory, it may not be easy to disentangle the mechanisms actually driving model results.
- Compared to standard input-output models, input-output econometric models may not have the sectoral resolution necessary to analyze the impact of a policy expected to have limited impacts.

8.4.6 Computable General Equilibrium Models

CGE models have been used in a number of applications in the analysis of environmental regulation. Examples include estimation of the costs of the Clean Air Act (CAA), the impacts of domestic and international policies for GHG abatement, and the potential for market-based mechanisms to reduce the costs of regulation.

CGE models simulate the workings of the price system in a market economy. Markets exist for commodities and can also be specified for the factors of production: labor, capital, and land. In each market, a price adjusts to equilibrate supply and demand. A CGE model may contain several hundred sectors or only a few, and may include a single "representative" consumer or multiple household types. It may focus on a single economy with a simple representation of foreign trade, or contain multiple countries and regions linked through an elaborate specification of global trade and investment. The behavioral equations that govern the model allow producers to substitute among inputs and consumers to substitute among final goods as the prices of commodities and factors shift. The behavioral parameters can be econometrically estimated, calibrated, or drawn from the literature. In some models, agents may be able to make intertemporal trade-offs in their consumption and investment choices.

Simulating the effects of a policy change involves "shocking" the model, by, for example, introducing a regulation, such as a tax on emissions. Prices in affected markets will then move up or down until a new equilibrium is established. Prices and quantities in this new equilibrium can be compared to those in the initial equilibrium. A static CGE model will be able to describe changes in economic welfare measures due to a reallocation of resources across economic sectors following a policy shock. In a policy simulation using a dynamic CGE model, a time path of new prices and quantities is generated. This time path can be compared to a baseline path of prices and quantities that is estimated by running the model without the policy shock. As some policies can be expected to have impacts over a

Text Box 8.2 - The Pollution Abatement Costs and Expenditures Survey

The Pollution Abatement Costs and Expenditures (PACE) survey is the primary source of information on pollution abatement-related operating costs and capital expenditures for the U.S. manufacturing sector (U.S. Bureau of the Census, various years). The PACE survey collects data on costs of pollution treatment (i.e., end-of-pipe controls), pollution prevention (i.e., production process enhancements to prevent pollution from being produced), disposal, and recycling. The survey is sent to approximately 20,000 establishments (who are required by law to respond to it) and was conducted annually by the U.S. Census Bureau from 1973 to 1994 (except in 1987) and then again in 1999.

EPA funded the 1999 PACE survey. However, this survey was substantially different from its predecessors, making direct longitudinal analysis difficult (see Becker and Shadbegian 2005 for a comprehensive description of the conceptual differences between the 1994 and 1999 PACE surveys). More recently, with the guidance and financial support of EPA, a completely revised version of the PACE survey was administered by the Census Bureau to collect 2005 data. The 2005 PACE survey was the result of a multi-year effort to evaluate the quality of the survey instrument and the accuracy and reliability of the responses to the survey. The 2005 PACE data, which was released in April 2008, is longitudinally consistent with previous PACE surveys, with the exception of the 1999 iteration. EPA has no current plan to collect PACE data beyond 2005, but hopes to reinstate the survey in the future to once again collect data on an annual basis. The annual collection of pollution abatement costs would provide EPA with information required for its RIAs, and would better enable researchers to answer questions of interest, particularly those that require longitudinal data.

The PACE survey contains operating costs and capital expenditures disaggregated by media: air, water, and solid waste; and by abatement activity: pollution treatment, recycling, disposal, and pollution prevention. Total operating costs are further disaggregated into: salary and wages, energy costs, materials and supplies, contract work, and depreciation.

The PACE survey data, both aggregate and establishment-level, have been used to analyze a wide range of policy questions. These include assessing the impact of pollution abatement expenditures on productivity growth, investment, labor demand, environmental performance, plant location decisions, and international competitiveness.

longer time horizon, dynamic models are used to capture, in addition to static impacts, the welfare consequences of reallocating resources over time, such as the impact that changes in savings may have on capital accumulation. Forward-looking models can also capture the effects that future policies may have on current decisions.

An example of the use of a CGE model at EPA is the retrospective BCA of the CAA, which used a dynamic CGE model to compute the costs of CAA compliance over the period 1970 to 1990 (U.S. EPA 1997a). Estimates of pollution abatement expenditures for the U.S. manufacturing sector were first calculated using Pollution Abatement Costs and Expenditures (PACE) survey data (see Text Box 8.2). As the analysis was retrospective, the relevant policy simulations involved *removing* the long-term capital and operating costs from the industries that incurred them. The retrospective BCA compared the simulated path of the economy without these abatement expenditures and the actual path of the economy, which included them. EPA computed changes in both long-run GDP and equivalent variation, as well as impacts on investment, household consumption, and sectoral prices, output, and employment.

CGE models have also been used extensively in estimating the costs of GHG mitigation. Here, the analyses have been prospective, such as efforts to estimate the costs of complying with the Kyoto Protocol and more recently, proposed climate change legislation. Some studies have focused on the control of CO_2 emissions by introducing carbon taxes or emissions trading. Other studies have expanded the analysis by examining other GHGs and incorporating the effects of changes in land use patterns and carbon sinks. Of particular concern has been the problem of "leakage," in which a fall in emissions in participating countries is offset by an increase in emissions in non-participating countries, induced by the fall in demand, and thus the world price, of energy inputs.

CGE models can be useful tools for examining the medium- to long-term impacts of policies that are expected to have relatively large, economy-wide effects. A growing use of these models has been to quantify previously unrecognized welfare costs that can occur when environmental policies interact with pre-existing distortions in the economy. An expanding body of work has begun to include non-market goods into CGE models (Smith et al. 2004, and Carbone and Smith 2008).

Given the large number of parameters in a typical CGE model, analysts should take great care in ensuring the accuracy of a model's data and specifications. Sensitivity analysis should be performed on critical parameters. One strategy, currently used in EPA's analyses of climate legislation, is to use two CGE models concurrently to analyze the same policy scenarios.

Advantages:

- CGE models are best suited for estimating the cost of policies that will have large economy-wide impacts, especially when indirect and interaction effects are expected to be significant.
- CGE models are generally most appropriate for analyzing the medium- or long-term effects of policies or regulations.
- With the appropriate specifications incorporated, CGE models can be used to estimate the distributional impacts of policy shocks on household groups or industrial sectors.

Limitations:

- Because of their equilibrium assumptions, CGE models are generally not appropriate for analyzing short-run transitional costs. However, when appropriate specifications are included in a model, they may be used in this type of analysis.
- CGE models are generally not well suited for estimating the effects of policies that will affect only small sectors or will impact a limited geographic area. Although the costs have been reduced in recent years, the effort and data required to construct a new CGE model or revise an existing one may be prohibitive for some analyses.