Chapter 8 - Analyzing Costs

As discussed in Chapter 1, the distinction between what is labeled a benefit or a cost in regulatory analysis is, to some extent, arbitrary so long as the analysis is internally consistent. The compliance cost of a regulatory action might be considered a benefit of a deregulatory action, and vice versa. Likewise, reduced fuel expenditures that accrue to a firm or consumer due to regulation have been described as both negative costs and positive private benefits. On which side of the ledger specific categories fall is somewhat immaterial. What is important is that analysts make every effort to account for all costs and benefits to illuminate key differences across the options under consideration with regards to *net* benefits. As noted above, these *Guidelines* are framed from the perspective of a policy that improves environmental quality, but at a cost. This chapter discusses methods and modeling approaches for estimating a regulation's costs, which are typically reflected in market outcomes, for use in benefit-cost analysis (BCA). For a discussion of methods and modeling approaches for estimating a regulation's benefits, see Chapter 7.

Estimating the costs of regulation involves a series of decisions. The analyst must determine the scope of the analysis to appropriately capture the range of anticipated effects from the policy.[1] Analysts must determine the types of costs that are likely to occur within a specific regulatory context and choose the most defensible way to measure them based on the best available data and methods. Both the scope of the analysis and how costs are measured will affect the choice of economic model.[2] Models vary in their ability to capture certain costs; whether they are static or dynamic; their level of geographic and sectoral detail; and their scope; among others. After selecting one or more economic models, analysts face a series of implementation decisions, such as how to best parameterize the model and how to account for uncertainty.

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1 Several executive and legislative mandates require that different aspects of costs be considered in a regulatory analysis. For instance, Executive Order (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)." The Unfunded Mandates Reform Act (UMRA) of 1995 requires that cost estimates account for indirect and implicit costs on state and local governments. Many of these "costs" are categorized as economic impacts and therefore discussed in Chapter 9.

2 A model is a "simplification of reality that is constructed to gain insights into select attributes of a particular physical, biologic, economic, or social system" (National Research Council (NRC) 2009) and the simplifications necessary to tractably model complex systems will introduce uncertainty.

8.1 The Economics of Social Cost

While estimating the costs of regulation is often portrayed as relatively straightforward — particularly compared to estimating benefits — it must be guided by economic theory. As such, the appropriate measure of cost to use in a BCA is social cost. **Social cost** represents the total burden that a regulation will impose on society, defined as the sum of all opportunity costs incurred as a result of the regulation. These opportunity costs consist of the value to society of the goods and services no longer produced and consumed as resources are reallocated away from other activities towards activities such as pollution abatement. To be complete, an estimate of social cost should include the opportunity costs of current and future consumption and leisure that will be forgone as a result of the regulation (e.g., effects in the future could occur because of effects on capital investment).[3] For example, errors can easily occur if the analyst confuses transfers with costs or ignores pre-existing regulation or taxes in the affected market.

The social cost of a regulation is generally not the same as its effects on gross domestic product (GDP) or other broad measures of economic activity.[4] See Section 8.2.2.1 for more discussion. Likewise, social cost is distinct from but includes the cost of compliance borne by the regulated entity. The **compliance cost** is the private cost that a regulated entity incurs to reduce or prevent pollution to comply with an environmental regulation — for instance, through the installation and operation of pollution abatement equipment.

To estimate social cost, analysts may use one or some combination of compliance cost, partial equilibrium and/or general equilibrium approaches. A compliance cost approach assesses the costs of abatement and other actions taken to comply (e.g., monitoring, testing, reporting and recordkeeping requirements) for the directly regulated sector(s).[5] A partial equilibrium approach models the supply and demand responses of the regulated sector(s) to these compliance costs and may be extended to consider a small number of related sectors (e.g., markets that supply intermediate goods to the regulated sector(s), markets for substitute or complementary products, or markets that supply abatement equipment or other services to comply with requirements). When broader economy-wide impacts are expected due to a regulation, a compliance cost or partial equilibrium approach will miss these impacts. In this case, a general equilibrium approach is needed to more fully estimate social cost. Regardless of the approach taken, it is expected that analysts will need to estimate compliance costs associated with abatement requirements, as they are a necessary input for generating estimates that rely on a partial or general equilibrium approach. Models that utilize each of these three approaches to estimate social cost are discussed in Section 8.3.

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3 For a more detailed treatment of the material in this section, see Pizer and Kopp (2005).

4 GDP is defined as the sum of the value (price times quantity) of all market goods and services produced in the economy and is equal to either Consumption (C) + Investment (I) + Government (G) + (Exports (X) – Imports (M)), or Labor (L) + Capital (K) + Taxes (T).

5 The term direct cost is sometimes used to refer to the costs incurred by regulated entities to comply with the regulation. The term indirect cost is sometimes used to refer to costs incurred in related markets or experienced by consumers or government not subject to the regulation, often transmitted through changes in the prices of goods or services produced by the regulated sector.

8.1.1 Compliance Cost Approach

A compliance cost approach estimates the direct compliance expenditures incurred by regulated entities (e.g., individual emitting units or facilities) when installing and operating abatement technologies or processes to comply with a regulation, conditional on a given level of output. It does not attempt to estimate welfare impacts associated with a change in the amount of production or use of inputs but generally assumes that regulated sources are cost-minimizing in their compliance behavior. Its primary advantage is the ability to generate highly detailed and, when data are available, relatively specific information on compliance options and their associated costs that reflect the heterogeneity of regulated entities. This detailed information can be very useful, as many stakeholders are keenly interested in understanding the anticipated cost of meeting regulatory requirements. Furthermore, reporting detailed assessments of how regulated entities are expected to respond to a regulation can generate useful public comments that further the U.S. Environmental Protection Agency's (EPA's) understanding of available compliance options and their costs.

A compliance cost approach typically does not account for other producer or consumer behavioral changes that may result from a new regulation.[6] However, it can still provide a reasonable estimate of social cost when changes in a regulated sector's outputs and input mix (aside from direct compliance activities) are expected to be minimal. However, when significant changes on the producer or consumer side are expected to occur or profit maximizing firm behavior differs from cost minimizing behavior due to market imperfections, a compliance cost approach may substantially misestimate the social cost of a regulation.[7] Likewise, a compliance cost approach does not capture supply side responses, such as changes in the composition of goods produced by the industry or changes in product quality, and the associated changes in consumer and producer welfare that result. A key question for analysts is whether it is worth expending additional resources to expand beyond a compliance cost approach to capture other potentially substantial costs within the sector itself, related sectors or in the overall economy.

8.1.2 Partial Equilibrium Approach

In contrast to a compliance cost approach, a partial equilibrium approach to cost estimation accounts for market changes in the regulated sector. Market responses to the regulation may include reduced industry output or higher prices as firms pass on some costs directly to consumers. The goal of a partial equilibrium approach is to measure the net change in consumer and producer surplus relative to the pre-regulatory equilibrium.[8]

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6 A compliance cost approach does not imply that the costs are ultimately borne by producers. Rather, these costs may be passed through to consumers (see Chapter 9). The key assumption with a compliance cost approach is that there are no significant changes in markets except for the compliance activity.

7 The degree to which a demand response influences social cost depends on a variety of factors, such as the magnitude of the price change, the price elasticity of demand for output of the regulated sector and the degree of competition in the market. An elasticity is a measure of how responsive a firm or consumer is to a change in price. In the case of demand, it is the percentage change in the quantity of the product that is demanded by consumers divided by the percentage change in the product's price. See Appendix A for more discussion of elasticities.

8 Consumer surplus is the sum of consumers' net benefits — i.e., what they are willing to spend on a good or service over and above market price. Thus, it is the area under the market demand (marginal benefit) curve but

In theory, in the absence of market distortions (e.g., pre-existing taxes), the social cost of a regulation can be assessed with a partial equilibrium approach of the regulated market (Just et al. 2005; Harberger 1964).[9] While a policy may have effects in many other markets, market clearing conditions effectively cancel out these effects with regard to aggregate welfare (Farrow and Rose 2018).[10] Thus, a partial equilibrium approach is sufficient for estimating social cost when the analyst expects that a regulation will result in appreciable changes in market activities, but the effects will be confined primarily to a single market or a small number of markets. The use of a partial equilibrium approach assumes that the effects of the regulation in all other markets, outside of those being modeled, will be minimal. See Appendix A.4.3 for more detailed discussion.

Figures 8.1 and 8.2 illustrate how social cost can be defined in partial equilibrium. Figure 8.1 shows a competitive market before the imposition of an environmental regulation. The shaded area below the demand curve and above the equilibrium price line is consumer surplus. The area above the supply curve and below the price line is producer surplus.[11] The sum of these two areas defines the total welfare generated in this market (i.e., the net benefits to society from producing and consuming the good or service represented in this market). For simplicity, total welfare as depicted ignores the negative pollution externality arising in this market, which the regulation is designed to correct.[12]

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. 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 from P_0 to P_1 and to decrease the equilibrium output from Q_0 to Q_1, holding all else constant. As seen by comparing

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above market price. Producer surplus is producers' revenues minus the variable cost of production. Thus, it is the area above the market supply (marginal cost) curve but below market price. See Appendix A.

9 As defined in Chapter 5, market distortions are factors such as pre-existing taxes, externalities, trade barriers, federal, state or local regulations or imperfectly competitive markets that move consumers or firms away from the economically efficient outcome. These factors should be accounted for in the baseline and analyzed when they interact with the policy under consideration.

10 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 to consider in inefficient related markets (Boardman et al. 2011). It is also likely that most regulations will result in winners and losers. Economic impact analysis evaluates how different groups are impacted by a regulation. See Chapter 9.

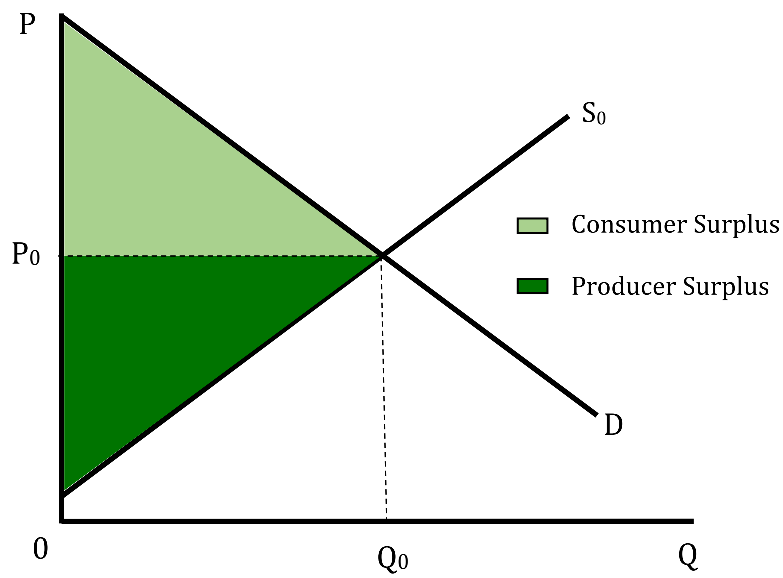
11 Producer surplus may be interpreted as the profits plus the fixed cost of producers. Profits equal total revenues, price multiplied by quantity of total output, minus the total costs that vary with the level of production (i.e., variable costs). These costs equal the area under the supply curve and exclude costs that do not vary with production (i.e., fixed costs). Over time, the share of costs attributable to investments that are fixed declines and the supply curve becomes more elastic. See Section 8.2.3.2.

12 Appendix A presents a graphical representation of how to account for this externality. Reduction of the 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.

Figures 8.1 and 8.2, the overall effect on welfare is a decline in both producer and consumer surplus.[13]

In the long run (i.e., when all costs are variable), compliance costs in this market equal the area between the old and new supply curves, bounded by the new equilibrium output, Q_1.[14] 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 cost estimate is based on the original level of output, Q_0), realized compliance costs will be misestimated. Extending the vertical dotted line in Figure 8.2 from the original equilibrium quantity to the new supply curve (S_1) and estimating costs assuming this quantity illustrates this point. A second insight is that realized compliance costs are only part of the total social costs of a regulation. The black triangle shown in Figure 8.2 is an additional, real cost arising from the regulation. It reflects the forgone net benefit (or opportunity cost) from the reduction in output.

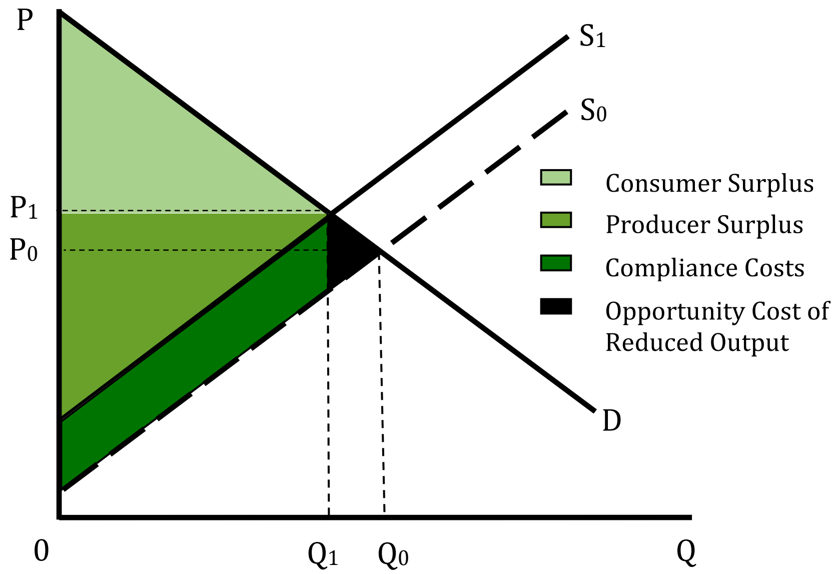
Figure 8.1 - Competitive Market Before Regulation



13 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 determine the magnitude of the price and quantity changes induced by the cost increase as well as the distribution of costs.

14 In the long run, costs are variable and are fully represented in the movement of the supply curve. In the short or medium run, fixed costs may not affect the supply curve although they could contribute to compliance costs. See Tietenberg (2002).

Figure 8.2 - Competitive Market After Regulation



Under the assumption that impacts outside this market are not significant, the social cost of the regulation is equal to the sum of the compliance cost and the opportunity cost of reducing output shown in Figure 8.2. It is exactly equal to the reduction in producer and consumer surplus from the pre-regulation equilibrium shown in Figure 8.1.

When the effects of a regulation are expected to impact a limited number of markets beyond the regulated sector, it still may be sufficient to use a partial equilibrium approach to estimate social cost. A multi-market approach extends a single-market, partial equilibrium representation of the directly regulated sector to include closely related markets. These may include the upstream suppliers of major inputs to the regulated sector (including pollution abatement equipment or services), 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.[15]

The preceding discussion describes the use of a partial equilibrium approach when the regulated market is perfectly competitive and both producers and consumers are price takers (i.e., their behavior does not meaningfully affect prices). In many cases, however, some form of imperfect competition (e.g., market power) may better characterize the regulated market or closely related markets. Firms in imperfectly competitive markets will adjust differently to the imposition of a new

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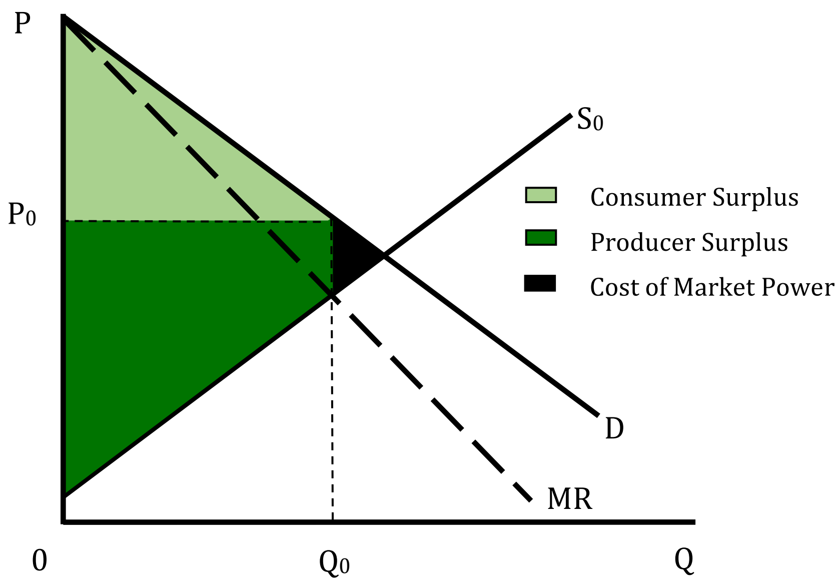
15 Just et al. (2005) detail methods for evaluating partial equilibrium welfare changes across multiple related markets (see also Bullock 1993). Estimating welfare is only possible when the relevant relationships among the sectors (e.g., cross-price elasticities) are correctly specified. Pizer and Kopp (2005) and Kokoski and Smith (1987) provide additional discussion of when these methods are suitable for estimating social cost.

regulation, which can alter the estimate of social cost.[16] If the regulated markets or closely related markets are imperfectly competitive, this may significantly influence compliance behavior and costs, in which case the market structure should be reflected in the analysis.[17]

Figures 8.3 and 8.4 demonstrate how imperfect competition can result in additional social costs. Figure 8.3 begins with the case of a monopolistic firm. Unlike the case of perfect competition, the price of the good is not set equal to its marginal cost.[18] Firms with market power can instead set price equal to their marginal revenue to maximize profit.[19] However, this results in less of the good being produced (shown as Q_0) than is socially optimal (i.e., what would occur under perfect competition), Q_0^*. The welfare loss from the lower-than-optimal level of production is the black triangle.

Figure 8.3 - Monopoly Market Before Regulation



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16 For further discussion of the welfare effects of environmental regulation in the context of imperfectly competitive markets, see Chapter 6 of Baumol and Oates (1988), Requate (2006), and Chapter 6 of Phaneuf and Requate (2017). See Ryan (2012), Ferris et al. (2014), and Wolverton, et al. (2019) for examples where accounting for the way market structure affected firm decision-making would have potentially led to a different estimate of a regulation's costs. Kellogg and Reguant (2021) provide additional examples in the energy sector.

17 Section 8.2.3.6 describes how environmental regulations may create conditions that lead to imperfectly competitive markets.

18 For expositional purposes we continue to label the marginal cost curve as the supply curve. However, in the case of a monopoly, this curve no longer identifies the amount that will be produced at a given market price (Mankiw 1998). However, as in the case of perfect competition, it still identifies the amount that will be produced given the marginal revenue received.

19 To maximize its profit, the monopolist produces Q0 units such that the additional revenue it receives from selling one more unit of the good (its marginal revenue) equals the additional cost of producing that unit of the good (its marginal cost). MR0 represents the additional revenue that the firm receives for each additional unit of production.

Figure 8.4 - Monopoly Market After Regulation

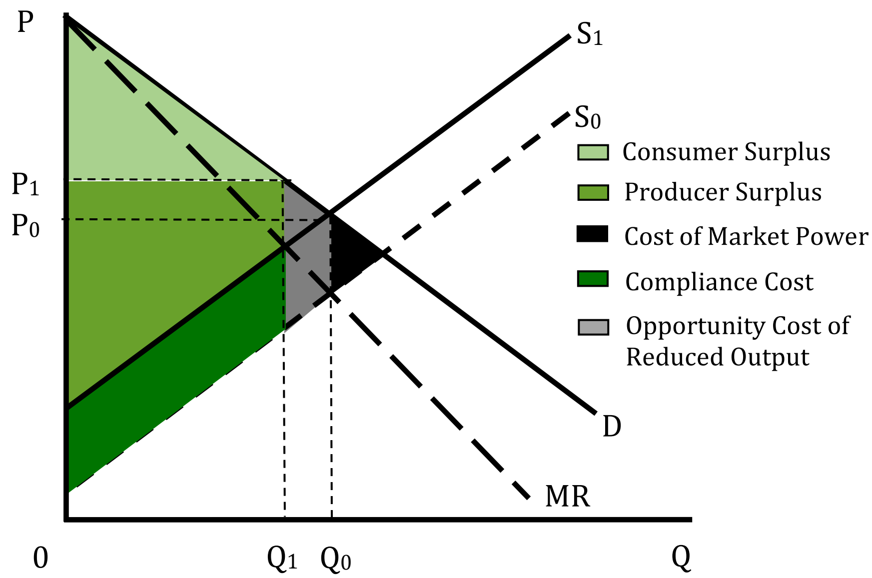

Figure 8.4 shows what occurs when the monopolist is subject to an environmental regulation. As in the case of perfect competition, the regulation causes the supply curve to shift upward from S_0 to S_1. The equilibrium price rises from P_0 to P_1 and output falls from Q_0 to Q_1. By further restricting output, the exercise of market power exacerbates the welfare loss from the regulation. The opportunity cost of this reduced production has now increased. The additional opportunity cost of the reduced output as a result of the regulation is greater than in a perfectly competitive market. Imperfectly competitive input markets may also exacerbate the social cost of a regulation (e.g., Busse and Keohane 2007).

Existing regulations may distort the behavior of regulated sources and other market participants in response to an environmental regulation and, in turn, result in additional social costs. A well-known example is in the context of electric utilities where some states regulate investment and retail prices to assure that producers do not exercise market power. However, this results in two potential distortions. First, retail prices in these states are lower than would occur in a competitive market, which means more electricity is consumed than is economically efficient.[20] Second, the ability to only pass along some types of costs and not others to consumers results in more capital-intensive production (including pollution abatement) than is economically efficient (e.g., Parry 2005; Burtraw and Palmer 2008; Fowlie 2010). Thus, it is important for analysts to be mindful of the potential for interactions with existing market regulations and, when feasible, account for them when modeling compliance behavior of market participants.

20 In some regulated electricity markets, prices are set equal to the average cost of production, which is lower than the additional (marginal) cost of production. In these circumstances, the production and consumption of electricity is greater than is economically efficient because the additional benefit of production exceeds the cost to produce it.

8.1.3 General Equilibrium Approach

A general equilibrium approach to cost estimation concurrently considers the effect of a regulation across all sectors in the economy. It is structured 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 approach 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, 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, will be determined in general equilibrium. 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.[21]

When the imposition of an environmental regulation is expected to have appreciable effects in markets beyond those that are directly subject to the regulation, a partial equilibrium approach may be insufficient to adequately estimate social cost. A general equilibrium approach, which captures linkages between markets across the entire economy, is most likely to add value when both cross-price effects and pre-existing distortions (e.g., taxes, regulations, market power in other markets) are expected to be significant (U.S. EPA 2017).[22,23]

Consider as an example a regulation that imposes emission limits on the electric utility sector. In the long run, we expect at least some, if not all, compliance costs are passed through to consumers as increases in the electricity price. Because electricity is used as an input in the production of many goods, the prices of these products may also increase to reflect the increase in their marginal cost of production. Increases in prices may cause households to alter their choices. For example, their consumption of energy-intensive goods and services may decrease relative to other goods. Furthermore, the number of hours they are willing to work may change in part because when goods become more expensive, households can afford less with the same income; thus, their real wage has declined.[24] On the margin, they respond by changing the number of hours worked. When an environmental regulation affects the real wage such that individuals opt to work fewer hours, it can exacerbate pre-existing tax distortions in the labor market (Goulder et al. 1997). The impacts of a regulation also may interact with pre-existing distortions in other markets, which may cause

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21 Computable general equilibrium (CGE) models are discussed in Section 8.3.3. Hazilla and Kopp (1990), Jorgenson and Wilcoxen (1990), U.S. EPA (1997), U.S. EPA (2011), and Marten et al. (2019) use CGE models to estimate the social cost of environmental regulations.

22 Cross-price effects are measured by elasticities. For example, the cross-price elasticity of demand is defined as the percentage change in the quantity of product X demanded by consumers in response to a change in the price of product Y. If two markets are unrelated, then the cross-price effect is expected to be near or equal to zero. If they are substitutes, then the cross-price elasticity is positive. If they are complements, then it is negative.

23 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 may cause an opportunity cost in that market. Distortions with similar opportunity costs already exist 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, which may cause additional impacts on welfare.

24 In general equilibrium analysis, all prices and wages are real, i.e., measured relative to a numéraire, a specific single price or weighted average of prices such as the gross domestic product (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.

additional impacts on welfare.[25] In cases such as these, a general equilibrium approach is capable of identifying the nature and magnitude of the costs of complying with a regulation as they flow through the economy, including changes in substitution among factors of production, trade patterns, endogenous demands and even intertemporal consumption. These effects are partially or wholly missed by compliance cost and partial equilibrium approaches.

Figure 8.5 illustrates how a regulation can interact with pre-existing tax distortions in the labor market. A pre-existing tax equal to a share of the gross (pre-tax) wage (W_g^0) causes the net (after-tax) wage (W_n^0) to be lower than the gross (pre-tax) wage by the amount of the tax. With this tax distortion, the quantity of labor supplied is L_0 and there is an opportunity cost of reduced labor supplied. When a new regulation is imposed in another market, raising production costs will increase the price level and may lower labor supply. This is shown in Figure 8.6 as a decrease in the net wage to W_n^1 and a decrease in the amount of labor supplied to L_1. The opportunity cost of the labor tax along with the increased distortion as the difference between the gross and net wage has increased.[26] The interaction between the effect of a regulation and the distortion from a tax is especially pronounced in the labor market.[27] Similar interactions are likely to occur in other markets with significant pre-existing distortions (e.g., capital markets). In cases where they are likely to have a significant impact, analysts should incorporate these distortions into models used to estimate social cost.[28]

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25 See Text Box 8.3 for a discussion of interactions that could also affect benefits estimation.

26 Recall in this example that the tax is a share of the gross wage, so as the gross wage goes up, the distortion from the tax also increases. Alternatively, if the amount of tax does not depend on the gross wage, it may need to be increased to maintain government revenues, which is a common assumption in general equilibrium analysis. However, it is not necessary for the tax level to change for the new regulation to exacerbate the pre-existing tax distortion in the labor market.

27 The labor tax distortion affects individual labor supply decisions at the margin. While full-time workers may not change (or be able to change) hours worked in response to a fall in the real wage, part-time workers — those in households with more than one full-time worker — or potential retirees may be more likely to adjust the number of hours they work. Parry (2003) discusses the theoretical and empirical basis for this depiction of the labor market.

28 Economists have long recognized the "tax interaction effect" (Ballard and Fullerton 1992), and a rich body of work has focused on them in the context of environmental regulation (Goulder, 2000; Parry and Bento 2000; Murray et al. 2005; and Bento and Jacobsen 2007). If an environmental regulation raises revenue through a tax on pollution or another 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, and in some cases, the overall efficiency of the tax system may actually improve. 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. One offsetting factor is that society also incurs a welfare loss from raising revenues through taxes due to the difference between the value of an additional dollar raised by the government and the value of that dollar to a private individual (i.e., the marginal cost of public funds).

Figure 8.5 - Labor Market with Pre-Existing Distortion Before Regulation

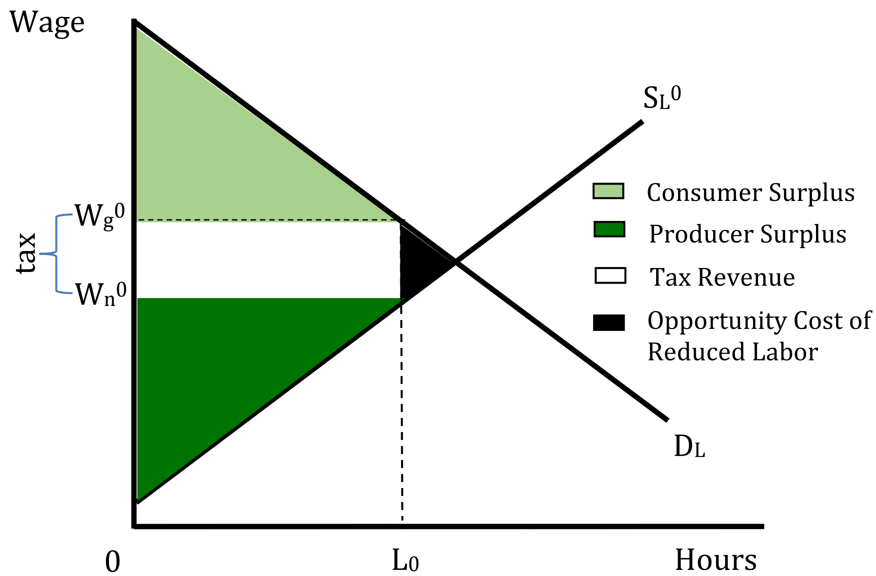
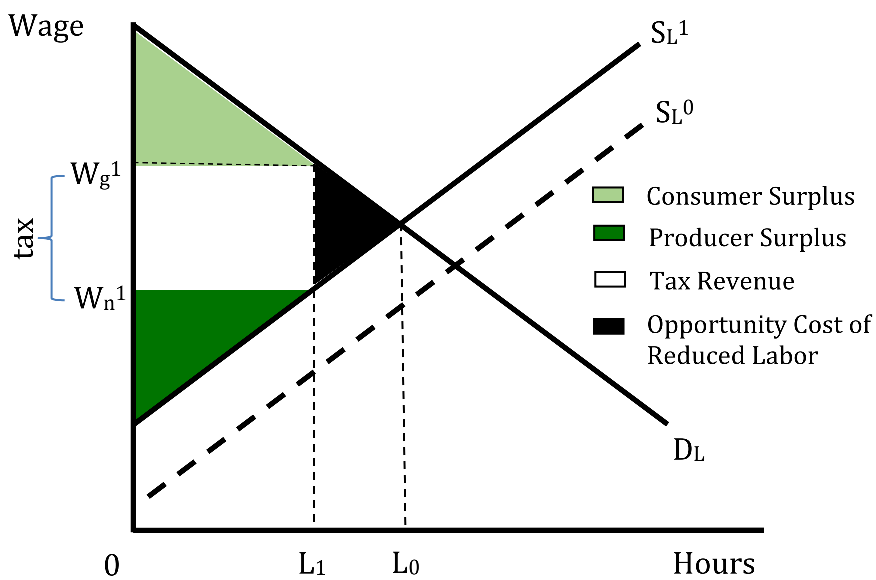


Figure 8.6 - Labor Market with Pre-Existing Distortion After Regulation



8.2 Estimating Social Cost

When estimating social cost, the objective is to measure the incremental cost for each regulatory option under consideration. Incremental cost is defined as the additional cost associated with a new requirement relative to a baseline.[29] Often when specifying a baseline from which to measure costs, the analyst needs to first identify what abatement activities are already in place or anticipated as a result of existing regulations. The costs associated with previously installed abatement controls are not counted toward the cost of the rule, as these occurred prior to the regulation under consideration and are therefore in the baseline.[30] Similarly, costs that have not yet been realized but will be incurred to comply with existing regulations should not be counted towards the cost of the regulation under consideration. Identifying which abatement controls are already in use also aids the analyst in identifying what additional abatement control options may be available to further reduce emissions.[31]

It is important that analysts derive the most defensible central estimates of the compliance costs associated with identified abatement strategies, as they are the building block for developing social cost estimates. Social cost estimates should continue to rely on central assumptions and inputs that are well-supported by standard engineering practice and the published scientific literature. In addition, analysts should ensure that: (1) the information supporting cost estimation is appropriate 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.[32,33] As previously discussed, analysts are advised to focus quantification on categories of costs that are expected to have a large influence on the net benefits and relative ranking of the options under consideration. Analysts also should describe the process for quantifying the different types of costs that underlie the aggregate cost estimate and present them in a disaggregated and informative manner.

8.2.1 Compliance Cost Estimation

Recall that compliance costs are the additional costs that regulated entities incur to reduce or prevent pollution to comply with the regulation. There are a variety of different types of compliance costs including but not limited to the following.

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29 While this chapter focuses on the anticipated social costs of regulation, the same approach also applies in a retrospective setting (see Chapter 5).

30 See Chapter 5 for a detailed discussion of establishing the baseline. Other issues relevant to specifying a defensible baseline for cost estimation include, for example, ensuring consistency in key assumptions across costs and benefits; and treatment of anticipatory actions to meet regulatory requirements.

31 Note that the expected abatement strategies that underpin estimates of social costs also affect the expected change in the level and exposure to the environmental contaminant and therefore the benefits of the regulation.

32 At times, EPA uses externally derived (e.g., contractor, industry association or advocacy group) cost estimates for its regulatory analyses. Any cost estimate produced by an external source and used by the EPA in its analyses should meet these criteria.

33 Some statutes require the EPA to choose a regulatory option that is demonstrably affordable. In this case, analysts should continue to rely on the most defensible central estimate of costs. Estimating an upper bound (instead of a central estimate) of the compliance cost associated with the chosen option to demonstrate affordability will bias the net benefits of the regulation downward and/or could result in artificially low levels of stringency.

- **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 on-site or off-site processing of waste for an alternative use.
- **Disposal:** The cost of the final placement, destruction, or disposition of waste after pollution treatment/capture and/or recycling has occurred.
- **Prevention:** The cost of preventing pollution from being generated or contamination from occurring during the production process.

Entities that directly incur compliance costs to meet regulatory requirements may include firms, households, and government agencies. For example, firms normally incur costs to purchase and operate pollution control equipment; households may incur the costs of periodic inspections of pollution control equipment on vehicles; and government agencies may implement, administer, monitor, and enforce a regulation. In the case of product standards, compliance costs include the incremental cost of designing and manufacturing the compliant product relative to the already existing noncompliant product.

It is relatively straightforward to infer a value for compliance costs when an explicit monetary payment (e.g., purchasing pollution abatement equipment) is made. Compliance costs for which monetary values are not readily available are often more difficult to quantify. For example, the value and length of time households spend on vehicle inspections may be uncertain. Guidance on how to value time spent on such activities is discussed in Section 8.2.4. Compliance costs are also more difficult to quantify when, instead of installing abatement equipment, firms modify production processes to prevent emissions. Regardless of the ease with which compliance costs can be estimated or what terminology is used to characterize them, if the compliance activities require resources that are redirected from other activities relative to the baseline, the value of those resources should be accounted for in compliance costs.

A compliance cost estimate reasonably approximates the social cost of a regulation when the value of the resources used for compliance generally reflect their social opportunity cost and prices or other producer and consumer behavior are not expected to change significantly as a result of a regulation. Determining whether compliance activities change prices or behavior requires: (1) estimates of supply and demand conditions, (2) an assessment of how compliance costs affect production costs, and (3) evidence of whether producers in the sector significantly change their level of production relative to one another. When compliance costs are used to estimate social costs, the analysis should provide evidence that justifies their choice.

It is common to refer to different categories of compliance costs, such as fixed or variable costs, as a way to systematically identify the costs that may result from a regulation. In practice, these categories of compliance costs may not be entirely distinct. Table 8.1 summarizes the main cost categories discussed in this and subsequent sections.

8.2.1.1 Fixed Costs

Fixed costs do not change with the level of production or abatement over a specific time period, often referred to as the short run. They are typically one-time costs, or costs that only occur once over the time horizon of the analysis, such as the installation of pollution control equipment. However, fixed costs may also refer to recurring costs that are independent of the level of production or abatement over a given time period (note that in the long run, virtually all fixed costs are variable.) Two common categories of fixed costs are described below.

Capital costs are costs related to the installation or retrofit of structures or equipment. These expenditures include materials and labor used for equipment installation and startup. Once equipment is installed, capital costs generally do not change with the level of abatement or production. Capital costs may also include changes to the production process.

Table 8.1 - Types of Costs Associated with Environmental Policies: Categories, Examples and Commonly Used Approaches to Quantification

Compliance Costs	Examples	Common Approach to Quantification[34]
Fixed costs	Capital costs; Research and Development investments	Compliance cost
Variables costs	Operating costs; Monitoring, reporting and recordkeeping costs; Transaction costs	Compliance cost

Other Opportunity Costs	Examples	Common Approach to Quantification
Reduced output in regulated markets	Higher product prices cause reduced quantity demanded	Partial equilibrium
Changes in product quality	Trade-offs with reliability or longevity	Partial equilibrium
Changes in behavior in the regulated or final goods markets	Changes in investment (e.g., delayed adoption); Rebound effects	Partial equilibrium
Transition costs	Search costs for new jobs; Costs of initially scarce new equipment	Partial equilibrium

Economy-Wide Costs	Examples	Common Approach to Quantification
Interactions with pre-existing distortions in related markets	Tax interaction effect; Trade barriers	General equilibrium
Macroeconomic feedbacks	Capital-induced growth effects	General equilibrium

Research and development (R&D) costs are incurred to develop new products, processes, or techniques. These costs are in addition to capital costs and should be accounted for when estimating compliance costs. Similarly, if a supplier to the regulated entity is expected to incur R&D expenditures in response to the regulation those costs should also be included in the estimate of the social costs.

In the case where a supplier incurs the R&D expense, care should be taken to avoid double-counting; in the long run, the supplier will reflect these R&D costs in the price charged to the

34 While opportunity and economy-wide costs may be quantified without explicit partial or general equilibrium modeling, such modeling may be necessary to avoid the double-counting that would occur if these costs were added directly to cost estimates from a compliance cost approach.

regulated entity. If social costs are estimated using the prices regulated entities pay, accounting for these additional R&D investments by the supplier, or any other resources reflected in prices charged to the regulated entity, do not need to be added to the estimate of social costs.

R&D costs incurred in the past by a regulated entity or supplier should not be counted as a cost of the regulation, as these costs are sunk.[35, 36] If past R&D costs are reflected in the market prices of inputs sold by the supplier (for instance, due to market power) then the cost associated with these past R&D expenditures should also be excluded from the social cost estimate when possible.

8.2.1.2 Variable Costs

Variable costs change with the level of production or abatement.[37] They are the sum of the marginal cost for each unit that is produced. Common categories of variables costs are described below.

Operating costs are recurring expenditures associated with the operation and maintenance of equipment, including salaries and wages, energy inputs, materials, and supplies, purchased services and maintenance or repair of equipment associated with pollution abatement or waste management. In general, operating costs increase with the level of abatement or the amount of production or use.

Monitoring, reporting, and recordkeeping costs are incurred to demonstrate or assure compliance with a regulation. They may be incurred by regulated entities or regulators and generally reflect the use of resources that should be accounted for when estimating the cost of a regulation. While these types of costs are identified here as variable costs, some may also be a fixed cost, such as the installation of pollution monitoring equipment.

Transactions costs are the costs incurred when buying or selling a good or service. They may include the costs of searching out a buyer or seller, bargaining and enforcing contracts. Transaction costs reflect the use of real resources (e.g., time, equipment) and should be included in an estimate of social costs.

8.2.2 Social Cost Estimation

Social costs most often differ from compliance costs because the imposition of the regulation causes changes in behavior beyond just the compliance activity required by the regulation. The most straightforward example of an opportunity cost not accounted for by a compliance cost approach is the value to producers and consumers of **reduced output in the regulated market** as demand

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35 "Sunk costs" are costs that have already been incurred and cannot be reversed (e.g., existing investments in pollution control equipment or previous use of labor). For a deregulatory action, those costs that are sunk should not be accounted for in the benefits of that action while avoided future compliance costs should be accounted for. Care should be taken when identifying whether certain costs are sunk as certain investments and other fixed costs may actually be, in part, reversible, in which case there is an opportunity cost of continuing to use those resources. For example, there may be scrappage value of pollution abatement equipment.

36 Note, however, that anticipatory actions — such as planning and designing for future R&D activities — that are initiated in expectation of promulgation (for instance, in response to the proposal) may still be attributable to the regulation.

37 Use of some resources, especially energy, also can cause negative environmental or other externalities. Techniques for non-market valuation can be applied even when impacts are counted on the cost side of the ledger in a benefit-cost analysis (BCA) (see Chapter 7).

responds to higher product prices. However, social costs can differ from compliance costs even without additional behavioral responses. For example, differences may occur when environmental regulations apply to the performance of a final good — for instance, a vehicle or cleaning product — and the installation of an abatement technology can sometimes also result in **changes in other product attributes** valued by consumers. While these changes may be positive or negative, examples in the literature mainly focus on trade-offs between emissions and attributes such as decreased performance or reliability or reduced safety due to material substitution (e.g., Klemick et al. 2015; Klier and Linn 2016).

Other behavioral changes in the regulated or final good markets are also not captured by a compliance cost approach. For example, the design of the regulation itself may result in changes in investment behavior to avoid the costs of new requirements. In particular, vintage-differentiated regulations that impose more stringent abatement requirements on new emission sources can result in delays in the adoption of new, cleaner equipment and potentially increase investment in older, dirtier equipment (e.g., Gruenspecht 1982; Nelson et al. 1993; Jacobsen and Bentham 2015). While this behavior lowers the cost of complying with the regulation, it also weakens its overall stringency. In other cases, the design of the regulation can lead to changes in the utilization of the regulated product. For example, the literature has estimated a rebound effect from energy efficiency and vehicle fuel economy standards; because these regulations make it cheaper to consume energy or fuel on a per-unit basis, demand for these services and therefore emissions from them increase relative to the case without the rebound (Gillingham and Rapson 2016).[38]

As already discussed, economy-wide costs also may arise when the regulation interacts with **pre-existing distortions** such as taxes, other regulations, trade barriers or market power to move private behavior further away from the economically efficient outcome.

When compliance costs do not fully represent all the opportunity costs of a regulation, partial or general equilibrium analytic approaches can be used to estimate social cost. In some cases, the analyst can construct or use available partial or general equilibrium modeling tools to credibly estimate expected changes in the social cost of regulation. When a model is not available, it may still be possible to estimate the social cost associated with anticipated behavioral change by applying findings from the peer-reviewed literature. Analysts should justify their choice of estimates and explain their applicability to the specific context of the rule. If a range of credible estimates are available, analysts should reflect that range in the analysis and discuss key factors or sources of uncertainty that influence the estimates. Regardless of the origin of the estimate — be it modeled, empirically estimated, or taken from published studies — it is also important that the underlying behavioral assumptions are consistent with the rest of the BCA.

8.2.2.1 Measuring Social Cost

It is possible to estimate the social cost of a regulation by adding up the net change in consumer and producer surplus in all affected markets. Consumer's equivalent variation (EV) and compensating

38 As Section 5.2 mentions, behavioral economics can have implications for benefits and costs of a regulation. For example, if consumers mis-optimize or are loss averse, they may not adopt energy-saving technologies for which private benefits of adoption appear to exceed private costs. This raises the possibility that a regulation could yield positive private net benefits to consumers or firms. See Section 7.2 for more discussion.

variation (CV) are other measures that have been utilized.[39] 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 demand.[40]

The social cost of a regulation is generally not the same as a change in GDP or aggregate consumption (U.S. EPA 2017). As measures of social cost, changes in GDP and aggregate consumption both miss potentially important regulatory effects, such as impacts on leisure demand or the demand for nonmarket goods.[41] GDP is also comprised of more than just changes in consumption as it is a measure of total economic output.[42] For instance, a regulation that requires firms to install new capital in a given year will see an increase in investment. However, capital also affects the availability of goods and services that can be consumed over a much longer time period. As a result, GDP effectively double counts the new capital installed since investment and consumption are both components of GDP.[43]

8.2.2.2 Transfers

Environmental regulations may also affect **transfers**. Transfers are shifts in money or resources from one part of the economy (e.g., a group of individuals, firms, or institutions) to another in a way that does not affect the total resources that are available to society. In other words, the loss to one part of the economy is exactly offset by the gain to another. Since social cost represents the total burden that a regulation imposes on the economy, it nets out transfers.[44, 45] Examples of transfers

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39 Both EV and CV are monetary measures of the change in household utility brought about by changes in prices and incomes resulting from the imposition of a regulation. Appendix A describes the relationship between consumer surplus, equivalent variation and compensating variation. EV and CV are particularly well-suited for partial and general equilibrium analysis because both modeling frameworks require the explicit characterization of consumer preferences. Calculating EV and CV requires only pre- and post-policy price and utility levels.

40 EV and CV can also provide a complete welfare metric (incorporating both benefits and costs) if non-market goods are explicitly accounted for in consumer utility functions. However, these metrics are often only used to assess the social cost of a regulation because traditional economic models do not yet incorporate non-separable benefits, or explicit linkages between environmental quality and economic costs (see Text Box 8.3).

41 See Paltsev et al. (2009), U.S. EPA (2011), and Paltsev and Capros (2013) for examples of how these measures differ in specific policy contexts.

42 It is also the case that transfer payments, which are excluded from BCA, are subsumed within the government spending category of GDP. In addition, while changes to trade patterns due to a regulation may be reflected in both GDP and welfare, they are not necessarily equivalent measures (Paltsev et al., 2009; Paltsev and Capros 2013).

43 Several reasons exist for why GDP is not the preferred measure of social cost and overall welfare in general. For instance, GDP does not include non-market environmental costs or benefits. An example of where it is a potentially misleading metric is when improvements in environmental quality from a regulation also lead to reductions in hospital visits that reduce GDP. GDP is also a flow measure of expenditures and does not account for changes in the capital stock. An example of when this is potentially important is if pollution damages buildings, then the expenditures on maintenance and repair would increase GDP at the expense of returning the stock of capital to its original state.

44 Transfers are important for understanding how a regulation affects the private cost of a regulation for different groups. Thus, they are included in an economic impact analysis. See Chapter 9.

45 An exception is when one group has economic standing in the analysis, and the other does not. See Chapter 5.

include payments for most taxes and subsidies received, as well as higher revenues for producers in imperfectly competitive markets due to higher prices.[46] However, it is important to note that not all taxes or subsidies should necessarily be excluded from estimates of social costs under the assumption that they are transfers. For example, the opportunity cost of a firm employing labor in a compliance activity is inclusive of payroll taxes since they are a form of compensation (e.g., insurance against old age) and not a transfer.

While transfers should be excluded from an estimate of social cost, the conditions leading to the transfer may create additional costs that should be accounted for in a partial or general equilibrium framework. For example, when existing taxes are already distorting behavior in a socially inefficient manner — for instance, by changing the decision of how much to work — the change in behavior induced by the regulation can cause the welfare loss associated with these distortions to also change. These additional changes in welfare due to interactions between the environmental policy and pre-existing tax distortion should be included in an estimate of social costs.

8.2.3 Evaluating Costs Over Time

After the imposition of a new environmental regulation, the economy moves to a new long-run equilibrium set of prices and quantities that allow all markets to clear. Since compliance costs represent permanent additions to the cost of production for a firm, effects in closely related sectors are incurred in the new equilibrium.

However, in some contexts it is possible that firms and/or consumers may incur additional short-term costs during the period when the economy is adjusting to the new equilibrium. These are known as **transition costs**. Examples include costs to train workers to use new equipment, search costs as some workers seek employment in other sectors, and additional costs associated with initially limited availability of new monitoring or abatement equipment. It is also possible that at least some factors of production are fixed initially, limiting the ability of firms to respond quickly to new regulatory requirements. For instance, contractual or technological constraints may prevent firms from fully adjusting their input mix or output decisions until those contracts expire or technology is ready to be replaced. Similarly, the number of firms may change over time depending on the cost of new firms to enter. If these types of adjustment costs are substantial, a sole focus on long run costs may underestimate the total social cost of regulation.

Thus, it is important to consider both short- and long-run effects when measuring costs over time. In addition, analysts must make choices about the time horizon of the analysis, the use of a static versus a dynamic framework, discounting and technical change, employment effects and effects on market structure.

8.2.3.1 Time Horizon

The time horizon for calculating producer and consumer adjustments to a new regulation should be considered carefully. The analyst should strive to estimate the present value of all future costs of a regulation (see Chapter 6). If the analyst is only able to estimate a regulation's costs for one or a few representative future years, the analyst must take care to ensure that the year(s) selected are truly

46 For example, taxes are generally thought of as transfers between households or firms and government such that an offsetting change in government revenue and household income due changes in behavior induced by the regulation are not social costs. Regulations may also create scarce compliance assets, such as allowances in cap-and-trade systems. Generally, the gratis receipt of or any payments for allowances are also a transfer (see, for example, Burtraw and Evans 2009).

representative, that no important transitional costs are effectively dismissed by assumption and that no one-time costs are assumed to be ongoing.

In the short run, at least some factors of production and consumer demand are fixed. If costs are evaluated over a short period of time, then contractual or technological constraints can prevent firms from responding quickly to increased compliance costs by adjusting their input mix or output decisions. In the long run, by contrast, all factors of production are variable. Firms can adjust any of their factors of production in response to a new regulation and can even change their production processes. Similarly, consumers, including producers in other sectors, may not be able to adjust demand for the output of the regulated sector in the short run, but have more flexibility in the long run. The time horizon for the analysis should be long enough to capture any flexibility the regulation provides firms in their compliance approach.

However, if transition costs seem likely, analysts should also consider presenting evidence that sheds light on the length of the transition period and the magnitude of these costs. In some cases, regulatory requirements are phased in gradually over time, either explicitly through graduated compliance dates or requirements or implicitly through characteristics like vintage differentiation (i.e., varying regulatory requirements based on the age of the plant). For example, consider a regulation that enacts more stringent requirements on new sources of a pollutant. Selecting a time period of analysis that is early in the program when only a few new sources of production are affected may not accurately capture a future year in which most sources of production are new for the purposes of the regulation. A regulation also may influence the rate at which old sources are replaced by new ones. Chapter 5 contains additional guidance on how to determine the most appropriate time horizon for analysis.

8.2.3.2 Dynamics

One key decision for the analyst is whether to assume that economic conditions are invariant over time (i.e., static) or attempt to account for expected future changes in prices and economic activity (i.e., dynamic). Costs that are estimated at a given point in time or for a selection of distinct points in time and compared to the baseline are static. They provide snapshots of costs faced by firms, government and households but do not allow behavioral changes from one time period to affect responses in another time period. A dynamic framework, one that explicitly captures trade-offs across time periods, allows for this possibility.[47]

In most cases, a regulation will continue to have economic impacts after its initial implementation. If these intertemporal impacts are likely to be significant, they should be included in the estimation of social cost. Pizer and Kopp (2005) note that static productivity losses from environmental regulations are amplified over time due to their effect on capital accumulation (a lower capital stock over time reduces economic output and therefore welfare). A static model would miss this effect. In some cases, the potential effect of a regulation on long-term growth may be significantly larger than its effect on the regulated sector alone.[48] In addition to these **capital-induced growth effects**, the

47 Note that a comparative static framework compares snapshots of key economic outcomes before and after a change in an exogenous factor such as a regulatory requirement.

48 Pizer and Kopp (2005) estimated that the "additional cost of this accumulation effect on welfare can be as much as 40 percent above the static cost that ignores changes in capital stock." Hazilla and Kopp (1990) and Jorgenson and Wilcoxen (1990) also showed that this effect is potentially significant. It is important to note, however, that this conclusion is based on studies of large-scale changes in environmental regulation (i.e., the welfare effects of the 1972 Clean Water Act and 1977 Clean Air Act Amendment).

evaluation of costs in a dynamic framework may be important when a proposed regulation is expected to affect product quality, productivity, innovation and/or changes in markets indirectly affected by the environmental policy. Dynamic effects also impact net levels of measured consumer and producer surplus over time. See Section 8.4 for how a regulation's potential dynamic impacts affect model choice.

Conceptually, a dynamic framework allows the analyst to specify the process by which the economy moves between equilibria in response to a regulation across time. In practice, however, economists have more experience characterizing long-run equilibria than the pathways between them. While shorter run equilibria can be approximated by treating some factors of production as fixed (e.g., labor or capital), very near-term transitional costs are typically ignored in the modeling approaches discussed in Section 8.3. [49]

8.2.3.3 Discounting

Costs that occur over time must be properly and consistently discounted to allow for legitimate comparisons with benefits.[50] Procedures for social discounting in economic analyses are reviewed in considerable detail in Chapter 6.

There are two applications of discounting that are closely related to the modeling of social costs. First, when modeling firms' behavior, 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, is calculated using the social discount rate, the same discount rate used for estimating the benefits of the regulation. Section 6.4 provides additional details on the choice of discount rate when modeling behavior, such as firms' compliance decisions. Second, when a dynamic general equilibrium model is used to estimate social costs, any displacement of investment due to the regulation has already been accounted for and the social cost estimates should only be compared to present value estimates of benefits discounted at the consumption discount rate.

8.2.3.4 Technical Change and Learning

Estimating the social cost of an environmental regulation over a relatively long time horizon requires assumptions about future technological change. Jaffe et al. (2002) lay out a conceptual framework for understanding how technological change in response to environmental regulation may affect the relationship between inputs and output, ultimately reducing the unit costs of production. It is possible for an environmental regulation to change overall productivity in a sector over time in one of two ways: 1) the sector is more productive than before, but inputs are used in the same proportion as before to produce output (i.e., unbiased technical change) or 2) the regulation affects the growth rate of one or more inputs over time in a way that changes the relative productivity of the inputs to production (i.e., biased technical change).

49 Dynamic stochastic general equilibrium (DSGE) models represent business cycles within an economywide framework via random autocorrelated productivity shocks. While built on rely on highly aggregate representations of the economy, they may offer general insights into the role of modeling uncertainty and how regulations interact with short-run dynamics (Annicchiarico et al. 2021, U.S. EPA 2017).

50 It is equally important to properly discount cost estimates of different regulatory approaches to facilitate valid comparisons.

Compliance with an environmental regulation may result in the adoption of existing technology, improvement, or application of existing technology to a new use and/or development of entirely new technologies or processes (Sue Wing 2006). Whether it is more appropriate to capture these compliance responses as affecting overall productivity or the relative productivity of one or more inputs is an empirical matter.

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 how compliance is achieved and the relative role of technological innovation (e.g., Fischer et al. 2003).[51] As a result, the same environmental end may be achieved at significantly different costs, depending on the pace and direction of technical change.

The empirical economics literature also has observed that variable costs of production or environmental abatement often decline over time with cumulative experience. Ferioli et al. (2009) note that just the act of deploying a new technology can result in substantial process improvements that translate into cost reductions. Building on this empirical observation, log-linear or S-shaped learning curves that related the scale of production to per unit costs of production have often been used to represent how costs decline over time with experience. However, explanations for why this occurs vary (e.g., workers learn from mistakes and determine shortcuts; ad hoc processes become standardized), and substantial uncertainty remains regarding how learning occurs over time for a specific technology (Yeh and Rubin 2012). For instance, what learning rate is appropriate for a new versus a mature technology? To what extent does the learning rate change over time or remain relatively constant? Do costs always decline or increase in some cases?[52]

The EPA's Advisory Council on Clean Air Compliance Analysis stressed the importance of relying on sector-specific empirical data to inform assumptions regarding learning effects whenever possible.[53] When no data are available or the evidence is outdated, it recommended the use of a single default learning rate for transparency reasons. Sensitivity analysis is also recommended to better understand the influence that learning curves can have on costs (U.S. EPA 2007).[54,55] Given uncertainty regarding how and when learning curves should be applied, analysts also should

51 For instance, the realized costs of Title IV of the 1990 Clean Air Act Amendment's Sulfur Dioxide (SO2) Allowance Trading program are considerably lower than initial predictions, in part due to incentives to innovate in response to the policy (e.g., Bellas and Lange 2011; Frey 2013; Chan et al. 2018). See Chapter 4 for a discussion of how different regulatory approaches may affect innovation.

52 Yeh and Rubin (2012) point to examples where technologies that were tested on a smaller scale or a controlled setting actually experienced increased costs upon deployment due to unexpected performance or reliability challenges.

53 OMB's Circular A-4 recommends that a cost analysis incorporate credible changes in technology over time, noting evidence from the literature that variable costs of deploying new technologies or existing technologies in new applications decrease over time (OMB 2023).

54 A useful description of the calculations used to identify a learning curve are found in van der Zwaan and Rabl (2004). The U.S EPA (2016b) reviews learning rates in the published literature for manufacturing and electric utilities with a specific focus on the production of transportation-related goods (e.g., cars, ships, trucks). Grubb et al. (2021) report estimated learning rates for energy and related technologies. 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).

55 Note that cost decreases associated with technological change and learning may have additional costs associated with them such as training costs.

discuss and justify their assumptions. See Section 5.5.3 for additional discussion of technical change and learning.

8.2.3.5 Social Cost and Employment Effects

Recall that compliance costs include the value of labor for activities such as the installation and maintenance of abatement technologies as well as monitoring, recordkeeping, and reporting. The social cost of a regulation also includes the value of lost output associated with the reallocation of resources (including labor) away from production of output and toward pollution abatement, the value of induced changes in consumption and the deadweight loss from changes in the use of time (i.e., due to pre-existing tax distortions in the labor market). Employment effects more generally, such as those driven by labor-leisure choice, are not part of social costs under two commonly held assumptions: if the economy is at full-employment (i.e., every worker who wants a job at the prevailing wage has one) and with *de minimus* transition costs (Ferris and McGartland 2014). Typically, a regulation reallocates workers among economic activities — increasing employment in some industries and decreasing it in others — rather than affect the general employment level (Arrow et. al 1996).[56] For these reasons, employment effects should be characterized in the economic impact analysis, as explained in Chapter 9.

8.2.3.6 Effects on Competitiveness

As discussed in Section 8.1.2, imperfect competition in baseline market conditions may influence the social cost of a regulation. Introducing an environmental regulation may also create conditions that affect the size and market structure of industry, which may then allow firms to exercise market power.[57] Analysts should assess any expected changes to market structure as a result of the regulation and, in particular, whether it will lead to imperfect competition and impact social cost.

Environmental regulations can potentially affect the number of producers and the market structure of the regulated sector by raising production costs, modifying economies of scale, or affecting barriers to entry. For example, spatial heterogeneity in the stringency of environmental regulations or compliance costs, and in turn their effect on production costs, can lead to market consolidation at existing firms (e.g., Gray and Shadbegian 2002). Market structure can also be affected by the impact of compliance activities and abatement technologies on the minimum efficient scale for firms in the industry.[58] Positive economies of scale for abatement technologies can lead to reduced entry and greater exit (Millimet et al. 2009). Similarly, larger firms in the industry may have a competitive advantage in the presence of economies of scale (Dean et al. 2000). Differences in product offerings by firms may also affect market structure. If some firms subject to new product standards already have compliant products, they will have a distinct advantage over others. Regional differences in

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56 This does not mean, of course, that specific individual workers are not harmed by a policy (e.g., if they lose their jobs).

57 The focus of this section is on how these changes may affect market structure, including reducing competition (i.e., increase market power), and consequently affect the social cost of a regulation. These consequences of a regulation may also affect the composition and distribution of costs within a sector and closely related markets. See Chapter 9 for discussion of these market impacts.

58 Note, however, that it is theoretically ambiguous as to whether a reduction in output will be accompanied by a net reduction in the number of firms in a regulated market for common regulatory designs such as performance standards (e.g., Requate 1997; Lahiri and Ono 2007).

regulatory requirements may also lead to product differentiation, which can then create or increase market concentration (e.g. Brown et al. 2008; Chakravorty et al. 2008). Regulations can also create barriers to entry either due to vintage-differentiated standards, whereby new entrants have stricter standards, or through the control of patents on abatement technologies held by incumbents who innovated as a result of the regulation. By decreasing opportunities for entry or the number of firms in a sector, it is possible that incumbent or otherwise advantaged firms may now be able to charge higher prices, which in turn further reduces competition and, all else equal, increases the social cost of the regulation (see Figure 8.3 which shows the additional cost associated with reduced output due to market power).

The effects of imperfect competition on the social cost of regulation may also increase over time as markets adjust. For example, Fowlie et al. (2016) evaluate the social cost of a cap-and-trade program in the cement sector, where firms have significant market power in local markets. They show that, in the short run before production methods and the number of firms adjust, the additional social cost of the regulation due to imperfectly competitive markets is relatively small. However, in the longer run as firms change their production processes and firms exit the market, the effect of imperfect competition on the social cost of the regulation is much higher. It is therefore important that analysts evaluate potential differences between short and long run effects of a regulation on market power.

8.2.4 Valuing Time

Compliance with environmental regulations changes the use of productive resources, including people's time. Often, these changes occur at the workplace where labor is required to undertake pollution control activities. Less often, time outside of the workplace is also affected; for example, product bans might cause consumers to switch to substitutes that occupy more time. Changes in time use can affect the social costs of a regulation. The EPA has produced a separate document on how to value work time and nonwork time in regulatory analyses. We summarize the recommendations below, but analysts should consult U.S. EPA (2020) for a detailed discussion.

The opportunity cost of worktime is determined by the value of the marginal product that would have occurred absent the regulation. As a proxy for this opportunity cost, analysts should use the employer's cost of employing a worker, consisting of the wage, fringe benefits and any overhead costs.[59] The value of work time will vary based on the industries and occupations affected by the regulation. If overhead data are not available, U.S. EPA (2020) recommends that analysts use a default multiplier applied to wages plus fringe benefits for the value of worktime.[60] U.S. EPA (2020) provides links to data sources for wages, benefits and overhead rates that normally are included when valuing worktime.

Non-work time includes time spent on leisure, household production or other unpaid activities. Its opportunity cost may vary by the types of activities forgone; the utility derived from the activity

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59 Overhead costs are employer costs associated with labor, but not paid directly to workers, such as the value of personnel services and training activities. For more information on how wages, fringe benefits and overhead costs are defined, see Section 2.1 of U.S. EPA (2020).

60 The default multiplier in U.S. EPA (2020) reflects multiplier values used in prior analyses based on industry Source: U.S. EPA (2020). The Bureau of Labor Statistics (BLS) Occupational Employment Statistics (OES) are available at https://www.bls.gov/oes/tables.htm, while the Employer Costs for Employee Compensation and occupation-specific benefit and overhead rates affected by EPA regulations.

that occupies time; whether workers have a continuous choice over their hours of paid work; the socioeconomic characteristics of affected individuals; and more. As a proxy for the opportunity cost of non-work time, analysts should add the value of voluntary fringe benefits to the wage net of any taxes paid by workers to federal, state and local governments on earned income.[61] Table 8.2 summarizes the recommended approach and data sources for estimating work time and non-work time.

In unusual circumstances, analysts may have access to information that allows an alternative approach to estimating the value of work time or nonwork time. If utilized, analysts should explain why the alternative is preferred to the approach recommended here and in U.S. EPA (2020).

Table 8.2 Estimating the Value of Work and Non-Work Time

Type of time affected	Displaced activity	Estimation approach	Data sources
Work time: Tasks completed while working for pay	Other market work in the same industry and occupation as workers asked to complete the required tasks	Employer costs of labor = Wages + Fringe benefits + Overhead costs	• BLS OES or ECEC data on wages and fringe benefits • For overhead costs, use industry specific data as available • If overhead is not available, use the recommended multiplier to obtain a fully loaded wage
Non-work time: Tasks completed outside of paid work time	Other nonmarket activities such as leisure and nonmarket work	Individual valuation of time = (Wages – Taxes on earned income) + Voluntary fringe benefits	• BLS OES or ECEC data on wages and voluntary benefits • Adjust wage estimates using Census CPS data on median household income before and after taxes to estimate average income tax rate

Source: U.S. EPA (2020). The Bureau of Labor Statistics (BLS) Occupational Employment Statistics (OES) are available at https://www.bls.gov/oes/tables.htm, while the Employer Costs for Employee Compensation.

8.2.5 Compliance Assumptions

In most cases, analysts should develop baseline and policy scenarios that assume full compliance with existing and newly enacted (but not yet implemented) regulations. Assuming full compliance focuses the analysis on the incremental effects of the new regulatory action without double-counting benefits and costs already accounted for in previous regulatory analyses. That said, it is important to determine whether specific policy options are more likely to result in compliance issues or may be more difficult to enforce. In such cases, it is important to evaluate these effects (e.g., options that require monitoring and reporting may have higher costs, but compliance is easier

61 Voluntary fringe benefits are the categories of employer-paid benefits that are not legally required and include paid leave, supplemental pay (e.g., for overtime), insurance and retirement and savings plans.

to verify) and explore whether alternative options would result in improved compliance and/or easier enforcement.

Assumptions about compliance behavior in the baseline and policy scenarios should be clearly explained in the analysis. When compliance rates are uncertain or expected to vary across policy options, analysts should explore the sensitivity of the results to these assumptions. See Section 5.4.2 in Chapter 5 for a more in-depth discussion.

8.3 Models Used in Estimating the Costs of Environmental Regulation

Several types of models have been used to estimate the social 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 U.S. economy. In this section, we focus on three main model types: compliance cost models, partial equilibrium (PE) models, and computable general equilibrium (CGE) models. Input-output and input-output econometric models should not be used to estimate social cost; however, these approaches and their limitations are also described. Analysts are encouraged to consult with the National Center for Environmental Economics (NCEE) early in the rulemaking process for help in identifying the most appropriate approaches for estimating the costs of a specific regulation.

In practice, some models are simple enough to be implemented in a spreadsheet. Others consist of systems of hundreds or even thousands of equations that require specialized software. Many models are data intensive.[62,63] Given model complexity, a simple model that captures key economic features may be useful to identify which aspects of the regulatory options under consideration likely matter from a cost perspective and therefore warrant further investigation in a more complex model. Likewise, the use of a simple analytic general equilibrium approach is a less resource-intensive way to build intuition within an internally consistent framework before utilizing a CGE model (U.S. EPA 2017). Analysts should rely on a model that is "no more complicated than necessary to inform the regulatory decision" (U.S. EPA 2009).

In some cases, use of more than one type of model may be warranted. Specifically, a more aggregate CGE analysis may complement the cost estimates of a detailed compliance cost or PE model (U.S. EPA 2017). For example, direct cost estimates from a compliance cost model can be used as an input into a PE or CGE model. In some cases, models also can be linked to combine the sectoral detail of a PE approach with the economy-wide features of a CGE model. Text Box 8.1 discusses linking models. Table 8.3 summarizes key attributes by model type.

When selecting a model, it is important to evaluate whether it is the most appropriate for the question at hand (i.e., fit for purpose) and does a reasonable job of approximating the market(s)

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62 Data requirements for these models vary, though advances in computing power, data availability and more user-friendly software packages continually reduce the barriers to sophisticated model-based analysis. Refer to Chapter 9 for a discussion of the public and private data sources that can be used for cost estimation.

63 Analysts should take great care in ensuring the quality of a model's data and specifications. See Section 8.4 for a discussion of approaches to parameter selection, and ways to address parameter and model uncertainty.

and behavioral responses of interest. Most model types involve tradeoffs between different strengths and weaknesses. Below are several factors that may be helpful in choosing a model.[64]

- **Types of impacts being investigated.** Models differ in their abilities to estimate different types of costs.
- **Geographic scope of expected impacts.** Some models are well-suited for examining regional or local impacts but may not capture the full range of costs at the national level and vice versa.
- **Sectoral scope of expected impacts.** Some models are highly aggregate and lack the detail necessary to capture important aspects of compliance behavior within a single sector. Likewise, highly detailed sector models often do not capture effects on other sectors and may not adequately capture demand response.
- **Expected magnitude of impacts.** A model well-suited for estimating the cost of a regulation with large effects may have difficulty estimating the cost of a regulation with relatively smaller expected effects, and vice versa.
- **Expected importance of interactions and feedbacks with other sectors.** When regulations are expected to have substantial effects on the broader economy, it is important to choose a model that can capture those effects.

Other criteria for ensuring a specific model are appropriate and of sufficient quality to analyze the effects of a regulation are discussed in Text Box 5.2. For example, chosen models should be subject to credible and objective peer review to ensure consistency with scientific and economic theory before being used in regulatory analysis. Comprehensive documentation of model components, and as possible, underlying data sources should be publicly available.

Usually, some combination of the above factors will determine the most appropriate type of model for a specific application. Analysts should present a reasoned discussion of the factors that inform their model choice. Analysts should describe the main upstream and downstream sectors affected, whether close substitutes to the regulated good are available, the extent to which the goods affected are substitutes or complements to leisure, and the existence of pre-existing distortions in affected sectors (e.g., subsidies, imperfect competition, other regulations, or externalities). Evidence from the literature such as supply and demand elasticities that indicate market responsiveness (e.g., of consumers, input markets, substitutes, and complements) will aid the analyst in justifying model choice. Ultimately, models need to be supported by the data: for example, a single-market PE analysis requires demand and supply elasticities, while a multi-market or CGE analysis requires cross-price elasticities.

64 This list of factors is informed by Industrial Economics, Inc. (IEc 2005).

Text Box 8.1 - Linking Models

CGE models are aggregate representations of the economy that allow an analyst to capture the interactions of producers and consumers as changes in prices and quantities in the regulated sector percolate through the rest of the economy. These economy-wide interactions are captured through exogenously specified elasticities of substitution that approximate detailed demand and supply responses from the policy. There may, however, be instances when CGE models do not have sufficient detail to quantify how regulated entities may respond to a regulation, such as the types of compliance methods that are available.

Partial equilibrium and compliance cost approaches typically do not suffer from a lack of detail. They often have technology-rich representations that reflect the range of salient characteristics for regulated sources as well as installation and operation costs for each individual compliance technology. However, often demand and supply are specified in a very simple way and interactions with other potentially affected markets are not considered.

Much could be gained by linking these two modeling approaches in a coherent and sensible way to take advantage of the technological detail of compliance cost or PE models and the theoretically consistent economic structure of CGE models (Böhringer and Rutherford 2008). There are a number of studies, many in the energy context, that have leveraged such linkages (e.g., Cai and Arora 2015; Rausch and Karplus 2014; Kiuila and Rutherford 2013; Lanz and Rausch 2011; Sue Wing 2006; Schafer and Jacoby 2005; McFarland et al. 2004). The Science Advisory Board (SAB) (U.S. EPA 2017) recommended that EPA make linking more aggregate CGE models to more detailed models of households, industries or sectors a research priority. It signaled a clear preference for two-way linkages between models: the CGE model simulates prices and investment for use as inputs to the compliance cost or PE model, while the compliance cost or PE model computes technology capacities and output supplies that are used as inputs by the CGE model. The two models are run in an alternating fashion until convergence.

It is important to note that, in practice, any linking exercise is dependent on the information available from the sector model and the representation of relevant sectors and markets in the CGE model. As the information and available models may differ significantly across regulatory analyses, any application of linking also may present unique challenges and considerations.

To link a compliance cost model with a CGE model, the accounting of outputs and inputs between the two models needs to be sufficiently aligned. To do this, it is important to disaggregate compliance costs into the factors (e.g., labor, capital, energy, materials) that correspond to the inputs to the sector's production function as specified in the CGE model. However, this is often not a straightforward exercise. For instance, the fixed cost of a compliance method may include both the capital used for a compliance technology and the labor to install it. Likewise, variable costs may include materials as well as labor for maintenance. However, in both cases the shares of the compliance cost from the specific inputs are rarely available. It is also a challenge to aggregate compliance cost information up to the sector level for the purpose of linking to the CGE model. A compliance cost model often provides information on the expected compliance behavior and cost for each affected entity. The CGE model usually represents a sector with a single representative firm.

Many of the challenges of linking compliance cost models to CGE models also apply to linking CGE models with PE models. However, because PE models may have their own sets of assumptions on baseline forecasts, elasticities of demand and supply, functional forms, and/or technical change that may differ from the underlying assumptions in the CGE model, there may be additional complexities that must be grappled with and reconciled in some way to ensure that the linkage remains feasible and produces sensible results.

Table 8.3 Summary of Key Attributes by Model Type

Attributes	Sector-Specific Compliance Cost	Sector-Specific Partial Equilibrium	Economy-Wide CGE
Significant industry detail; rich set of technologies	✓	Sometimes	None
Account for facility or market constraints	Sometimes	✓	✓
Model changes in regulated producer behavior (e.g., input and process changes)	Sometimes	✓	✓
Represent interactions and feedbacks between sectors	None	Limited or none	✓
Model demand side response	None	Limited	✓
Can directly estimate welfare effects	None	Sometimes	✓

8.3.1 Compliance Cost Models

Compliance cost models are used to estimate the 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 and are usually determined for individual facilities or for categories of model facilities with varying baseline characteristics. To estimate the control costs of a regulation for an entire sector, disaggregated data that adequately reflect the industry's heterogeneity are used as an input into the model. The disaggregated cost estimates are then aggregated to the industry sector level. These models are most informative when the data are available to capture heterogeneity across facilities, both in terms of individual characteristics (e.g., facility age and production technology, input costs) and compliance options.

The structure of compliance cost models can vary depending on the scope of an analysis. For instance, compliance cost models may include many of the categories of costs previously described in Section 8.2.1 (e.g., capital costs, operating and maintenance expenditures, monitoring, measurement, and reporting costs). Moreover, some compliance cost models are designed to allow the integrated estimation of control costs for multiple pollutants and multiple regulations. Some models account for cost changes over time, including technical change and learning. While most compliance cost models are for facilities within a specific industry, they may also be models of households.

While precise estimates of compliance costs are an important component of any analysis, recall that, in cases where the regulation is not expected to significantly affect market supply and demand in the regulated market, compliance costs can be considered a reasonable approximation of social cost. Compliance cost models usually focus on the supply side because regulations are typically imposed on producers. In circumstances where producer and consumer behavior are appreciably affected, these models are not able to provide estimates of changes in industry prices and output resulting from the imposition of a regulation.

Advantages

- Compliance cost models often contain significant industry detail and can provide relatively precise estimates of the costs incurred by regulated sources (or categories of regulated sources) when complying with a regulation.
- Once constructed, compliance cost models often require fewer resources to implement and are relatively straightforward to use and easy to interpret.

Limitations

- As they usually focus on the supply side and do not capture changes in production among affected sources, compliance cost models can only provide estimates of social cost in certain cases.
- Compliance cost models are often limited to estimating the costs of complying with regulatory requirements for a single industry.

Linear Programming Models

Often linear programming models are used in the analysis of EPA regulations to estimate compliance costs. Linear programming models minimize (or maximize) a linear objective function by choosing a set of decision variables, subject to a set of linear constraints. In the EPA's regulatory context, the objective function is usually to minimize compliance costs incurred by the regulated sources. The decision variables represent the production and compliance 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 even economy-wide effects, they are 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.

In addition to compliance costs, the outputs from the model may include other related variables, such as projected input use, emissions, and demand for new capacity in the regulated industry. In some cases, linear programming models may also include supply and demand representations (e.g., elasticities) of multiple markets and therefore more closely resemble the partial equilibrium models described in Section 8.3.2.

While the estimated change in expenditures incurred by the regulated sector may be of policy interest, it is not equal to social cost when input or output prices change. If the linear programming model captures changes in market prices in response to the policy, then it is possible to use the model outputs to estimate a partial equilibrium estimate of social cost (e.g., changes in producer and consumer surplus).

8.3.2 Partial Equilibrium Models

In cases where the effects of a regulation are confined to a single or a few markets, partial equilibrium single or multi-market models that incorporate anticipated demand and supply responses can be used to estimate social cost.

Inputs into a partial equilibrium model may include regulatory costs estimated using a compliance cost model and the supply and demand elasticities for the affected market (as well as cross-price elasticities when there are multiple affected markets). 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.

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 in the region at which expected changes are to occur. The shapes of these curves reflect the underlying elasticities of supply and demand. These elasticities either can be estimated from industry and consumer data or taken from previous studies. While in practice these models often assume perfect competition, it is also possible to construct a partial equilibrium model that accounts for the role of market power in production decisions.

If the elasticities used in an analysis are drawn from previous studies, they should reflect:

- A similar market structure and level of aggregation;
- The appropriate spatial resolution (i.e., local, regional, or national);[65]
- Current economic conditions; and
- 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 to these additional markets as well.

Advantages

- Because they usually simulate only a single or small number of markets, partial equilibrium models generally have fewer data requirements relative to a CGE approach and are more straightforward 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 broader effects in the overall economy.
- 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.

8.3.3 Computable General Equilibrium Models

The most appropriate type of model to estimate the social cost of a regulation in a general equilibrium framework is a computable general equilibrium model. This type of model is comprehensive and internally consistent, accounting for budgetary and resource constraints operating throughout the economy. A key advantage over the other types of models discussed in this section is its ability to capture interactions between economic actors (often delineated with multiple sectors and regions) and with pre-existing distortions (e.g., taxes, other regulations, or externalities) across the entire economy. Relative to PE and compliance cost approaches, however,

65 For instance, Bernstein and Griffin (2006) estimated short-run price elasticities of demand for electricity in the United States that varied from -0.04 to -0.31 by region, and long-run price elasticities of demand for electricity that varied from about -0.05 to almost -0.6 by region.

CGE models are highly aggregate and often use simplified representations of production decisions (e.g., perfect competition, characterization of abatement opportunities) within a sector. They may also be more difficult to parameterize.

CGE models assume that an economy can be characterized by a set of conditions in which supply equals demand in all markets. When the imposition of a regulation alters conditions in one market, a general equilibrium model determines a new set of relative prices for all markets that return the economy to a long-run equilibrium. These prices in turn determine changes in sector outputs and household consumption of goods, services and leisure in the new equilibrium. In addition, the model determines a new set of relative prices and demand for factors of production (e.g., labor, capital and land) — the returns to which compose business and household income. The social cost of the regulation is estimated in CGE models as the change in economic welfare in the post-regulation, simulated equilibrium compared to the pre-regulation, "baseline" equilibrium.[66]

CGE models are built using structural micro-theoretic foundations to capture behavioral responses.[67] In canonical CGE models,[68] firms are generally assumed to be profit-maximizers with constant returns to scale in production; households maximize utility from the consumption of goods and services using a specific functional form; and markets are perfectly competitive. Multiple household types can be included in the model (for instance, differentiated based on geography or income) to calculate distributional impacts of policy changes. A common feature in many models is an underlying model of international trade following Armington (1969) where preferences for goods are differentiated by country of origin to allow for two-way trade for otherwise identical goods. Labor and capital are typically fully mobile between sectors with labor fully employed and no involuntary unemployment.

CGE models are generally more appropriate for analyzing medium- or long-term effects of regulation, when most inputs are free to adjust and consumers can modify purchasing and labor-leisure decisions in response to new prices. A longer time horizon also affords greater opportunities for firms to change production processes (i.e., innovate). The time required to move from one equilibrium to another after a new policy is introduced is not defined in a meaningful way (and is usually assumed to be instantaneous). As such, CGE models are generally not well-suited for

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66 Regulatory compliance creates a need for additional inputs to produce goods in the regulated sector along with pollution abatement. While the total cost of these additional inputs can be derived from detailed compliance cost estimates, it is not always clear how to allocate the total cost among the inputs specified in the CGE model because CGE models are by their nature an aggregated, parsimonious representation of the economy.

67 Structural models explicitly specify underlying preferences, production and resource allocation in ways that are consistent with economic theory. The calibration of structural or behavioral model parameters with actual data ensures that the model represents important economic features while remaining in agreement with the underlying theory (Woodford 2009).

68 Here, the term "canonical" is indicative of off-the-shelf models, or models with features that are most common in the literature. In reality, 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 make intertemporal trade-offs in consumption and investment.

analyzing transition costs as the economy moves to the new equilibrium unless a transition path can be appropriately specified.[69]

The case for using CGE models to evaluate a regulation's effects is strongest when the regulated sector has strong linkages to the rest of the economy and the regulation is expected to affect most firms in a broadly defined sector. Narrowly targeted regulations are more difficult to capture without explicitly linking a CGE model to a detailed PE sector model (U.S. EPA 2017). Linking models is discussed in Text Box 8.1. The extent to which CGE models will add value to the analysis also depends on data availability (see Text Box 8.2 on input-output data efforts).[70] When developing a plan for analysis, analysts should consult with NCEE if they anticipate using a CGE model to evaluate the effects of a regulation.

Note that absent a credible way to represent environmental externalities in a CGE model — or the benefits that accrue to society from mitigating them — a CGE model's economic welfare measure is incomplete.[71] However, the inability to account for interactions between costs and benefits in a CGE model does not invalidate their use to estimate costs or make it impossible to design consistent approaches to cost and benefit estimation (U.S. EPA 2017). The possibility of incorporating benefits into a CGE framework is discussed in Text Box 8.3.

Advantages

- CGE models are best suited for estimating the cost of policies that will have a broad set of economy-wide impacts, especially when indirect and feedback effects are expected to be significant.
- CGE models are most appropriate for analyzing medium- or long-term effects of policies or regulations.

Limitations

- Because of their equilibrium assumptions, CGE models are generally not appropriate for analyzing short-run transition costs.
- CGE models are highly aggregate and do not provide detailed cost estimates for narrowly defined sectors or small geographic areas.
- CGE models may be more difficult to parameterize and use highly simplified representations of sector production and abatement decisions.

8.3.4 Other Input-Output Based Models

Several other economy-wide approaches are referenced in the literature, including input-output (I-O) models and I-O econometric models. These methods should not be used to estimate the social cost of environmental regulation (U.S. EPA 2017).

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69 For instance, Williams and Hafstead (2018) embed short run transitional unemployment costs in a general equilibrium model.

70 Data limitations are a significant obstacle for all of the modeling approaches discussed in Section 8.3, both in terms of achieving the granularity needed to adequately represent a regulation and to estimate its effects.

71 An expanding body of work has begun to include non-market goods in CGE models (Smith et al. 2004; Carbone and Smith 2008).

Text Box 8.2 - Input-Output Data and Open-Source Initiatives

Input-output (I-O) data are a basic input into any CGE model. An I-O table assembles data in a tabular format that describes the interrelated flows of market goods and factors of production over the course of a year. It may consist of hundreds of sectors or just a few sectors. In the United States, the Bureau of Economic Analysis (BEA) provides a time series of national level I-O accounts with multiple levels of sectoral aggregation (between 15 and 402 sectors) based on North American Industry Classification System codes. For more information on constructing I-O tables, see Miller and Blair (2009), Horowitz and Planting (2009), and https://www.bea.gov/industry/input-output-accounts-data.

Below is an aggregated I-O table for the U.S. for 2022 based on BEA data. The columns for the individual sectors denote how much of each commodity is used to produce that sector's output (cost of annual production). A sector's cost schedule (upstream sectoral linkages) is composed of intermediate inputs, factors of production (labor and capital) and tax payments. Payments to factors (wages and profits) and tax payments comprise sectoral value added. Take the agricultural sector -- intermediate input costs consisted of $195 billion of agricultural inputs, $129 billion of manufactured inputs, $338 billion of other intermediate inputs and $286 billion of value added, for a total of $948 billion in input costs. The row for each commodity shows how that commodity is consumed (also known as downstream linkages). For the agricultural sector, $711 billion is consumed as intermediate inputs for sectoral production ($195 + $6 + $443 + $66), while $237 billion is consumed as final demand (i.e., C + G + I + (X-M), or $246 + $0 - $25 + $15). In this framework, the total output receipts must equal total input costs.

I-O Table for the United States (2022)

Account	Agriculture	Mining	Utilities	Construction	Manufacturing	Transportation	Services	C	G	I	X-M	Other Taxes	Total Outputs
Agriculture	195	0	1	5	443	0	66	246	0	-25	15	0	948
Mining	2	89	47	33	583	1	84	0	0	99	-21	-32	886
Utilities	10	21	52	15	89	19	319	359	0	0	0	-36	847
Construction	2	5	13	2	23	10	315	0	382	1497	0	-3	2243
Manufacturing	129	108	65	808	2650	226	2391	5097	187	1545	-1315	-596	11296
Transportation	94	106	17	3	413	249	561	320	0	0	51	-4	1809
Services	230	175	141	228	4543	384	9600	11489	3878	1641	298	-285	32322
Labor	67	70	185	726	1225	529	10653						
Capital	206	282	289	410	1258	370	7793						
Prodn. Taxes	13	30	39	14	70	21	540						
Total Inputs	948	886	847	2243	11296	1809	32322						

Source: Numbers are based on tables from the BEA. All values are in billions of 2022 dollars. Note: zeros capture small numbers that round to zero; missing entries reflect actual zeros in the data. C is household consumption (excluding leisure), G is government expenditures, I is investment and X-M is exports minus imports. The sum across these demand accounts equals U.S. GDP in 2022.

In a CGE framework, columns for the individual sectors determine input shares used to calibrate production functions. Columns for final demand determine expenditure shares used to calibrate household expenditure functions. These data, along with "transactions and transfers between institutions related to the distribution of income in the economy," form the basis of the social accounting matrix (Miller and Blair 2009). Constructing a social accounting matrix requires reorganizing the data shown above to link sources of household income to expenditures. I-O accounts with sub-national or international detail are not provided by the BEA but have been established by others. For instance, the Global Trade and Analysis Project (GTAP) compiles and reconciles data from many sources to have consistent sectoral and agent aggregations across countries (https://www.gtap.agecon.purdue.edu/). Further, the Wisconsin National Data Consortium (WiNDC), develops consistent subnational I-O tables based on publicly available data (http://windc.wisc.edu/).

8.3.4.1 Input-Output Models

I-O models are highly disaggregated empirical descriptions of the interrelated flows of good and factors of production.[72] They are generally static and assume a fixed, strictly proportional relationship between inputs and outputs via multipliers.[73] 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, most input-output models are demand driven and not constrained by limits on supply, which would normally be transmitted through increases in prices. While some of the rigidities in the models may be reasonable assumptions in the very short run or for regional analysis with limited ties to the broader national economy, they limit the applicability of I-O models for evaluating medium- to long-run effects or national issues. For instance, the lack of resource constraints and substitution effects that occur over the longer run means that I-O models tend to overestimate the effects of a policy.[74] Importantly, the I-O approach does not necessarily account for shifts in economic activity toward the pollution abatement sector (e.g., when the directly regulated sector purchases pollution abatement equipment or services to comply with the regulation). 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.[75]

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72 Miller and Blair (2009) is a standard reference on input-output analysis.

73 The assumption that output changes translate directly to proportional changes in inputs is not empirically founded and therefore should not be used, even in the short run, because it ignores the potential for factor substitution. Such shifts may change the labor-, capital-, energy- or materials-intensity of production.

74 Studies that rely on I-O models often calculate some combination of direct, indirect and induced effects. Direct effects are the changes in output that result from an increase in the cost of inputs (e.g., fuel) in the directly regulated sectors, using the fixed, proportional relationship mentioned above. Indirect effects of a regulation are calculated by using the I-O relationship between outputs in the directly affected sectors and required inputs in related sectors (e.g., suppliers). Induced effects are general re-spending effects that result from changes in household income.

75 See U.S. Chamber of Commerce and NERA Consulting 2013; OECD 2004, and Dwyer et al. 2006.

Text Box 8.3 - Separability between Benefits and Costs

When estimating the benefits and costs of environmental regulation, it is almost always assumed that the two are separable, such that the beneficial impacts of the polices do not meaningfully affect the factors that determine the cost of the policy, and vice versa. This is due, in part, to a lack of empirical evidence regarding the sign or importance of the relationship between environmental quality, which is typically not priced in the marketplace, and market goods (Carbone and Smith 2008).

Benefits and costs are non-separable when either the compliance costs borne by firms or households interact with and alter the valuation of environmental benefits (other than through changes in environmental contaminants), and/or the beneficial impacts of the regulation alter the costs. Non-separability may occur for several reasons. The costs of an environmental policy may alter the budget constraint for households — for instance, when compliance costs are passed on to consumers as higher prices for goods such as electricity, and this, in turn, affects their willingness to pay for the beneficial impacts of the policy. It may also be the case that changes in environmental quality and health status lead to changes in household behavior, which for large policies could affect relative prices in equilibrium and the cost of complying with the policies. For example, greenhouse gas mitigation polices in the electricity sector may reduce future demand for space cooling and therefore electricity, in turn reducing the costs of complying with the policy.

Ongoing work also suggests that reductions in mortality risk may affect how households smooth consumption over time (i.e., through savings), which may interact with pre-existing capital taxes or affect the price of investment in pollution abatement capital (Marten and Newbold, 2017). The fact that changes in environmental quality and health status can affect behavior in markets underpins the revealed preference approaches for estimating willingness to pay discussed in Chapter 7.

As noted by the SAB (U.S. EPA 2017), when either the costs or benefits of a regulation are estimated while holding the other constant, any potential non-separability between costs and benefits is missed, which complicates comparing them and calculating social net benefits. The specific magnitude and ultimate impact of non-separability on the net benefits of environmental regulations is an empirical question that requires additional study and is the subject of an emerging literature (Sue Wing 2011). The SAB noted that potential non-separability for large policies does not invalidate estimates of costs and benefits using existing methods. However, caution should be applied when obvious interactions exist.

8.3.4.2 Input-Output Econometric Models

I-O based econometric models integrate the high level of detail from an input-output model with the forecasting properties of a macro-econometric forecasting model. Unlike standard I-O models, this approach accounts for supply-demand conditions in the economy, including resource constraints, through a series of accounting (e.g., savings equal investment) and econometrically estimated relationships (Hahn and Hird 1991). Feedbacks between supply and demand occur via econometric equations (CGE models accomplish this via a price mechanism and market clearing assumptions (West 1995)). The predictions generated by this type of model “are integrated and simultaneously determined … price increases in one sector are translated into cost and price increases in other sectors" (Portney 1981). This is a key advantage over standard I-O models that assume away these effects.

While CGE models assume full market clearing, I-O econometric models assume imperfect knowledge of product and factor markets, with an emphasis on tracking short run disequilibrium (West 1995). This makes them particularly attractive for analyzing transition costs. However, a major drawback of I-O econometric models is that because they are reduced-form models predicated on historical relationships, they cannot take into account the possibility that a firm or consumer may modify their long-run behavioral response to changes in policy (referred to as the Lucas critique). The inability to account for this dependence invalidates these models for purposes of policy evaluation outside of short-term forecasting (Schmidt and Wieland 2013; Fischer and Heutel 2013; U.S. EPA 2017).

8.4 Modeling Decisions and Challenges

Even when the analyst has determined what types of models are most appropriate for the estimation of social cost, several important modeling decisions remain, including deciding on the level of sectoral and regional aggregation, whether to use a static or dynamic framework, and how to parameterize the model. In addition, analysts should evaluate key uncertainties and take care not to double count, particularly when using outputs from one type of model as an input into another.

8.4.1 Aggregation

The level of sectoral and regional aggregation assumed in a model will determine what aspects of the sector or economy can and cannot be captured explicitly in a regulatory analysis. Matching the level of aggregation in a model to the level needed to evaluate a policy's main effects is important to ensure that the analysis does not miss important contributors to the cost. For example, consider the effects of a new regulation on refrigerant gases in the frozen bakery products sector. In a CGE model, the frozen bakery products sector is not typically separated out as its own sector. Instead, it is captured in a more aggregate category — food products — along with many other related industries such as soft drinks, cereal and chewing gum. As a result, the frozen bakery products that are affected by the policy "may be too small a part of the model's food products sector to give meaningful results due to 'aggregation bias.'[76] Put another way, there are too many products in the model's sector to accurately isolate the frozen bakery products industry" (Rivera 2003).

The level of aggregation can affect sectoral and economy-wide results. For instance, sectoral disaggregation allows for a differentiated representation of production technologies, behavioral parameters (e.g., elasticities) and emission intensities that may matter for estimating costs and other impacts (Alexeeva-Talebi et al. 2012).[77] However, models that are highly specialized for

76 Caron (2012) defines "aggregation bias" for a specific variable as the difference in its value from an aggregated model relative to a disaggregated model that has been re-aggregated after the fact to a comparable level.

77 Alexeeva-Talebi et al. (2012) and Caron (2012) found that the range and standard deviation of sectoral impacts increased with disaggregation. In some cases, even the direction of the estimated impacts was reversed relative to more aggregate results. However, while a highly aggregated model may not be a reliable predictor of sub-sectoral impacts, for many applications, they found that these models produce satisfactory estimates of the overall impacts on the economy.

capturing impacts in a specific sector will usually miss impacts on a broader set of sectors. It is also important to consider how costs are allocated spatially (and temporally) to avoid a mismatch between affected facilities' locations and the scale of the model. While proficient at capturing major impacts and interactions between sectors, CGE models generally are not well-suited for focusing on a single or small number of specialized sectors because of their level of aggregation.

8.4.2 Choosing Between a Static and Dynamic Framework

It is possible to construct static or dynamic versions of all three types of economic models discussed in this chapter (i.e., compliance cost, PE and CGE). In a compliance cost framework, the analyst may assume that economic conditions are static or dynamic. If future economic conditions are expected to change meaningfully, a dynamic framework should be used because compliance decisions may be influenced by future economic conditions even when the regulation is not expected to meaningfully influence production or prices. For example, if an affected source anticipates operating for a long time it may choose a more capital-intensive compliance option over a less-capital intensive option because there is a longer period over which it can recover the cost of that investment. Similarly, if the number of affected sources is anticipated to change over time, then the cost of complying may change over time. A dynamic compliance cost framework may also be preferred if, for example, regulated sources may make anticipatory investments prior to a regulation's compliance dates or to account for the potential for technological change (see Section 8.2.3.4).

When the analyst expects intertemporal effects of a regulation to be confined to the regulated sector or a few related sectors, it may be appropriate to simply apply partial equilibrium analysis to multiple periods. As with compliance cost models, 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 also 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. 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.

Analysts should keep in mind that the evolution of variables in a dynamic model sometimes depends on exogenously imposed assumptions that are not always easy to validate. For instance, modelers sometimes need to constrain the pace at which some variables in the model change (e.g., how quickly technology changes) based on an external assessment of what is technically feasible. Key exogenous assumptions should be clearly documented and explained. In some cases, it also may be useful to explore the robustness of cost estimates to alternative assumptions.

8.4.2.1 Expectations

Dynamic models must specify the ways in which households and firms formulate and update expectations about future prices, returns, growth or other key economic variables. There are a variety of ways to formulate expectations about the future, but they generally fall into two general categories: backward-looking and forward-looking. With advances in computer power, forward-looking expectations are the more common assumption in CGE models.

The two main backward-looking formulations are myopic and adaptive expectations. Myopic households and firms do not anticipate future changes to the economy or regulatory setting, and do not make investments or change consumption and savings behavior until the period when the change takes effect (Paltsev and Capros 2013). Households and firms with adaptive expectations base their expectations about the future primarily on past experiences and are, therefore, relatively slow to modify behavior in response to new information.

In forward-looking models, households and firms have either perfect foresight or rational expectations. A household or firm with perfect foresight knows what the future values of key economic variables will be with certainty and incorporates this information immediately into current decisions (Paltsev and Capros 2013). Modeling rational expectations allow for households and firms to account for uncertainty in future conditions; in this case, they incorporate all relevant information, both past and future, into decision-making and are assumed to get future values correct on average. In other words, they do not systematically make forecasting errors.

There are several analytic implications tied to the degree of model foresight assumed in a dynamic model. For instance, a backward-looking model may lead to higher estimates of compliance costs and welfare impacts compared to a forward-looking model since it restricts the response flexibility of households and firms relative to reality. However, in cases where they are assumed to have perfect foresight but the future path of key variables is uncertain in reality, a deterministic forward-looking model may underestimate the compliance costs and welfare impacts of regulation. Note that many EPA regulations phase in standards or allow for intertemporal smoothing of compliance (e.g., banking of emissions allowances) that could at least partially alleviate this concern. Section 5.5.1 provides additional information on the role of uncertainty on household and firm behavior when estimating the impact of regulation.

Another consideration is the large number of variables and constraints that must be simultaneously determined in a forward-looking model. This, in turn, restricts the level of detail that can be included in the model, which may be critical to adequately assessing the social cost of a regulation. As such, a more aggregate forward-looking CGE model should be viewed as a complement to analysis supported by detailed compliance cost or PE sector model. All else equal, these considerations are even more restrictive for forward-looking models of decision making under uncertainty that also necessitate integrating over all temporal sources of uncertainty to form household and firm expectations.

8.4.2.2 Time Steps

Static models provide cost estimates for one period, typically a year. They either assume that conditions are invariant over time or that the cost estimate is indicative of a typical or representative period. Static models exist for all three frameworks discussed in this chapter (i.e., compliance cost, PE and CGE). As discussed above, if economic conditions are expected to change over time, or if changes in behavior to come into compliance and/or to new market equilibria take time, static models may provide incomplete estimates of costs (and benefits).

Most dynamic models operate using discrete time steps. Time steps between periods are chosen to provide enough detail regarding the adjustment to policy over time, while using a manageable number of time periods for computational reasons. For instance, because dynamic CGE models are often solved over periods of 50 years or more, it is not always practical to solve the model for each individual year. However, when using a dynamic CGE model, the year in which a regulation comes into effect may not be explicitly modeled. Due to the expense and time required to adjust the model and baseline, adding a new solution year may not be an option. In this instance, analysts may use the model year closest to the year in which the regulation will come into effect as a proxy.

Regulations that are introduced gradually or vary timing of compliance by region or state pose additional challenges for model representation.

In addition, if the end-year chosen for a dynamic model stops short of capturing important regulatory effects, the social cost estimate may be biased downward. When compliance costs cannot be estimated for all future years, a forward-looking model may smooth them over time, which can also lead to biased social cost estimates, though the direction of the bias will depend on what is assumed about future compliance costs.

8.4.3 Model Parameterization

Regardless of the chosen modeling framework, there is a distinction between values determined within the model (those that are endogenous) and values determined outside of the model (those that are exogenous). Model parameterization is concerned with the latter.[78] The values that are imposed exogenously will depend on the type of model used to capture economic behavior.

In general, model parameterization takes place in two steps. First, the analyst attempts to accurately represent the current structure of the sector(s) or markets of interest. For compliance cost models, this step typically relates to specifying relevant compliance options and constraints (e.g., production capacities). In the case of CGE models, this step consists of characterizing a baseline and calibrating model functions to a reference equilibrium. Second, parameter values are chosen that best characterize economic relationships (i.e., the curvature of different functions) in the model. In the case of compliance cost models, the analyst may need to specify constraints on economic behavior (e.g., production levels, other regulatory requirements) and cost functions (e.g. slopes, nonlinearities). For partial and general equilibrium models, this second step is more difficult and requires the analyst to choose appropriate behavioral parameters (e.g., elasticities).

Parameter values can be estimated or based on existing values from the literature. While basing parameter values on the existing literature is the more common approach, inconsistencies between the underlying structure of the model and the empirical analyses from which values are drawn can lead to modeled responses that are not supported by the underlying data of the empirical analyses.[79] To alleviate some of these concerns, some researchers have econometrically estimated the model parameters in a framework that is consistent with the underlying model (e.g., Jorgenson et al. 2013). If parameters are estimated by the analyst, preference should be given to using publicly available data where possible. When borrowing estimates from the literature to parameterize a model, analysts should use estimates that reflect the most recent scientific methods and data as possible, discuss the reasons for choosing one value over another, and discuss any limitations. For instance, available parameter values in the literature may not be regularly updated and produced using data that are significantly older than the modeled year(s) of interest. In cases where there is

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78 Specifically, parameters are "terms in the model that are fixed during a model run or simulation but can be changed in different runs, either to conduct sensitivity analysis or to perform an uncertainty analysis when probabilistic distributions are selected" (U.S. EPA 2009).

79 This point also applies to instances where analysts estimate their own parameters for a model. Identifying assumptions in the empirical framework need to be consistent with assumptions in the model of interest. For CGE analysis illustrating this point, see Shoven and Whalley (1984) and Canova (1995).

no clear consensus in the literature on the most defensible estimates to use, sensitivity analysis to understand the robustness of cost estimates to the parameters chosen is recommended.[80]

Often, a regulation covers many highly heterogeneous facilities where both the compliance options available and abatement costs vary widely. When highly disaggregated source-level data are unavailable, analysts may pursue a model plant approach to estimate compliance costs, where a subset of individual facilities sharing certain characteristics (e.g., plant age, type of production process, industrial sector) are represented by a single model plant. Analysts also may use a model plant approach to reduce the computational requirements of a compliance cost model.

The model plant is intended to represent the typical conditions of a group of facilities. While this provides a way to overcome data limitations and simplify the model, parameterization can still prove challenging. This is particularly true when conditions vary significantly across seemingly similar facilities. For example, if an abatement technology exhibits positive economies of scale, the compliance cost of an average-sized facility will not equal the average cost of all the facilities represented by that model plant. This is because, with economies of scale, the higher cost to smaller facilities will outweigh the lower cost to larger facilities relative to the average-sized facility. In this case, the compliance costs of the facilities represented by the model plant will be under-estimated. It is therefore important for the analyst to carefully consider the number of model plants needed to capture the heterogeneity among constituent facilities that could affect compliance cost estimates.

Assumptions on variables and parameters determined outside of the model can be important drivers in applied CGE analysis. For instance, estimates of elasticities that help define production processes and agent preferences are of particular interest because model results are often sensitive to these parameters. CGE-derived social cost estimates are particularly sensitive to parameters that affect behavior in labor markets due to their pre-existing distortions, such as the assumed elasticities governing the labor-leisure choice of consumers and production elasticities between factors of production (Marten et al. 2019).[81] Model results tend to be more sensitive to behavioral assumptions, for instance, the values chosen for elasticities relative to other data inputs such as the benchmark input-output data (see Text Box 8.2) (Elliot et al. 2012). Additional model closures often used in CGE modeling, like a fiscal budget closure, can also impact social costs and/or incidence depending on the modeling context. It may be important to conduct additional sensitivity analysis around these assumptions to understand the robustness of results if there is uncertainty in which closure mechanisms should be chosen.[82]

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80 Moreover, while many models are parameterized by a point estimate, Hertel et al. (2007) suggest that the confidence in modeled results may depend on the precision of the parameter estimate. The authors note that standard errors derived from the estimation framework for the parameter can also be used to guide sensitivity analysis. Also, see Section 8.4.4.

81 Previous research has also illustrated these sensitivities in other contexts. For instance, Shoven and Whalley (1984) observe that results from CGE analyses of the U.S. tax system are sensitive to labor supply, saving and commodity-demand elasticity assumptions. Fox and Fullerton (1991) find that estimates of welfare changes associated with tax reform are more sensitive to assumptions about the elasticity of substitution between labor and capital than the actual level of detail about the U.S. tax system in the model.

82 Closure rules are exogenous assumptions made in the CGE model that characterize aspects of the economy that are not explicitly modeled. For instance, many CGE models hold government consumption fixed by assigning a fiscal closure rule that assigns how budget surpluses or deficits induced by a policy are recycled back to households (e.g., lump sum, through the tax system). Goulder (2013) summarizes the economics literature on the implications of alternative revenue recycling closures for climate policy analysis.

8.4.4 Uncertainty

Clear communication of uncertainties is critical for transparency of the analysis. Uncertainty in social cost estimates can arise from uncertainty regarding the baseline, affected universe of facilities, policy responses, the number of affected markets and the cost of compliance activities. The degree to which these and other factors affect the confidence placed in the social cost estimates should be carefully reported and quantified when appropriate and possible.

While some key uncertainties have implications for both benefits and costs (e.g., for the baseline or affected facilities), several are unique to social cost estimation. For instance, estimates of compliance costs are often "study-level" estimates, used by engineers to judge the economic feasibility of projects prior to engaging in a costly planning process, and are associated with an error (e.g., +/- 30%).[83] In some cases, more precise cost estimates, described by engineers as "scoping" or "detailed" estimates, may be available. When compliance costs are used to approximate or generate social cost estimates, qualitative and quantitative information available on the degree of precision in the underlying estimates should be prominently discussed to provide appropriate context.

Uncertainty regarding the costs of compliance will propagate through to the estimate of social costs when used in a partial or general equilibrium model. Estimates of social costs may also be subject to model and parameter uncertainty. Model uncertainty refers to uncertainty in a model's ability to accurately represent underlying processes relevant to understanding how an intervention affects the system of interest (for example, due to simplifications necessary to tractably model complex systems) (NRC 2009). As noted in Section 8.4.3, challenges in parameterizing models, including the choice of functional form, also may be a prominent source of uncertainty. Conducting sensitivity analysis or more sophisticated probabilistic analysis across a tractable range of identified uncertainties can provide information on the robustness of the central social cost estimates.[84]

As noted in Section 8.2.3.4, technical change and learning can have an important effect on future compliance costs. Estimates about the effect of innovation will be inherently uncertain and, in some cases, may not be available. Even so, the expectation is that technological change and learning generally leads to lower social costs over time compared to a scenario that assumes no innovation occurs; uncertainty in this case is asymmetric, as innovation is unlikely to increase future costs.

Uncertainty may also affect social cost estimates when projecting the costs of regulations that are implemented by local or state jurisdictions in the future. For example, in illustrative attainment analyses conducted for some National Ambient Air Quality Standards (NAAQS), once all identified control technologies have been applied, some areas of the country may still be modeled as out of compliance with the air quality standard. In these cases, it is uncertain how attainment will be achieved and at what cost. Similarly, in the case of deregulatory actions, how state and local jurisdictions respond — for example by potentially enacting protections in place of the forgone federal standards — can affect the ultimate cost (and benefits) of relaxing the federal standard. In these cases, sensitivity analysis is useful for understanding the robustness of social cost estimates to alternate assumptions.

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83 For example, EPA's Air Pollution Control Cost Manual (U.S. EPA 2018) notes that "costs and estimating methodology in this Manual are directed toward the "study-level" estimate with a probable error of +/-30 percent."

84 See Chapter 5 for further discussion of uncertainty and sensitivity analyses.

8.4.5 Potential for Double-Counting

Because a regulation may have multiple effects through the economy, the analyst should take particular care to avoid double-counting costs. 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. Also, when reporting private costs for certain groups, the portion of those costs that reflect social costs versus transfers to other groups should be clearly identified in the analysis.

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. Instead, focusing on measures of changes in final demand, so that intermediate goods are not counted, can avoid the double-counting problem.

When analysts rely on multiple models that take fundamentally different approaches to cost estimation, care should be taken to separately report and characterize each model's output to avoid double-counting. For example, if a technology-rich PE model is linked to a CGE model, the estimate of social costs comes from the CGE model. The social cost is not the sum of the costs from the CGE and PE models. Furthermore, the cost estimate from a compliance cost model, for example the increased expenditures on compliance activities in the sector, should not be reported as the social cost of the regulation without further elaborating what this cost estimate represents, why it provides a reasonable estimate of the social cost, and that it is not equivalent to the actual social cost of the rule.

Chapter 8 References

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