1 Introduction

This Element focuses on benefit-cost analysis (BCA) of regulations that improve air quality, save energy, and reduce climate risks. Regulations are the dominant approach for managing environmental risks, rather than price-based instruments like carbon taxes. The distinction between quantity and price-based approaches is not always sharp, however. For example, grandfathered tradable permits can be viewed as a way to implement performance standards. The comparative properties of regulatory standards and price-based instruments are also widely studied. The Element emphasizes regulatory evaluation, but price-based policies are also considered when comparative assessment is informative for the topic at hand.

There is a well-institutionalized process for regulatory evaluation in which BCA is conducted. This process is known as "Regulatory Impact Analysis" in the United States or "Regulatory Impact Assessment" in other OECD countries (hereafter RIA). In the United States, the use of BCA for the evaluation of environmental regulations is associated with the implementation of nine major environmental statutes passed between 1969 and 1980 (Ferrey, 2013). In Europe, RIA has historically addressed the administrative burdens that regulations place on business, with environmental BCA more commonly applied to public infrastructure investments, for example, in transportation and energy. However, the use of BCA for the assessment of environmental policies and regulations is increasing throughout the OECD (Atkinson et al., 2018).

Benefit-cost analysis is inherently a tool for applied policy assessment, but it rests on a theoretical foundation in welfare economics. Conceptual approaches and trends in academic scholarship affect government guidance documents (Groom et al., 2022). Debates about methodology are common in the academic literature, and the relevance of methods and insights may not be clear to policymakers. This Element attempts to provide an integrative perspective of the academic literature, complemented with information from RIA practice. The goal is to better understand the methodology implications of the academic literature and its relationship to best practice, the gaps where more research is needed, and how RIA methodology for air, energy, and climate regulations (hereafter, AEC regulations) may evolve in the future. The intended audience is regulators and other constituencies interested in the nexus between scholarship and practice, analysts in government agencies and research organizations, and academic scholars and their graduate students.

The economic evaluation of environmental regulations is a large topic, and some limiting assumptions will guide our work. With the exception of the discussion of the Ramsey discount rate, the literature reviewed relies on the potential Pareto criterion rather than a social welfare function and distributional

weighting.[1] Our review also focuses on ex ante evaluation rather than ex post appraisal. The latter has been recommended by regulatory reform proponents in recent years (e.g., Dudley and Mannix, 2018). Finally, our review focuses selectively on some key topics: specifically, regulatory cost estimation, benefit valuation, discounting, distributional assessment, and uncertainty evaluation. We hope that reviewing this swath of material within this single Element will help inform readers with a selective knowledge of some of the topics, while conveying a current view of the larger field.

Even within this demarcated scope, space constraints limit the range and depth of the coverage afforded to individual topics. Thus, our review is liberally sourced to allow readers to follow up with more detailed investigations of subjects of particular interest. Two other Elements in this series provide a general review of BCA (Johansson and Kriström, 2018) and behavioral approaches to public policy (Sunstein, 2020).

We start in Section 2 with the evolution of the RIA process. Section 3 then assesses the literature on regulatory cost estimation, considering engineering cost approaches, partial equilibrium (PE) models, and the extensive general equilibrium (GE) literature. Section 4 categorizes the benefits of AEC regulations, and then addresses two important topics in more detail: the value of reducing the risk of illness and premature death from local air pollution, and methods for pricing greenhouse gas emissions. Section 5 turns to the topic of discounting. We review the standard discounting approaches and discuss how the discounting choice is related to the method for pricing carbon emissions. Section 6 reviews the literature on the distributional effects of AEC regulations, including the distribution of regulatory costs on the supply side; the incidence of regulatory costs on consumers; the implications of the distribution of pollution rents, and the distribution of the benefits. Section 7 reviews uncertainty analysis methods relevant for AEC regulations. These include methods for valuing "less fundamental" uncertainty, as well as decision-science methods such as robust decision-making (RDM) relevant for "more fundamental" uncertainty. Section 8 summarizes and offers recommendations for future research.

2 The Evolution of Regulatory Impact Analysis

2.1 Introduction

A regulation places legal obligations or constraints on those covered, usually individuals, businesses, or other organizations in society. Regulation is different from a public investment program, where the government raises funds and uses

[1] See Adler (2016), Kaplow (2020), and Weisbach (2015) for insightful but contrasting views on conceptual frameworks for benefit-cost analysis.

those funds to pay the costs of the program. For a regulation, the costs of compliance are typically incurred – at least initially – by the individuals and/or organizations subject to the regulation. Over time, regulatory costs to businesses may be passed on to consumers in the form of higher prices for products and services, or they may be paid for by diminished compensation to employees or owners of businesses.

Some regulations have strong policy rationales (e.g., civil rights protection), but the rapid proliferation of regulations in the twentieth century led to increasing concerns among businesses and the public. Critics argued that regulation was hurting the performance of the economy by contributing to inflation, reducing productivity, and curbing market innovation. Advocates of "regulatory reform" sought to eliminate unnecessary or overly burdensome regulations. When a regulation is justified, reformers promoted "smart regulation" that accomplished societal goals in ways that minimize cost and preserve as much flexibility as possible for personal and business choice.

One outgrowth of the reform movement is the requirement that regulators commission RIAs, a key element of evidence-based approaches to policymaking (Radaelli, 2020). An RIA may be undertaken before a new regulation is imposed and/or after a regulation takes effect, to ensure that the intended outcomes are achieved at reasonable cost.

The OECD defines RIA as a critical assessment of the positive and negative effects of proposed and existing regulations and nonregulatory alternatives (OECD, 2021). This definition is broader than BCA, even though BCA is a commonly used tool in RIA. Other methods include cost-effectiveness analysis, formal uncertainty analysis, scenario analysis, multiobjective decision analysis, risk assessment, and distributional analysis.

Some form of RIA is now commonplace in all OECD countries, but the practice of RIA is relatively recent in many developing countries (OECD, 2021).

2.2 Evolution of Regulatory Impact Assessment in the United States

President Ronald Reagan's 1981 Executive Order 12,291 is often cited as the origins of RIA in the United States even though presidents Gerald Ford and Jimmy Carter were both strong proponents of rigorous regulatory analysis. Executive Order 12,291 required federal agencies to prepare RIAs in support of proposed and final regulations. It also prohibited agencies from publishing proposed and final rules in the Federal Register without clearance from the Office of Management and Budget (OMB), which enabled OMB analysts to negotiate changes to rulemaking packages, including RIAs (Gray, 1998; Miller, 2011).

The Reagan administration's implementation of Executive Order 12,291 triggered substantial controversy and negative press for the Reagan White House. Critics charged that Reagan was more interested in a "relief" program for business than a constructive reform of regulatory process and policy (Eads and Fix, 1984; Olson, 1984). Some Reagan appointees at the agencies were slow to respond to legislative deadlines for new regulations.

The Reagan administration, facing a possible cutoff of funding for the Office of Information and Regulatory Affairs (OIRA), compromised by making the OIRA review process more open to public scrutiny and by agreeing to subject future OIRA administrators to a formal Senate confirmation process. Under president George H. W. Bush, the Senate did not confirm Bush's OIRA nominee, so OIRA staff worked informally with a special White House office, the Council on Competitiveness, overseen by vice president Dan Quayle. Agencies such as the Occupational Safety and Health Administration and Environmental Protection Agency (EPA) persistently resisted the efforts of OIRA staff to make changes to their RIAs and rulemaking documents. Gradually, as the unitary theory of executive power became better developed, White House regulatory review through OIRA became better accepted (Sunstein, 2012).

Under presidents Bill Clinton, George W. Bush, Donald Trump, and Joe Biden, implementation of the RIA aspects of the federal rulemaking process stabilized with some important exceptions. A Clinton executive order narrowed the OIRA review scope to "significant" regulations but granted OMB broad authority to decide which rules are significant. Clinton called for more consideration of distributional equity issues in RIA and replaced Reagan's numerical benefit-cost test with a more nuanced "benefits justify costs" test. The word "justify" is seen as allowing agencies to consider qualitative benefits and costs as well as equity issues (Katzen, 2018). Under George W. Bush, OIRA largely retained the Clinton approach but issued a technical guidance document on how to perform RIA, guidance that remains in effect today (OMB, 2003). The Obama administration emphasized the review of existing regulations and incorporated more behavioral economics into RIAs (Sunstein, 2014). The Trump administration launched an ambitious deregulatory agenda but much of this agenda was lost in court, in part due to poor-quality RIAs that did not adequately consider the foregone benefits of regulation (Belton and Graham, 2019). The Biden administration repealed the Trump administration's "regulatory budget" (aimed at spurring deregulation) but also announced it will retain the RIA process overseen by OMB. It pledged to modernize OMB Circular A-4, in part to give more emphasis to justice/equity concerns.

2.3 Evolution of Regulatory Impact Assessment in Europe

The United Kingdom and the Netherlands pioneered the "Better Regulation" agenda in Europe, leading to the European Union's eventual embrace of the agenda. The term "Better Regulation" has no universal definition but typically encompasses ex ante RIA, transparency in regulatory development, reduction of the administrative costs of regulation, consultation with stakeholders, and proportionality in the regulatory response to a problem (OECD, 2019; Wiener, 2006).

In 1985, the UK Government initiated a requirement that regulators prepare compliance cost assessments, emphasizing impacts on businesses and the economy. A broader RIA requirement, including benefits and costs, was adopted in 1998 and remains in effect today. A full RIA must accompany any proposals for primary or secondary legislation when they are proposed to the Parliament.

The Netherlands initiated business-impact studies in the 1980s. In 1994, the Dutch government called on regulators to streamline regulation "to what is strictly necessary." In the late 1990s, analysts in the Dutch government developed a new "Standard Cost Methodology" for "administrative costs" – what in the United States politicians call "red tape" or "paperwork burden." Using this metric, the Dutch government has accomplished one round of 25 percent reduction in administrative costs. However, administrative costs typically account for a small share of the overall business or societal costs of regulation, and the Dutch government is moving toward more comprehensive ex ante RIAs that quantify benefits and costs of regulatory proposals.

The European Union was slow to embrace Better Regulation until the Lisbon Agenda's emphasis on a competitive European economy in March 2000. Several years later, under the leadership of the Italian politician and economist Romano Prodi, the European Commission issued preliminary guidance on how to conduct RIAs. In 2005, under the leadership of Portugal's former prime minister, Jose Manual Barasso, the Commission instituted a mandatory RIA requirement and empowered a new Impact Assessment Board to review the quality of Commission RIAs, before they were released to the Parliament and the Council. With minor modifications, the EU process established by Barasso remains in effect today. In general, the EU embrace of RIA entailed less controversy than occurred in the United States, in part because the EU was able to learn from and respond to the US experiences (Golberg, 2018)

2.4 Comparing Regulatory Impact Assessment Requirements in Europe and the United States

The scope of the EU's RIA requirement is much broader than the scope in the United States (Wiener and Alemanno, 2010). The US RIA requirement does not

apply to primary legislation considered by Congress; it applies only to the implementing regulations developed by the executive branch. In Europe, RIAs are required for all proposals of primary legislation as well as secondary legislation, regulations, directives, communications and White Papers.

On the other hand, the results of RIAs have more potential impact on decision-making in the United States than they do in the EU. The United States uses OMB as a centralized authority to ensure that regulators perform RIAs and use the results of RIAs in rulemaking. The OMB is involved in regulatory policymaking as well as analysis quality. The EU's centralized process focuses primarily on analysis quality, delving less frequently into the substance of policy making choices. As an agent of the president of the United States, OMB has more authority than the EU's centralized review body – now called the Regulatory Scrutiny Board (formerly the Impact Assessment Board). As a nationally elected politician, the president of the United States has more power than the president of the Commission, who is selected by the heads of state in Europe, and this difference reveals itself in the usually strong powers of OMB relative to US regulatory agencies (Kagan, 2001).

Judicial review of RIAs, and their use in regulatory decisions, is also a bigger factor in the United States than in Europe (Bull and Ellig, 2017). Regulatory Impact Assessments in the EU rarely play a role in litigation after a regulation is adopted but in the US RIAs are often considered in judicial review of a final regulation (Cecot and Viscusi, 2014). Through the Administrative Procedure Act, the US Congress has empowered any individual or organizations harmed by a new regulation to challenge its legitimacy in federal court, and US courts tend to encourage benefit-cost reasoning (Noe and Graham, 2019). In Europe, absent compelling circumstances, judicial review of a new regulation is available only to one or more of the twenty-eight member states of the EU (Sweet, 2003).

The technical quality of RIA is highly uneven in both the United States and Europe (Dudley and Mannix, 2018; Fraas and Lutter, 2011; Radaelli and De Francesco, 2013). The quality challenge has magnified as many of the twenty-eight member states in the EU and the fifty states of the United States have initiated RIA programs of various degrees of comprehensiveness and technical sophistication.

In the following sections, we shift from the institutional setting of RIA to the methodology issues associated with formulating regulatory BCA, particularly, BCA applied to air pollution, energy, and climate change regulations. In the United States, the benefits of AEC regulations have dominated the total benefits of the US federal regulatory program, and BCA of these regulations has generated significant political controversy and associated legal actions from environmental and industry groups. The role of BCA in the evaluation of AEC

policies and regulations in Europe have been less significant than in the United States, but the use of BCA continues to advance with EU initiatives like the EU's Clean Air Policy Package and country initiatives to reduce air pollution and implement commitments under the Paris Accord.

3 Regulatory Cost Estimation

3.1 Introduction

Regulatory compliance diverts resources from other activities in the economy, imposing opportunity costs. Costs occur in the present, and also in the future when a regulation affects savings, investment, and capital accumulation. Forecasts of future regulatory impacts can also affect current-period economic adjustments.

The distributional pattern of regulatory costs affects their estimation. As noted in Section 2, regulatory costs are "off budget," falling on multiple actors in the economy. The incidence of compliance costs can be shifted, as when a polluter passes on some costs to consumers; regardless, costs are ultimately borne by the private sector without compensation.

Different kinds of regulatory costs can be identified. Direct "abatement costs" are the amount by which the costs of output increase over a given range. Partial equilibrium (PE) costs add the opportunity costs associated with output and price adjustments in the regulated market. General equilibrium (GE) costs incorporate the adjustments and feedbacks among all markets in the economy impacted by regulatory compliance.

For both practical and conceptual reasons, the scope and specificity of regulations influences the costing method. Some regulations target specific products or processes, such as appliance efficiency standards, rules governing the accidental releases of methane from natural gas pipelines, or pollution control requirements for refinery emissions. At the other end of the spectrum, regulations can apply economy-wide, such as a permit trading system used to implement a country's carbon emissions target.

For differentiated regulations of limited scope, engineering cost assessments of abatement costs is the feasible method, given data availability and limited budgets for conducting economic analyses. The proportionality requirement for RIA in the EU is less stringent than in the United States, and engineering cost estimates are likely to be used for many regulatory analyses in the EU.

Partial equilibrium models are useful when a fine-grained resolution of the regulated market is necessary for assessing the structure of regulatory alternatives and their market impacts (e.g., see Abito, 2020). Partial equilibrium modeling can also assess the dynamics of market behavior, such as regulatory

effects on savings and investment, firm exit and entry, and industry concentration (e.g., Fowlie et al., 2016).

General equilibrium modeling is conceptually justified when the regulated market is linked to other markets, and these markets are distorted (SAB, 2017). Linkages result when the good produced in the regulated market is a substitute or complement to goods produced in other markets, and/or the regulation affects equilibrium conditions in input or output markets upstream or downstream in the supply chain. The welfare cost of distortions in these markets will increase or decrease as their equilibria changes, depending on the nature of the distortion and the direction of the market adjustment (Harberger, 1964).

From a conceptual point of view, linkages to distorted markets, rather than the size of the regulation, determine the relevance of GE approaches (SAB, 2017).[2] From a practical point of view, data constraints limit the specificity with which policy options and the structure of regulated markets are represented in current-generation computational general equilibrium (CGE) models, making them difficult to apply in the RIA of many kinds of regulations. The continual evolution of methods is likely to make CGE modeling more routine in RIA, building from the large academic literature that shows the significance of "second-best" welfare costs for regulatory evaluation.

We review each of these costing approaches in the subsections that follow. Costs are taken as the measurement of changes between static equilibria in the presence and absence of the regulation, or in dynamic models, between steady states or balanced growth paths. Factors are assumed to be fully employed before and after the regulation (this assumption is reconsidered in Section 6 on distributional effects). Structural rigidities in the economy that reduce the mobility of inputs, such as sector-specific capital or labor, can be reflected in this assessment, but transactions costs arising from property rights exchanges are excluded (these costs are also addressed in Section 6). The economic implications of transition paths between steady states or balanced growth paths in dynamic models are not assessed in the literature reviewed in this section.[3]

3.2 Estimating Abatement Costs

Abatement costs are derived from "engineering cost" estimates that compile the cost of each of the resources that are estimated to be used in compliance, both one time and recurring. Market prices, which are often available from surveys of

[2] As an illustration, comparative static analyses around the equilibrium neighborhood of the solutions to analytically solved GE models manifest general equilibrium effects for the very small changes involved.

[3] See Rogerson (2015) for the economic implications of transition paths in dynamic models.

polluters and/or vendors of pollution control equipment, are used to represent unit values.[4] Vendor prices sometimes differ from those stated by polluters, but a range of estimates can be used. In complex cases, a regulatory agency can contract with a consulting firm to provide engineering cost estimates of pollution control technologies.

Direct abatement costs are affected by the type of regulation. Technology-based standards or stringent performance standards compel particular "end of pipe" control methods such as catalytic converters or particle traps to reduce vehicular emissions, or wet and dry scrubber technologies to reduce point-source emissions. Even with the specification of technologies, however, there may be more than one compliance option. The engineering cost algorithms used in EPA's greenhouse-control RIAs for vehicular emissions contain literally hundreds of control technologies that can be combined in various ways depending on the market segment. Forecasting the cost-effective technology choices for heterogenous polluters facing a variety of technological compliance options can be difficult.

When regulations cause a technology to be used on a larger scale than the historical pattern, the supply chain of the technology may experience cost savings due to learning by doing and economies of scale. When forecasting the unit costs of mass-produced technology, the US EPA often incorporates gradual rates of savings to account for these processes.

It is not uncommon for emissions regulations to stimulate technological innovation in pollution control and / or monitoring technologies, lowering the cost of regulation. The EPA's original tailpipe standards in the 1970s induced costs due to new designs of motor vehicle engines but the performance advantages of the new engines produced nonpriced advantages that, when valued using hedonic methods, were larger than the market costs of the engines.

Experience with new technologies is not always better than anticipated. A new technology may not perform as well as vendors projected or may produce side effects that were not anticipated (e.g., sulfuric acid emissions from the early catalytic converters). Some fuel-efficiency technologies alter the way a vehicle feels when driven, and consumers have rejected some of these technologies.

Performance standards are another approach to controlling pollution. These standards impose emissions limitations without specifying the method to achieve them, offering more compliance flexibility than technology-based standards. A performance standard can limit total emissions, or the level of

[4] In theory, these prices should be shadow priced for economic distortions. In practice, such adjustments are often omitted.

pollution produced per unit of output or input. For example, standards can limit the usage of energy per megawatt hour of electricity or limit the mass of pollutants emitted per unit of energy input. These differences lead to different economic adjustments, giving different abatement costs (Helfand, 1991).

An important justification for performance standards is asymmetric information. Polluters know more about their abatement options than regulators, giving polluters the flexibility to exploit their private information to choose the combination of pollution control methods that minimize their costs. To comply with an emissions standard, for example, a stationary-source polluter might increase boiler maintenance, change boiler running times or operational conditions (e.g., for NO_x emissions control), or fuel switch, altering the mix of operational inputs per unit of output. Pollution controls are another option. These cost-minimizing choices can be difficult to forecast.[5] As with more prescriptive approaches, it is not uncommon for analysts to make educated guesses about polluters' compliance strategies.

Incentive-based instruments like emissions taxes or tradable permits allow the additional flexibility for cost-minimization across a population of polluters, broadening compliance options to include differential emissions control among them. Regulations that specify allowable air pollution concentrations over a geographic area, usually averaged over a period of time (e.g., twenty-four hours to one year) give the most compliance flexibility. National Ambient Air Quality Standards in the United States offer an example of this type of regulation. To comply with ambient standards, abatement tradeoffs can be made among different sectors and end uses.

If priced-based policy instruments like emissions taxes or tradable permits are implemented, the marginal costs of pollution control are revealed in the market price of pollution. This property avoids the need to estimate abatement costs, an important advantage in addition to the cost-efficiency of these approaches. On the other hand, forecasting compliance modalities for ambient air quality standards is a significant challenge. As a result, abatement cost estimates for ambient standards come with a large uncertainty bound.

3.3 Behavioral Effects and Partial Equilibrium Costs

Direct abatement cost estimates do not reflect market responses to regulation. In the general case, the equilibrium output level in regulated markets will decline in response to regulatory actions. This "output substitution effect" provides an

[5] As an example, in the United States between 2005 and 2015, unanticipated declines in natural gas prices (owing to the development of fracking) and growth in renewables technology displaced coal in the fuel mix for electricity generation, reducing the anticipated cost of pollution control (Fell and Kaffine, 2018).