Cobenefits and Regulatory Impact Analysis: Theory and Evidence from Federal Air Quality Regulations

Joseph Aldy, *Harvard University and NBER,* United States of America

Matthew J. Kotchen, *Yale University and NBER,* United States of America

Mary Evans, *Claremont McKenna College,* United States of America

Meredith Fowlie, *University of California, Berkeley, and NBER,* United States of America

Arik Levinson, *Georgetown University and NBER,* United States of America

Karen Palmer, *Resources for the Future,* United States of America

Executive Summary

This article considers the treatment of cobenefits in benefit-cost analysis of federal air quality regulations. Using a comprehensive data set on all major Clean Air Act rules issued by the Environmental Protection Agency over the period 1997–2019, we show that (1) cobenefits make up a significant share of the monetized benefits; (2) among the categories of cobenefits, those associated with reductions in fine particulate matter are the most significant; and (3) cobenefits have been pivotal to the quantified net benefit calculation in nearly half of cases. Motivated by these trends, we develop a simple conceptual framework that illustrates a critical point: cobenefits are simply a semantic category of benefits that should be included in benefit-cost analyses. We also address common concerns about whether the inclusion of cobenefits is problematic because of alternative regulatory approaches that may be more cost-effective and the possibility for double counting.

JEL Codes: D61, Q53, Q58

Keywords: benefit-cost analysis, regulatory impact analysis, Clean Air Act, cobenefits, air quality, regulatory rebound, double counting

I. Introduction

Benefit-cost analysis (BCA) is a useful and widely employed tool for informing and evaluating public policy decision making. Its primary objective is to assess whether a particular policy or policy proposal promotes

Environmental and Energy Policy and the Economy, volume 2, 2021.
 https://doi.org/10.1086/711308

economic efficiency compared with a baseline scenario. At the most general and comprehensive level, BCA is a systematic aggregator of all anticipated or realized impacts, positive and negative, to all relevant parties, and at all relevant points in time. The benefit-cost criterion is simply a test of whether the benefits exceed the costs: if the net benefits are positive, then the policy promotes economic efficiency compared with the baseline status quo.

The use of BCA by agencies of the US federal government has a long bipartisan history. President Reagan established a requirement for regulatory actions such that "the potential benefits to society for the regulation outweigh the potential costs to society" (EO 12291). As part of this objective, the Reagan administration also required agencies to produce a regulatory impact analysis (RIA)—in effect, a BCA in most cases—of major rules.[1] President Clinton continued the requirement for BCA but modified the standard so that agencies "shall assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs" (EO 12866). Every administration since has employed this same approach to guide its review of federal regulations, including most recently the Trump administration, which added new provisions seeking to manage overall regulatory costs (EO 13771; OMB 2017).

BCA has played a particularly important role in support of federal regulations aimed at protecting human health and environmental quality. Those analyses applied to regulations focused on improving air quality often yield the greatest quantified costs and benefits of all regulations across government agencies. For example, in a review of all new federal regulations during the 10-year period from FY 2007 to FY 2016, the Office of Management and Budget (OMB 2019) finds that Environmental Protection Agency (EPA) rules account for 80%–84% of all monetized benefits and 63%–71% of all monetized costs.[2] Moreover, rules coming out of the EPA's Office of Air and Radiation in particular are found to have especially high net benefits.

The anticipated impacts of many federal policies are broad, with some benefits and costs directly linked to the policy's intended focus and other benefits and costs arising only indirectly. Nevertheless, BCAs conducted in line with best practices seek to count all significant benefits and costs, whether they arise as a direct result of the policy's intended objectives or as a result of an ancillary change attributed to the policy. Historically, BCAs conducted by the EPA have treated ancillary benefits and costs in ways consistent with economic theory and regulatory guidance—on an equal footing with benefits more directly linked to the policy. Recently, however, the EPA has made decisions and solicited feedback that indicate a potential shift in—or at least questioning of—its treatment of ancillary benefits and costs, here referred to generally as "cobenefits" and "cocosts."[3]

It is within that context that the present article considers the treatment of cobenefits in BCAs, with a particular focus on air quality regulations, where the issues are front and center. Specifically, the article has two primary objectives:

1. to provide a descriptive overview of the role cobenefits have played in BCAs of federal air quality regulations, using detailed data from all available RIAs, 1997–2019; and
2. to develop a simple theoretical framework to clarify how cobenefits are simply another category of benefits that should be included in BCAs and elucidate some of the unique challenges that arise for measuring them well.

The next section provides background on cobenefits in the context of energy and environmental policy and recent policy actions. Section III describes our data collection, reports a range of descriptive statistics and trends over time, and discusses a few specific cases to illustrate salient issues. Section IV develops a theoretical framework that introduces major concepts and definitions, and it explicitly addresses some concerns raised about cobenefits. Section V concludes with a summary of our findings and observations about the political economy of why cobenefits have become increasingly important and a growing topic of concern.

II. Background and Recent Actions

A. Cobenefits and Cocosts

Cobenefits (or cocosts) arise when compliance with a regulation leads to benefits (or costs) that are not directly tied to a regulation's intended target. Although we focus on air quality regulations, the notions of cobenefits and cocosts are not unique to this setting. Consider, for example, the Emergency Highway Energy Conservation Act of 1974, which established a speed limit of 55 miles per hour. The purpose was to "conserve fuel during periods of current and imminent fuel shortages," and thus the direct benefits of the act included fuel savings. However, a cobenefit of the act was reduced road fatalities (Friedman, Hedeker, and Richter 2009). Another example is the Americans with Disabilities Act, which mandated that sidewalks have curb cuts to benefit individuals in wheelchairs, but the curb cuts also helped pedestrians pushing strollers, pulling heavy carts, or wheeling luggage, and those are considered cobenefits (Blackwell 2017).

There are many examples in the environmental economics literature where cobenefits and cocosts have played a role. Sigman (1996) shows that regulations of hazardous waste disposal lead to increases in air pollution emissions. Kotchen et al. (2006) conduct an ex post BCA of a hydroelectric project's effect on river flows, yet the analysis accounts for the cobenefits of reduced emissions because of displaced electricity generation from fossil fuels. In another example, Hansman, Hjort, and León (2018) show that a regulation designed to limit overfishing exacerbates air pollution from fishmeal processing plants.

A growing literature also explores the local air pollution implications of policies targeting greenhouse gas (GHG) emissions and climate change. Lutter and Shogren (2002) illustrate how regulating carbon dioxide (CO_2) emissions under a cap-and-trade program improves local air quality, primarily through reductions of particulate matter (PM). Burtraw et al. (2003) show cobenefits of taxing CO_2 emissions in the form of reduced nitrous oxide (NO_x) emissions and lower compliance costs with other NO_x and sulfur dioxide (SO_2) regulations. More generally and recently, Karlsson, Alfredsson, and Westling (2020), reviewing 239 peer-reviewed studies that assess the cobenefits of climate mitigation policies, find that most studies focus on air pollution-related benefits, where the cobenefits alone often outweigh compliance costs. Other cobenefits that emerge from their review include enhancements to biodiversity, energy security, and water quality.

Overall, the range of studies in the academic literature recognizes that the ancillary pollutant effects could either worsen or improve as a consequence of regulating the targeted pollutant. Moreover, these examples illustrate the appropriateness and importance of accounting for both cobenefits and cocosts.

B. *Regulatory Guidelines*

Federal agencies have formally recognized the potential importance of cobenefits and cocosts to their rulemakings. They have therefore developed guidance for systematically accounting for these indirect effects in evaluations of regulatory proposals. OMB, which is responsible for reviewing major regulations before they are finalized, directs all agencies to account for cobenefits and cocosts in its guidance for agency RIAs. It states that when evaluating the benefits and costs of regulations, agencies should "identify the expected undesirable side-effects and ancillary benefits of the proposed regulatory action and the alternatives. These should be added to the direct benefits and costs as appropriate" (OMB 2003, 2–3). This general guidance makes clear that the scope of regulatory analysis extends beyond determining whether the regulation achieves the statute's primary goal. That is, cobenefits and cocosts should be included in the analysis.

The EPA's *Guidelines for Preparing Economic Analyses*, with specific provisions for conducting BCAs, likewise calls for explicit accounting of cobenefits and cocosts: "An economic analysis of regulatory or policy options should present all identifiable costs and benefits that are incremental to the regulation or policy under consideration. These should include directly intended effects and associated costs, as well as ancillary (or co-) benefits and costs" (EPA 2014, 11–12).[4]

C. *Cobenefits and the Clean Air Act*

Air quality regulations have a long history of delivering multiple types of social benefits, including cobenefits. Some of these were accounted for in the design stages of the Clean Air Act (CAA); others were not fully understood until after CAA regulations were introduced. Here we review several examples.

To reduce air pollution from cars and light trucks, the EPA has often regulated both vehicles and the fuels they use (Aldy 2018). This system-based approach has delivered multiple emissions benefits. In 1973, the EPA promulgated a regulation requiring gasoline stations to market unleaded gasoline (EPA 1973). This regulation was motivated by the fact that lead in the fuel harmed catalytic converters, a new technology mandated by other CAA regulations intended to reduce tailpipe emissions of carbon monoxide. The EPA subsequently established a National Ambient Air Quality Standard (NAAQS) for lead in 1976 (EPA 1976). Removing lead from gasoline therefore delivered on two air quality objectives in the 1970s and 1980s: reducing ambient concentrations of carbon monoxide and of lead (Nichols 1997).

The 1990 CAA Amendments authorized the first cap-and-trade program for power plant SO_2 emissions. The primary goal was to reduce the risks posed by acid rain, including the acidification of forests and waterbodies (Schmalensee and Stavins 2013). Most of the monetized benefits, however, have resulted from reducing human exposure to fine PM that contributes to premature mortality. In this case, the sizable health benefits caused by the reduction in SO_2—an important precursor to PM formation—were not fully appreciated or anticipated at the time the regulation was implemented. Advances in epidemiology after the 1990 CAA Amendments provided increasingly strong evidence on the public health risk of fine PM.

Another prominent example is from 2015, when the EPA promulgated the Clean Power Plan to reduce CO_2 emissions in the power sector (EPA 2015). Cobenefits played an important role in this rulemaking because it was anticipated that, in the process of reducing CO_2, power plants would also significantly reduce SO_2 and NO_x, with subsequent reductions in fine PM and ozone because of chemical precursor relationships. As a result, the agency projected billions of dollars of monetized benefits per year from mitigating climate change and billions of dollars of monetized benefits per year from reductions in premature mortality due to reduced exposure to ambient PM and ozone.

Sometimes Congress has specifically amended legislation to expand the target objectives of existing rules, effectively converting cobenefits into targeted benefits. This has happened when rules targeted at fossil fuel consumption were expanded to mitigate climate change. For example, the 1975 Energy Policy and Conservation Act created the corporate average fuel economy standards and introduced fuel economy labels for new vehicles in response to the 1973–74 oil shock. The goal was to reduce fuel consumption.[5] The Energy Independence and Security Act of 2007 added the goal of reducing GHG emissions, setting more ambitious fuel efficiency standards and directing the Department of Transportation (DOT) to revise fuel economy labels to include information about GHG emissions.[6]

A similar expansion occurred with respect to biofuels in transportation. The Energy Policy Act of 2005 created renewable fuel standards with annual goals for biofuel consumption, with the goal of reducing US oil consumption.[7] The Energy Independence and Security Act of 2007 revised this program, recognizing GHG cobenefits by setting more ambitious biofuel volume goals and mandating multiple low-carbon biofuel categories so that the policy could simultaneously reduce oil consumption and CO_2 emissions.[8]

D. Recent Actions Related to the Inclusion of Cobenefits and Cocosts

Despite the important role that cobenefits (and cocosts) have played in shaping outcomes under past CAA regulations, and the well-established regulatory guidance about including them, the EPA has undertaken recent actions with the potential to diminish the value of cobenefits or to question their inclusion in economic analyses.

EPA Science Transparency Proposed Rule, 2018. The EPA (2018b) issued the proposed rule in the name of improving transparency and replicability of the science underlying its assessment of regulatory benefits and costs. This proposal does not explicitly address cobenefits. Instead, it raises obstacles to including monetized value of PM improvements that form the basis for many of the cobenefits in recent EPA rulemakings. In particular, the proposed rule would limit the EPA's use of proprietary or confidential health data of the type commonly used to evaluate the consequences of PM exposure. In many cases, these studies are done with the understanding that individual information will be kept confidential and thus not made publicly available.

EPA Affordable Clean Energy Final Rule, 2019. The EPA (2019b) issued the Affordable Clean Energy rule (ACE), a replacement for the 2015 Clean Power Plan, which set CO_2 emissions standards for existing power plants. In its summarization of the benefits and costs of ACE, the EPA presented two tables. One followed the standard practice, reporting the costs, climate benefits, ancillary health benefits, and overall net benefits. The second summary table contained the same information but with the ancillary benefits excluded. That exclusion runs contrary to OMB guidance, EPA guidance, and standard practice. The presentation of results in this way is significant because it substantially reduces the overall net benefits and signals a shift within the EPA away from counting all benefits on an equal footing.

EPA Increasing Consistency and Transparency in Considering Benefits and Costs in the Clean Air Act Rulemaking Process Proposed Rule, 2020. The EPA (2018a) solicited public feedback on the conduct of BCAs, including the following: "What improvements would result from a general rule that specifies how the Agency will factor the outcomes or key elements of the benefit-cost analysis into future decision making? For example, *to what extent should EPA develop a general rule on how the Agency will weigh the benefits from reductions in pollutants that were not directly regulated (often called 'co-benefits' or 'ancillary benefits') . . .* ?" (EPA 2018a, 27527, emphasis added). In 2020, the EPA (2020b) proposed a new rule focused on BCAs of CAA regulations. Under the proposal, future

EPA CAA regulations would include two summaries of the RIA: one characterizing all benefits and costs, as has been standard practice, and the other including only "a listing of the benefit categories arising from the environmental improvement that is targeted by the relevant statutory provision, or provisions[,] and would report the monetized value to society of these benefits" (EPA 2020b, 35622).

EPA MATS Appropriate and Necessary Determination, 2020. The EPA (2020c) finalized a new rule reversing its previous finding on the legal basis of the Mercury and Air Toxics Standards (MATS), a regulation designed to reduce the emissions of mercury and other hazardous air pollutants (HAPs) from power plants. Whereas the EPA concluded in 2011 and 2016 that it was "appropriate and necessary" to regulate mercury and other HAPs under authority of the CAA, it reversed this decision in 2020. The reversal rests entirely on omitting from consideration the cobenefits of reducing fine PM, which accounted for the vast majority of monetized benefits in the original 2011 RIA (Aldy et al. 2019, 2020). The EPA's new rationale is that only the target pollutant benefits should count when making the legal determination.

EPA Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources Review, 2019. The EPA's new approach to the ancillary impacts of regulation does not, however, appear to be consistently applied across rulemakings. The proposed amendments to the New Source Performance Standards (NSPS) for the oil and gas sector reflect an inconsistent regulatory treatment of cobenefits. In the case of this proposed rule, the EPA (2019a) argues that regulating volatile organic compounds (VOCs) results in a cobenefit: lower methane emissions. As a result, the agency's proposal opts against setting methane-specific standards because they "are entirely redundant of the existing NSPS for VOCs" (EPA 2019a, 50254).

EPA/DOT Tailpipe CO_2/Fuel Economy Final Rule, 2020. The EPA's new approach that discounts the ancillary effects of regulations is also not represented in the revision to the EPA tailpipe CO_2 emission standards and National Highway Traffic Safety Administration (NHTSA) fuel economy rules. Issued in 2020, this joint rule targets fuel economy and GHG emissions from automobiles. But the EPA analysis accounted for expected cobenefits and cocosts arising from changes in traffic fatalities and traffic congestion (EPA and NHTSA 2020). These ancillary changes were included in the calculations of the total net benefits of the rule, not weighted differently from the primary objectives of the EPA's authority for the regulations under Title II of the CAA.

Those recent EPA rulemakings trouble us, for two reasons. First, as noted, they appear to be inconsistent. Sometimes cobenefits and cocosts are excluded from BCA analyses or listed separately, as in the case of ACE or MATS. But other recent rulemakings include cobenefits and cocosts, as in the NSPS for oil and gas and the joint EPA-NHTSA fuel economy rules. And second, treating cobenefits and cocosts differently from targeted benefits and costs departs from standard EPA practice. To document the extent of that departure, in the next section we review the EPA's treatment of cobenefits in its RIAs for major CAA rules since 1997.

III. Trends and Patterns across CAA RIAs

We now examine long-term trends and patterns in the role of cobenefits in EPA analysis of CAA rules and regulations. We begin with an overview of our data collection and preparation, before turning to the results of our analysis. The complete database that we created, along with additional details to those described later, are available in the online supplementary information to this article.[9]

A. Constructing the Sample

We focus on the category of major rules, because these consistently have well-developed assessments of the economic impacts of the regulations in question. We reviewed the OMB annual reports to Congress on the benefits and costs of regulations to identify all major CAA rules issued by the EPA over the period 1997–2019. We provide further details in the appendix, along with full citations to all rules and RIAs compiled in our data set. Over this 23-year period, the EPA issued 58 major regulations identified in the OMB annual reports, and figure 1 shows the number of rules issued in each year. In some cases, especially for rules promulgated in the 1990s, the EPA conducted cost-effectiveness analysis rather than a BCA. This means that those RIAs focus on estimating the regulatory expenditures per ton of emissions reduced, rather than on estimating the monetized value of air quality benefits. After excluding these cases, we compiled a sample of 48 air quality rules for which the EPA published a prospective BCA that explicitly monetized at least some of the rule's benefits in its RIA.[10]

B. Distinguishing between "Targeted Benefits" and "Cobenefits"

To determine the "targeted benefits" of a rule and distinguish these from the "cobenefits," we reviewed the RIAs and the promulgated regulations.

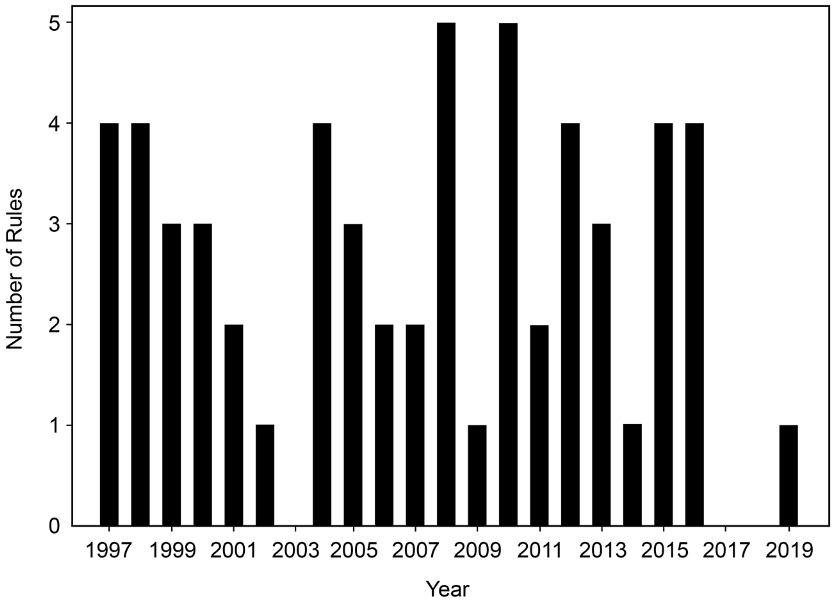

Fig. 1. Major Clean Air Act regulations promulgated by Environmental Protection Agency, 1997–2019. Annual counts were produced by the authors based on a review of Office of Management and Budget reports to Congress.

Each EPA rule describes the relevant statutory authority or authorities that motivate the regulatory action, which can often identify the pollutant or pollutants targeted under the law. The rule and the RIA also describe the specific emissions standards by pollutant, and the identification of each pollutant that must be monitored under the rule is one way to identify those that are targeted. There are, however, a variety of cases in which the targeted benefit is identified in the statutory authority, yet the specific emission standards set in the rule apply to emission precursors for that pollutant. An example is ozone as a targeted pollutant, with emissions standards that apply to the precursors of NO_x and VOCs.

In some cases, the identification of the targeted benefits appears quite straightforward. For example, during our sample period, the EPA issued National Ambient Air Quality Standards for lead, ozone, $PM_{2.5}$ (particulate matter less than 2.5 μm in diameter), and SO_2. These regulations set the maximum permissible ambient air quality concentrations for these specific air pollutants—and thus the targeted benefits of the lead standard, for example, are those benefits clearly associated with the reduction in lead pollution.

In other cases, the identification of the targeted benefits is more complicated. To illustrate some of the challenges involved and to describe our procedure, we walk through a particular example: the 1998 "NO_x SIP Call" rule (regulation identifier number [RIN] 2060-AH10).[11] The rule was motivated by the need to address the cross-state transport of ozone pollution and the adverse public health consequences of high ambient ozone concentrations (Napolitano et al. 2007). Indeed, it built on and expanded the then-existing Ozone Transport Commission NO_x trading program for Mid-Atlantic and Northeast states (Linn 2008). To achieve reductions in ozone, the rule focused on NO_x, a precursor to atmospheric ozone. The monetized benefits of the rule arise from reductions of ozone, $PM_{2.5}$, and water pollution through nitrogen deposition.

The question in this case is whether to treat the targeted pollutant as ozone or NO_x: the choice has important consequences for the categorization of benefits. We treat ozone as the targeted pollutant because of the rule's clear intent and classify the benefits associated with fine PM and water pollution—which result from the NO_x emissions but are distinct from ozone pollution—as cobenefits.

More generally, we apply the following classification procedures for identifying the monetized targeted benefits from the monetized cobenefits. First, we review the rule as published in the *Federal Register* to identify specific statutory authorizations. Second, we review the rule and the RIA for information on specific pollutant emission standards. Third, we review the rule and the RIA to assess how regulating a precursor pollutant may connect to the targeted pollutant under the statutory authority. Finally, we account for (but do not automatically follow) the EPA's specific description of some benefits as cobenefits.

Two further conventions that we employ are worth mentioning to clarify how we made classifications. The first is that all benefits directly associated with a targeted pollutant are considered targeted benefits. For example, ozone benefits of the NO_x SIP Call rule include those associated with ozone effects on worker productivity, commodity crop production, and commercial forest production, all of which go beyond the public health focus of the primary NAAQS. The second convention is that when targeted pollutants are themselves precursors to other pollutants for which reductions lead to monetized benefits, these "downstream" benefits are considered cobenefits. This scenario is most common when the target pollutant is SO_2, which is a precursor for fine PM and often generates significant cobenefits.

Finally, we recognize that, for some rules, the classification procedures we employ require a degree of subjectivity. We have nevertheless sought to define categories in ways that respond to emerging concerns about the role of cobenefits in EPA RIAs. Although a central part of our theoretical contribution later in the article is that such categorizations should not matter in BCAs, having some empirical foundation on which to anchor the discussion is important. We provide additional information in our data appendix (https://doi.org/10.7910/DVN/J2HWDA), including a link to our database so that other scholars, analysts, and stakeholders can replicate, modify, and expand on this analysis.

C. Selecting Benefits and Costs Estimates

Few of the RIAs in our sample produce present values for the streams of costs and benefits over time. Notable exceptions are the joint EPA-NHTSA rules that address CO_2 emissions and fuel efficiency in vehicles. These RIAs produce annual streams of benefits and costs out to 2050.

As we will show later, EPA RIAs have consistently accounted for all the targeted and ancillary benefits and costs of regulations. But on other issues, RIAs have been considerably less consistent. The most common practice is to generate a "snapshot" estimate for the annual costs and benefits in a future year during "full implementation" of the rule. In many but not all of these cases, the benefits are not discounted to produce a present value in the year the regulation is promulgated. They are the value of benefits and costs in some future year expressed in some base year dollar equivalent. In a subset of these cases, the premature mortality benefits associated with PM—some of which occur with a period of latency—are discounted back to the snapshot year at either a 3% or a 7% discount rate. In addition, reducing CO_2 emissions and methane (CH_4) emissions that occur in a snapshot year generate benefits, which are spread out over hundreds of years, that are monetized using the social cost of carbon (SCC) and social cost of methane based on a 2.5%, 3%, or 5% discount rate.

Many RIAs also present ranges of estimates. Some may reflect differences in assumptions on the premature mortality dose-response functions for ozone and PM. Some may reflect a range over multiple implementation and compliance scenarios, especially in those cases where states have some discretion on how they implement the rule (e.g., the Regional Haze Regulations, RIN 2060-AF32).

The preceding discussion means that it is challenging to construct a consistent set of benefits and costs that enable true apples-to-apples comparisons across RIAs. In our analysis, we have nevertheless endeavored to create a data set that produces measures of benefits and costs that are as comparable as possible, given the information published in the RIAs. In general, we have opted for a full-implementation, snapshot-year measure of benefits and costs based on a 7% discount rate, where discounting is applied to the extent possible.[12] The SCC and some compliance cost calculations will be exceptions because of the differing rates used in the underlying analysis. Our database includes upper- and lower-bound estimates, but here we report results based on the average of the two, unless otherwise indicated. All values are reported in 2019 dollars, with conversions made using the standard gross domestic product (GDP) deflator.[13]

In some RIAs, the costs represent the amortization of capital and operating costs for complying with the regulation over a specified time horizon. This approach is typically estimated with a 7% discount rate. In other RIAs, the snapshot-year costs are simply the estimated compliance costs for that year, and it is unclear the extent to which these snapshots account for initial investments in pollution control equipment. In a few rules, the underlying model for estimating compliance uses discount rates other than 3% or 7%. For example, the model runs used for the NO_x SIP Call rule are based on a 6% rate.[14]

D. *Results of Analysis of EPA CAA RIAs*

The EPA regulatory program consistently delivers the greatest monetized benefits and imposes the largest costs of any federal regulatory agency's actions (e.g., OMB 2019). To provide context for an assessment of cobenefits, figure 2 illustrates the net social benefits for the CAA regulations in our database. The median rule has about $4.1 billion in net social benefits, based on the average of the lower and upper bounds of benefits and costs for that regulation's snapshot of a full-implementation year. Every rule has positive net social benefits, with five exceptions: (1) the 1997 NAAQS for ozone (RIN 2060-AE57), with an estimated –$6 billion in net social benefits; (2) the 1997 medical waste incinerator standards (RIN 2060-AC62), with an estimated –$125 million in net social benefits; (3) the 2008 NAAQS for lead (RIN 2060-AN83), with an estimated –$90 million net social benefits;[15] (4) the 2005 mercury power plant rule (RIN 2060-AJ65), with an estimated –$1 billion in net social benefits; and (5) the 2016 NSPS for methane at oil and gas operations (RIN 2060-AS30), with an estimated –$200 million in net social benefits.

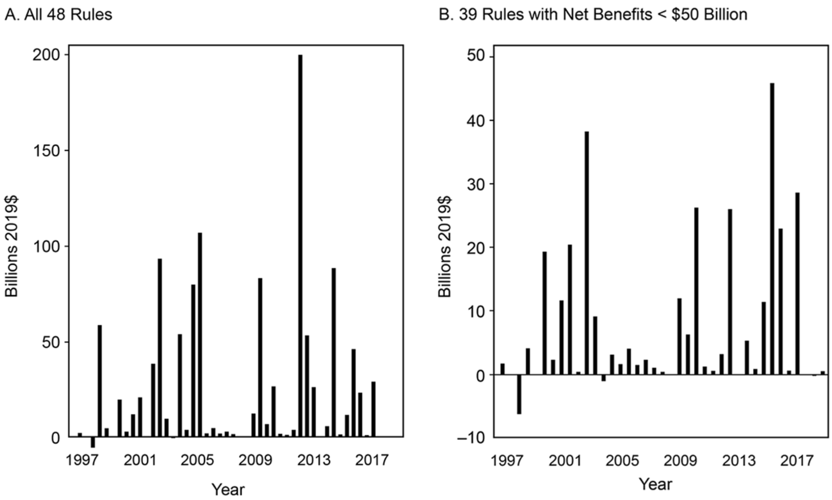

Fig. 2. Net social benefits of Clean Air Act regulatory impact analyses, 1997–2019. The amounts are based on 1-year full-implementation snapshots of monetized benefits and costs. In each panel, regulations are ordered chronologically. Panel A presents results for all 48 regulations in our database, and panel B excludes 9 regulations with net social benefits in excess of $50 billion to better illustrate impacts of rules with smaller net economic effects.

We find that cobenefits account for about 46% of the monetized benefits on average across all RIAs. As figure 3 illustrates, this average masks considerable heterogeneity among the rules. Some rules have no monetized cobenefits, such as the 2013 fine PM NAAQS and the 2014 Tier 3 motor vehicle and emissions standards, which targeted both fine PM and ozone. Other rules, especially several of those focused on HAPs, have zero monetized benefits for the targeted pollutant. In these cases, fine PM pollution reductions are the primary, if not exclusive, source for monetized benefits. For the three joint EPA-NHTSA regulations targeting carbon dioxide emissions and fuel economy (RINs 2060-AP61, 2060-AQ54, and 2060-AS16), we consider reduced fuel costs one of the target benefits of the regulation, given NHTSA's statutory authority. If, however, we were to consider reduced fuel costs a cobenefit from the standpoint of the EPA under its CAA authority, then about $130 billion of benefits over 2011–16 would shift and several of the black bars at the bottom of figure 3 would fall substantially.

The monetized cobenefits in CAA RIAs are primarily a story about fine PM. This has long been acknowledged by the EPA and OMB, the latter in its annual reports to Congress on the benefits and costs of regulation

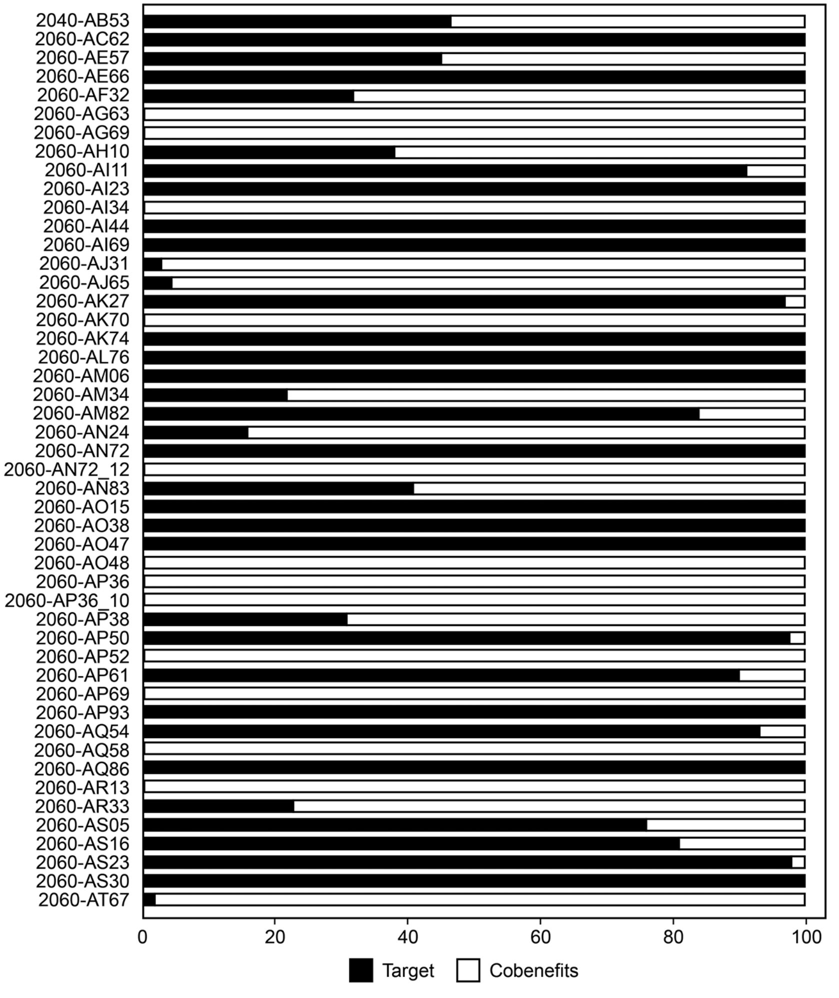

Fig. 3. Relative contribution of target pollutant benefits and cobenefits to total monetized benefits. Regulations are listed by regulation identifier number (RIN) and ordered chronologically from top to bottom spanning 1997–2019. The appendix lists each regulation with its associated RIN.

(e.g., EPA 1997; OMB 2005). In our assessment, the reductions in fine PM identified as cobenefits represent 96% of all monetized cobenefits over 1997–2019. The other categories are visibility (2%) and SO_2, ozone, CO_2, and energy and electricity savings (less than 1% each).

We should also note that in several cases, the EPA estimated cocosts because the regulation would increase emissions of a monetized pollutant. For example, the lower bound of the SO_2 cobenefits in the 1998 pulp and paper "cluster rule" are negative, and the 2010 HAPs standards for Portland cement plants include CO_2 cocosts that result from the increased electricity demand expected under facilities' compliance strategies.

Cobenefits and cocosts often play a pivotal role in determining the sign of net social benefits among the monetized categories of costs and benefits for many CAA regulations. For exactly 50% of the regulations in our database, the monetized benefits from reductions in the targeted pollutant exceed the monetized costs. That is, these rules would show positive net benefits even without the inclusion of cobenefits. The flip side is that half of the rules in our database would have negative net social benefits if cobenefits were omitted from the analysis. In these rules, the EPA also identifies but does not monetize a variety of additional categories of benefits. In the conclusion, we address why the agency may stop counting monetized benefits under the CAA after it has demonstrated positive net benefits.

Some categories of rules have targeted benefits that consistently outweigh monetized costs. For example, the 16 rules that explicitly target fine PM each have positive net social benefits based on an exclusive accounting of monetized benefits associated directly with the targeted pollutant. The joint EPA-NHTSA rules addressing tailpipe CO_2 emissions and fuel economy always have positive net social benefits based only on targeted benefits; this finding follows because of our accounting of fuel economy as a primary motivation of these rules and the sizable fuel savings benefits estimated by the agencies.

In contrast, regulations targeting HAPs—such as the National Emission Standards for Hazardous Air Pollutants—frequently have zero or modest monetized benefits for the targeted pollutant. Most regulations that focused on HAPs, 79% of those in our database, have monetized target benefits less than the monetized costs. In these cases, the monetized cobenefits derive from reductions in fine PM, and in some cases, the regulation explicitly limits PM emissions as a proxy for the HAP. For example, the HAP standard for combustion sources at various pulp mills (RIN 2060-AI34) explicitly notes that the "rule promulgates PM emissions limits as a surrogate for HAP metals" (66 *Federal Register* 3184). Although we classified the PM benefits in this case as cobenefits, these PM emissions limits are explicitly prescribed by the rule. Another reason, at least in the case of the MATS rule, is that the science for and means of economic evaluation for mercury emissions have evolved only recently, whereas the techniques for valuing the health consequences for fine PM are well established (Aldy et al. 2019). The value of monetizing additional benefits based on recent science in the context of RIAs for new air regulations is a topic to which we return later in the article.

Cobenefits and cocosts have been an important part of EPA analysis of its regulations for more than 2 decades. In nearly half the major rules, monetized benefits would not exceed monetized costs without consideration of cobenefits. The EPA's approach was consistent over time, following OMB and EPA guidance set long ago. Despite that, as we described in Section II, EPA rules in the past several years appear to be departing from this long-standing practice. In part, that departure responds to legitimate-sounding questions about the merits of counting untargeted benefits. In the next section, we look at the questions that have arisen, then address them in a simple economic model.

IV. A Simple Theory of Cobenefits

The previous section demonstrates how the EPA has been considering cobenefits in RIAs for decades. Have they been counted appropriately? Although we do not answer this question on a case-by-case basis, this section describes a simple theoretical framework to help make such determinations. That is, we make the straightforward case for when cobenefits should or should not be fully counted in any BCA. We also address a few of the specific questions that have been raised about including cobenefits: (1) If cobenefits are large, wouldn't regulating them directly be more efficient or cost-effective? (2) How do we count cobenefits if the copollutant is already regulated? And (3) under what circumstances does the inclusion of cobenefits result in double counting?

A. Decision Criteria

We begin with a discussion about the metrics used to judge the merits of alternative pollution policies. These are important because, as we will show, some of the questions and concerns raised about cobenefits are based on an appeal to different decision-making criteria. The first metric, taught in every Economics 101 course, is efficiency. In this context, efficiency requires that the marginal benefit from abating a unit of each pollutant equal the marginal cost. Though often the focus of conceptual discussions of pollution control policy, efficiency is rarely the metric by which policies are judged in practice. Establishing efficiency is a high bar, as it requires identifying and monetizing the incremental benefits and costs of regulating each pollutant.[16]

A second, less strict metric is cost-effectiveness, which is met when a given policy goal is achieved at least cost. The policy goal might be defined in terms of achieving an arbitrary regulated amount of pollution reduction or in terms of the monetary social benefits of pollution. Either way, cost-effectiveness is a weaker metric than efficiency. All efficient policies are cost-effective, but cost-effective policies are not necessarily efficient. Relative to efficiency, cost-effectiveness is easier to evaluate because it does not require knowing the incremental benefit of abating pollution. OMB (2003) Circular A-4 recommends that cost-effectiveness analysis, in addition to BCA, be used to support major rulemakings.

Finally, the criterion used implicitly by most federal agencies, and the one informed by BCA, is positive net benefits—that is, do the benefits of a policy exceed its costs? Having positive net benefits guarantees neither efficiency nor cost-effectiveness. Although all efficient policies have positive net benefits, policies with positive net benefits are not necessarily efficient. Alternatively, policies can minimize the cost of achieving a policy goal while incurring negative net benefits, or they can have positive net benefits but fail to minimize the costs of achieving a policy goal. We focus on this criterion in our discussion later because agency practice has emphasized this objective. The CAA does not provide an efficiency objective in setting pollutant and emission standards, and the cost-effectiveness objective is permissible under some but not all statutory authorities under the CAA. Moreover, the typical practice of regulatory agencies under EO 12866 has been to demonstrate whether benefits justify costs, which has typically been interpreted as a positive net benefits standard.

B. The Setup

Consider two pollutants, a target pollutant, denoted pollutant 1, and a copollutant, denoted pollutant 2. Pollutant 1 is the direct focus of a particular regulatory action, a policy, and pollutant 2 is secondary.[17] Each pollutant can be reduced through costly investments in abatement (e.g., fuel switching, installing abatement equipment). Abatement functions map investments in abatement into units of pollution reduction. Suppose there are two abatement activities. Let x_i denote investment in abatement activity $i = 1, 2$. The quantity of each pollutant ultimately reduced or the level of abatement, denoted a_1 and a_2, depends on investments in abatement activities. To simplify the intuition (and the math), we denominate the abatement activities x_1 and x_2 in units of pollution abated—the same units as a_1 and a_2.

To capture the idea of cobenefits, we assume that abatement activity 1 is a more direct means of abating pollutant 1, but it has some spillover benefits in the form of reductions in pollutant 2. The reverse is true for abatement activity 2: it is the most direct mechanism for abating pollutant 2 but also abates pollutant 1. We write these abatement functions as

$$a_1 = x_1 + \gamma_2 x_2 \text{ and } a_2 = x_2 + \gamma_1 x_1, \tag{1}$$

where the γs are each less than 1 and greater than 0. A 1-unit increase in x_1 yields 1 fewer unit of pollutant 1 as well as γ_2 fewer units of pollutant 2. Similarly, when x_2 increases by 1 unit, abatement of pollutant 2 increases by 1 unit and abatement of pollutant 1 increases by γ_1 units.

Figure 4 depicts this basic setup. Investments x_1 and x_2 are represented on the two axes. Abatement and benefits are increasing to the northeast, as are costs. An iso-cost curve $C(x_1, x_2)$ shows all the combinations of investments x_1 and x_2 that lead to the same cost, $\bar{C}$. Because we denominate the investments in pollution abated, the marginal costs of abating each pollutant using investments x_1 and x_2 are increasing. This leads to a convex iso-cost curve, as depicted in figure 4.

C. Policies

Now consider a policy that mandates a particular amount of abatement for the target pollutant a_1 at some arbitrary level k_1. In this case, suppose that the regulator implements the target through a performance standard that permits discretion by regulated entities on the choice over pollution control investment so long as they limit their emissions to or below a specified emissions level or rate. Note that the target level of abatement can be achieved entirely by investment in abatement activity 1 ($x_1 = k_1$), entirely by investment in abatement activity 2 ($x_2 = k_1/\gamma_2$), or by some linear combination of the two. The constraint on abatement of the target pollutant imposed by the policy is depicted as the straight line in figure 4, corresponding to the equation $k_1 = x_1 + \gamma_2 x_2$.

The least costly way to comply with the regulation is represented by the lowest iso-cost curve tangent to this line. Depending on the shape

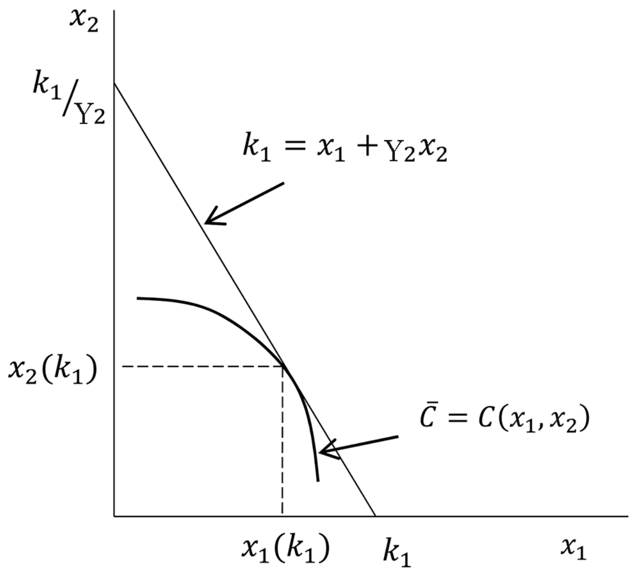

Fig. 4. Cost-effective compliance using two activities (x_1 and x_2) with regulation on one target pollutant ($a_1 \geq k_1$).

of the iso-cost function, that could be at the corner solution using only x_1, at the corner solution using only x_2, or as depicted in the figure at an interior solution using some of both. The least-cost combination $(x_1(k_1), x_2(k_1))$ is by definition cost-effective.

In this example, compliance with regulation of the target pollutant in the least costly way also results in some abatement of the second pollutant. In particular,

$$a_2 = x_2(k_1) + \gamma_1 x_1(k_1). \tag{2}$$

Equation (2) results from plugging the cost-minimizing values of x_1 and x_2 from figure 4 into the abatement function for a_2 in equation (1). The abatement a_2 is a benefit of policy k_1 that targets pollutant 1; it would not have occurred absent the policy. The abatement of pollutant 2 arises from cost-effective compliance with the policy on pollutant 1 through investments in both abatement activities, x_1 and x_2. Note that by equation (2), even with the corner solution at which $x_2(k_1) = 0$, there would still be abatement of a_2 as long as γ_1 is positive.[18] Abatement of the copollutant is a cobenefit only in the semantic sense that the regulatory policy goal was to reduce pollutant 1.

Any policy requiring $a_1 \geq k_1$ that passes a BCA while ignoring those cobenefits would also pass a BCA considering those cobenefits. Nevertheless, some policies that would fail a BCA ignoring cobenefits would pass a BCA once cobenefits are considered. Moreover, in some cases, cobenefits alone may be sufficient for a policy to pass a BCA. Of course, as discussed earlier, passing a BCA does not mean that a policy is efficient or even cost-effective. This raises one of the chief criticisms of counting cobenefits—that if they are important, they should be regulated directly.

D. *Targeting Copollutants Directly*

Concerns about cobenefits often focus on questions related to cost-effectiveness. For example, when commenting on the MATS rule, Dudley (2012) wrote, "If [$PM_{2.5}$ co-benefits] are legitimate, certainly confronting them directly would achieve $PM_{2.5}$ reductions more *cost-effectively* than going after them indirectly using statutory authority designed to reduce toxic air pollutants" (173, emphasis added). Smith (2011) asserted that "$PM_{2.5}$-related benefits would be more certain and more *cost-effectively* obtained through a different regulation altogether than an air toxics rule" (14, emphasis added).

To address this cost-effectiveness critique, suppose that the regulator considers an alternative policy approach: designing a performance standard to regulate pollutant 2 directly with the target of achieving at least as much abatement as resulted indirectly from the policy targeting pollutant 1 (Sec. IV.C). This approach would require a policy a_2 that satisfies $a_2 \geq k_2 = x_2(k_1) + \gamma_1 x_1(k_1)$ as in equation (2). As earlier, this target level of abatement for pollutant 2 can be met by any linear combination of x_1 and x_2, depicted by the new line added to figure 5, which corresponds to the equation $k_2 = x_2 + \gamma_1 x_1$.

Because the new policy rule is designed to meet the same level of reduction in pollutant 2 achieved by the original policy, it must go through the original cost-minimizing point for compliance with k_1. Note that one way to comply with the new policy is to do exactly the same thing that complied with the original policy. But the slope of the new k_2 policy is less steep than the slope of the original k_1 policy because $-\gamma_1 > -1/\gamma_2$. As shown in figure 5, the line representing the new policy necessarily passes below portions of the iso-cost curve that is tangent to the original k_1 line. This means that a different, lower iso-cost curve, representing smaller

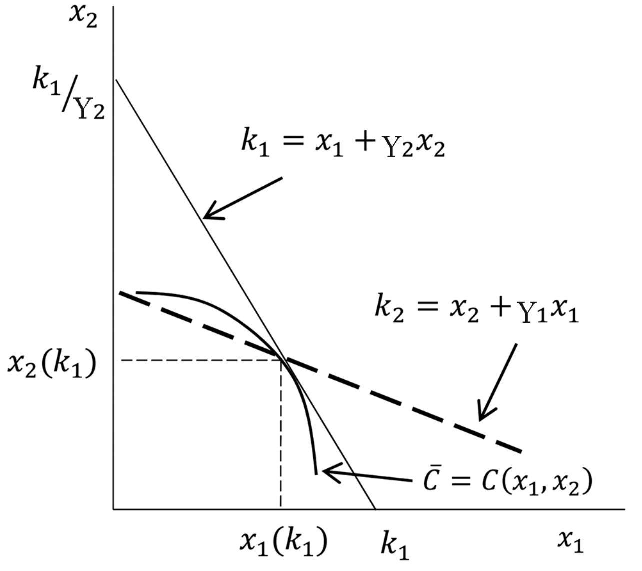

Fig. 5. Cost savings that arise from directly targeting cobenefits but ignoring reductions in originally targeted pollutant.

investments in x_1 and x_2, could achieve the same level of abatement for pollutant 2 at lower cost than $\bar{C}$.

But important, the cost savings do not come for free. The achievement—abating pollutant 2 by an amount equal to the cobenefits from targeting pollutant 1—occurs with an opportunity cost: reduced abatement of pollutant 1. In figure 5, there are no points along the line k_2 where both the original pollutant 1 regulation is met (above k_1) and costs are reduced (below $\bar{C}$). Therefore, the argument against cobenefits ("Wouldn't it be better to target them directly?") works only if we ignore the broader benefits of abating the target pollutant. In this case of the policy targeting pollutant 2, abatement of pollutant 1 arises as a cobenefit due to the same connected abatement activities that resulted in reductions in pollutant 2 originally.

To put it bluntly, the efficiency argument against considering cobenefits holds in general only if we ignore cobenefits. Ultimately, however, it is an empirical question as to whether taking a more cost-effective approach to targeting pollutant 2 results in greater net benefits relative to a counterfactual of targeting pollutant 1. Regulatory decision making is also critically important to a reliance on the cost-effectiveness rationale. The assertion that it would be more cost-effective to regulate pollutant 2 can hold only if the regulator decides to adopt a regulation that targets pollutant 2. As an illustration of how lack of follow-up can come up short, the EPA (2020c) promulgated, on May 22, 2020, its final rule withdrawing the "appropriate and necessary" determination of the MATS rule (Sec. II.D) by excluding consideration of $PM_{2.5}$ benefits. This final rule could have teed up the agency to pursue a new regulatory approach to target $PM_{2.5}$ directly and possibly obtain the associated benefits more cost-effectively. Instead, the EPA (2020d) issued a proposal against setting a more stringent $PM_{2.5}$ NAAQS at effectively the same time (April 30, 2020).

E. Preexisting Policies

We have focused so far on examples in which no preexisting policies regulate either pollutant. With no preexisting policies, benefits are never double counted. Nevertheless, another argument related to the treatment of cobenefits in BCA relates to the potential for double counting in the presence of preexisting policies. For example, Gray (2015, 32) argues that "whenever EPA counts $PM_{2.5}$ or ozone reductions in its cost-benefit analysis for other rules, it is double-counting reductions already mandated."

To examine this concern, we add a preexisting policy targeting pollutant 2, such that abatement must be at least as large as $\bar{k}_2 = \gamma_1 x_1 + x_2$. Figure 6 depicts this case. Note that the preexisting policy can be met with any level of $a_2 \geq \bar{k}_2$ and does not imply a specific level of abatement, as in the previous section. Least-cost compliance with the preexisting policy on a_2 occurs at point A in the figure. The associated cost is $C(x_1(\bar{k}_2),\ \ x_2(\bar{k}_2))$.

In the presence of the preexisting policy on pollutant 2, consider a new policy that will target pollutant 1. Will this lead to cobenefits or cocosts associated with changes in the abatement of pollutant 2? The answer turns out to depend on the stringency of the new policy, the technology parameters (γ_1 and γ_2), and the cost functions. Figure 6 depicts several possibilities.

The first case is trivial, and arises if the new policy, k_1' in figure 6, is nonbinding. In this example, compliance with the original policy $\bar{k}_2$ already led to abatement of the first pollutant, a_1, sufficient to comply with the new regulation. There were, in a sense, reverse cobenefits generated from reductions in a_1 due to compliance with the preexisting $\bar{k}_2$ policy, and these reductions were more than sufficient to meet compliance

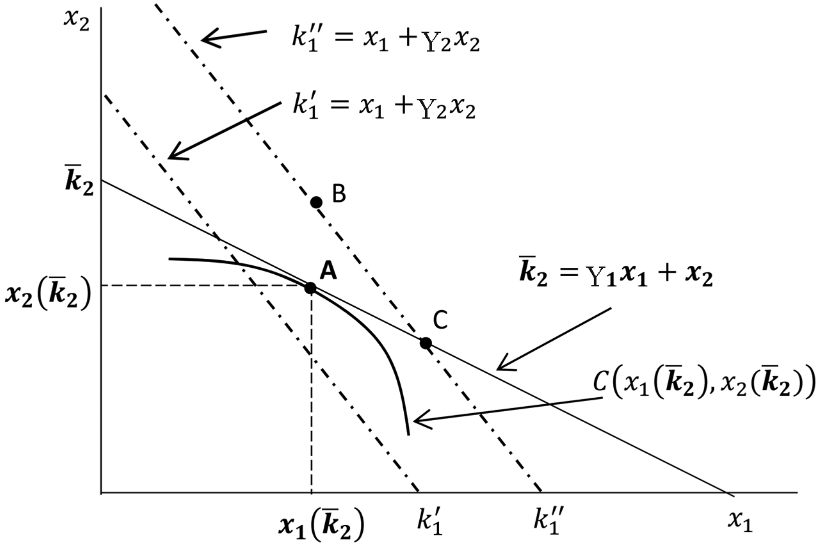

Fig. 6. Effect of preexisting policy on possibility, or lack thereof, of cobenefits.

with the k_1' policy. Polluters therefore need to make no changes, and cost minimization remains at point A in the figure. The new policy k_1' has no benefits or costs.

The more interesting case arises if the new policy binds, as in k_1'' in figure 6. Here compliance with the new policy must increase costs, because the original point A is insufficient to comply with the new policy targeting pollutant 1. In this case there are two possibilities: an interior solution and a corner solution. In the first, depicted as point B, polluters must overcomply with the original policy $\bar{k}_2$ to meet the new k_1'' policy. Compared with point A, abatement of both pollutants is higher at point B, so benefits are also higher. The increase in a_1 generates the target pollutant benefits from the new policy, and the new and additional increase in a_2 represents cobenefits.[19]

In the corner-solution case, represented by point C, there are no cobenefits. Polluters exactly comply with both policies. They comply with the original policy $\bar{k}_2$ in a less cost-effective way, by increasing x_1 and decreasing x_2, but in doing so they comply with the new rule k_1''. Emissions of pollutant 2 simply remain at the level originally mandated under the policy $\bar{k}_2$, reflecting firms' investment adjustments in the two abatement activities. Without accounting for these adjustments, double counting would be a concern. We return to the subject again later, but first we discuss the possibility for the relevant adjustments.

F. Regulatory Rebound

A more nuanced criticism of counting cobenefits on par with benefits associated with the directly targeted pollutant relates to what Fowlie, Rubin, and Wright (2020) call "regulatory rebound." The argument is that when a preexisting regulation limits the level of emissions of pollutant 2, a new policy that indirectly generates reductions in pollutant 2 when it targets reductions in pollutant 1 can induce a regulatory response that permits an increase in the level of pollutant 2 back to the originally mandated level.[20] In the previous discussion, this possibility was unlikely, except in the corner-solution case, because we assumed the two abatement activities generated reciprocal cobenefits; that is, both γ_1 and γ_2 were assumed to be greater than 0. If cobenefits are not reciprocal, then there are two additional possibilities to explore: $\gamma_2 = 0$ or $\gamma_1 = 0$. We start with the first.

Suppose $\gamma_2 = 0$ and $0 < \gamma_1 < 1$ such that investments in abatement activity 1 reduce emissions of pollutant 2 (in addition to pollutant 1) but investments in abatement activity 2 reduce only emissions of pollutant 2.[21] Also suppose there is a preexisting policy on pollutant 2 such that $a_2 \geq \bar{k}_2$. Because $a_2 = \gamma_1 x_1 + x_2$, the policy constraint is just a sloped line as before, depicted in the left panel of figure 7. Cost-minimizing compliance with the $\bar{k}_2$ is depicted as $(x_1(\bar{k}_2), x_2(\bar{k}_2))$. If the regulator now adds a new policy targeting pollutant 1 and denoted as k_1, then the associated constraint can be represented by a vertical line, as in the figure, because $\gamma_2 = 0$. The new policy effectively mandates a minimum level of x_1, investment in abatement activity 1. Complying with the new k_1 policy involves higher costs, less x_2 and more x_1, but no additional abatement of pollutant 2 (i.e., $a_2 = \bar{k}_2$ as before). In this case, there are no cobenefits. Polluters merely comply with the new policy k_1 in a way that increases the cost of meeting the preexisting policy k_2, but that generates the same amount of reduction in pollutant 2. Compliance costs from the new policy k_1 are represented in the graph by the difference between the two cost curves, and the new policy's benefits arise from the increase in a_1. This is 100% regulatory rebound and is a special case of the corner solution depicted as point C in figure 6, which occurs if the new policy k_1 is sufficiently low. If instead the new policy constraint were to the right of the horizontal intercept of $\bar{k}_2$, there would be cobenefits.

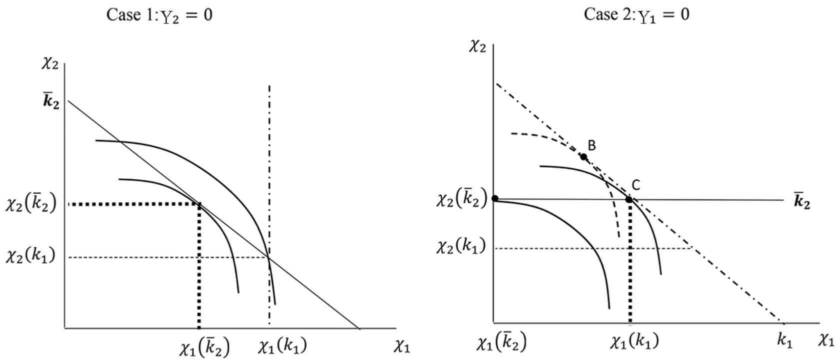

Fig. 7. Special cases with preexisting policies. Case 1 is 100% regulatory rebound with increased costs and no cobenefits; case 2 is increased costs and either cobenefits (point B) or 100% regulatory rebound and no cobenefits.

For completeness, examine the alternative scenario with no cobenefits from the target pollutant to the previously regulated pollutant ($\gamma_1 = 0$), but reverse cobenefits from the previously regulated pollutant to the target pollutant ($0 < \gamma_2 < 1$). This case is depicted in the right-hand panel of figure 7. Here, the preexisting policy $\bar{k}_2$ is represented as a horizontal line; because $\gamma_1 = 0$, the preexisting policy targeting pollutant 2 effectively mandates a minimum level of x_2. Complying with the preexisting policy involves a corner solution, where $x_1 = 0$. When the new policy targeting abatement of pollutant 2 is added such that $a_1 \geq k_1$, then cost-minimizing compliance involves increasing x_1 but not necessarily increasing x_2. First consider point C, which depicts one possibility—cost-minimizing compliance with no increase in x_2 or a_2. This is another special case of the corner solution depicted as point C in figure 6 (Sec. IV.E).

Now consider point B, which represents the cost-minimizing compliance outcome at the tangency between the dashed iso-cost curve and the new policy k_1 (above the $\bar{k}_2$ constraint). In this case, the new policy k_1 yields overcompliance with the preexisting policy $\bar{k}_2$, and therefore cobenefits, as in the interior solution depicted as point B in figure 6. Indeed, figure 7 contains nothing more than two exaggerated examples of what happens in figure 6. In figure 7, as in all the figures, the k_1 policy line is steeper than the $\bar{k}_2$ policy line, by the assumption that $0 < \gamma_1, \gamma_2 < 1$.

In sum, when we add a policy targeting pollutant 1 in the presence of a preexisting policy that targets pollutant 2, there are three possible outcomes. The new policy is (1) moot, and there are no benefits or cobenefits (point A in fig. 6); (2) a corner solution with no cobenefits (point C in fig. 6); or (3) an interior solution with cobenefits (point B in fig. 6). Expanding the analysis in figure 6 by considering extreme values for the cobenefits, as done in figure 7, such that the k_1 line is completely horizontal or the $\bar{k}_2$ line vertical, makes no difference. We still get one of the three possible outcomes.

G. *Double Counting*

Returning now to the question: Does considering cobenefits amount to double counting? In some cases, the concern is that the EPA does not follow its own guidelines, which stipulate that baselines for RIAs must assume full compliance with all previously enacted rules, even if those rules have not yet been implemented or complied with (EPA 2014). In other cases, however, critics seem to presume that any consideration of cobenefits would represent double counting.

Our analysis addresses both concerns. Any analysis that ignores a previous policy and assumes that all reductions in pollution stem from compliance with a new policy will double count benefits already counted in a BCA for the original policy. That is why we consider cobenefits to be 0 at points A and C in figure 6, in case 1 in figure 7, and in the corner solution of case 2 in figure 7. In some of these cases, an important mechanism to recognize is the regulatory rebound. Even if the new policy initially reduces a copollutant, adjustments in compliance to a preexisting policy may be such that actual copollutant levels do not change after those adjustments take place. But if the original benefits were already counted, double counting would result.

At the same time, cobenefits represent true benefits when they result in overcompliance with the original rule, as in point B in figure 6 or the dashed interior solution in case 2 in figure 7. Not considering those cobenefits would represent undercounting, not double counting.

V. Discussion and Conclusion

This article considers the treatment of cobenefits in BCAs, with a particular focus on federal air quality regulations, for which questions and concerns about the role of cobenefits have been gaining momentum. Using a comprehensive data set on all major CAA rules issued by the EPA over the period 1997–2019, we show several trends and patterns. First, cobenefits make up a significant share of the monetized benefits in EPA

RIAs over this period. Second, among the categories of cobenefits, those associated with reductions in adverse health effects due to fine PM are the most significant. Third, the inclusion of cobenefits has been critical in the majority of RIAs for making the determination in prospective analyses that the monetized benefits of the rule exceed the costs.

Are these findings cause for concern? We find that, in general and from a welfare economics perspective, the answer is no. We develop a simple conceptual framework to illustrate a critical point: cobenefits are simply a semantic category of benefits that should be included in BCAs to make an appropriate determination about whether a given policy promotes economic efficiency compared with a baseline status quo. Indeed, this finding is not novel and is covered in standard textbook treatments of best practice for BCAs (e.g., Boardman et al. 2018).[22]

More novel is our consideration of specific questions and concerns about cobenefits that have been raised in the context of CAA rules. First, if cobenefits are large, wouldn't regulating them directly be more efficient or cost-effective? Although a regulator could deliver a given level of cobenefits more cost-effectively by targeting the copollutant directly, such a direct policy is not necessarily a more efficient alternative. In fact, we show that this line of argument against considering cobenefits depends on a tautology, whereby it holds generally only if one starts with the proposition that we should ignore cobenefits. The argument also relies on the questionable starting point that a proposed regulation for one pollutant can be replaced by one for another. Though possible in theory, the idea does not square with the required statutory basis for most CAA regulations.

The second question relates to how we should count cobenefits if the copollutant is already subject to a preexisting regulation. In this case, we show how care needs be taken to measure only those benefits that are the incremental consequence of the policy under consideration. But these challenges are the same as those that arise more generally when regulators are identifying the most appropriate baseline for analysis, and they are not unique to the estimation of cobenefits. In doing so, however, particular attention should be given to the potential for regulatory rebound—that is, the policy under consideration may shift behaviors related to compliance with another policy that targets the copollutant. Taking account of these effects will avoid the possibility for double counting.

By carefully accounting for the cobenefits (and cocosts) of a proposed regulatory action, the EPA can better understand the impacts of the envisioned rule on society and, in theory, use this information to craft a better regulation. Exploiting the full information from a BCA could enable more efficient regulatory design. It may also highlight the potential for greater benefits by targeting both pollutants through regulation. Indeed, there are cases—such as the 1998 pulp and paper cluster rule (RIN 2040-AB53) and the more recent joint EPA-NHTSA tailpipe CO_2/fuel economy standards (RINs 2060-AP61, 2060-AQ54, and 2060-AS16)—where the agencies implemented multiple statutory authorities to realize multiple types of societal benefits.[23]

We conclude with some observations about the political economy underlying why it appears that cobenefits are an increasing topic of debate, notwithstanding how the questions are relatively "settled science" from the perspective of how to conduct BCAs. First, it is important to recognize that in practice, BCAs rarely (if ever) quantify and monetize all the expected benefits and costs of an action. Even as the science and methods of valuation continue to advance, many categories of benefits remain exceedingly difficult or impossible to estimate. Estimating more categories of benefits also takes time and resources, which are often scarce. It is nevertheless sufficient to show that a subset of the benefits, which may arise entirely from cobenefits, are greater than the costs to conclude that a regulation has positive net benefits. This aim in itself can explain why cobenefits are important to BCA of CAA regulations. Research and the development of best practices tend to focus on the impacts that have the greatest value, and the health benefits of reducing fine PM appear to be dramatically larger than the health impacts of cutting other air pollutants. Because the CAA does not require—and in some cases explicitly prohibits consideration of—BCA to inform the setting of air quality standards and regulations, the value of the information in an RIA lies in its communication to the public, stakeholders, and Congress. For many consumers of this information, once the EPA has demonstrated that the monetized benefits exceed the monetized costs, the value of incremental information on other benefits becomes quite low.

Second, the distinction between the quantified, monetized benefits and the true total benefits means that there are two possible interpretations of our findings. It could be that cobenefits truly make up a large part of the actual total social benefits. Alternatively, it could be that cobenefits just happen to be easier for the EPA to monetize, and so make up a large share of the quantified, monetized benefits reported in RIAs.

Finally, let us observe a fundamental tension in the implementation of federal regulatory policy as it pertains to the CAA. As noted earlier, for

4 decades the White House has directed regulatory agencies to adopt rules whose benefits justify or exceed the costs and to pursue, where feasible, regulatory options that maximize net social benefits. Since 2017, however, the Trump administration has focused on the costs of regulations, both through a "regulatory budget" that effectively places limits on the incremental costs new rules can impose on society (regardless of net social benefits) and in its deregulation agenda (CEA 2019). With virtually every CAA regulation since 1997 estimated to deliver monetized benefits in excess of monetized costs (see fig. 2), the removal of any of these rules through deregulatory actions would impose social costs in excess of the benefits.[24] Casting doubt on the applicability or validity of the benefits from reducing fine PM by questioning the appropriateness of including cobenefits could enable a regulator to pursue actions that reduce regulatory costs without appearing to impose net social costs. But for reasons we have discussed, this conclusion would be wrong.

Appendix

Table A1
Major Clean Air Act Regulations, Compiled from Office of Management and Budget Reports to Congress, 1997–2019

RIN	Rule	Date	*Federal Register*	Monetized Benefits?
2060-AE66	National Ambient Air Quality Standards for Particulate Matter	July 18, 1997	62 FR 38652	Y
2060-AE57	National Ambient Air Quality Standards for Ozone	July 18, 1997	62 FR 38856	Y
2060-AC62	Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital/Medical/Infectious Waste Incinerators	September 15, 1997	62 FR 48348	Y
2060-AF76	Control of Emissions of Air Pollution from Highway Heavy-Duty Engines	October 21, 1997	62 FR 54694	N
2040-AB53	National Emission Standards for Hazardous Air Pollutants for Source Category: Pulp and Paper Production; Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards: Pulp, Paper, and Paperboard Category	April 15, 1998	63 FR 18504	Y
2060-AD33	Emission Standards for Locomotives and Locomotive Engines	April 16, 1998	63 FR 18978	N
2060-AF76_98	Control of Emissions of Air Pollution from Nonroad Diesel Engines	October 1, 1998	63 FR 56968	N
2060-AH10	Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone	October 27, 1998	63 FR 57356	Y
2060-AE29	Phase 2 Emission Standards for New Nonroad Spark-Ignition Nonhandheld Engines at or below 19 Kilowatts	March 30, 1999	64 FR 15208	N
2060-AH88	Findings of Significant Contribution and Rulemaking on Section 126 Petitions for Purposes of Reducing Interstate Ozone Transport	May 25, 1999	64 FR 28250	N

Continued

Table A1
Continued

RIN	Rule	Date	*Federal Register*	Monetized Benefits?
2060-AF32	Regional Haze Regulations	July 1, 1999	64 FR 35714	Y
2060-AI23	Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements	February 10, 2000	65 FR 6698	Y
2060-AE29_00	Phase 2 Emission Standards for New Nonroad Spark-Ignition Handheld Engines at or below 19 Kilowatts and Minor Amendments to Emission Requirements Applicable to Small Spark-Ignition Engines and Marine Spark-Ignition Engines	April 25, 2000	65 FR 24268	N
2060-AI12	Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-Duty Highway Engines and Vehicles; Revision of Light-Duty On-Board Diagnostics Requirements	October 6, 2000	65 FR 59896	N
2060-AI34	National Emission Standards for Hazardous Air Pollutants for Chemical Recovery Combustion Sources at Kraft, Soda, Sulfite, and Stand-Alone Semichemical Pulp Mills	January 12, 2001	66 FR 3180	Y
2060-AI69	Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements	January 18, 2001	66 FR 5002	Y
2060-AI11	Control of Emissions from Nonroad Large Spark-Ignition Engines, and Recreational Engines (Marine and Land-Based)	November 8, 2002	67 FR 68242	Y
2060-AG63	National Emission Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines	June 15, 2004	69 FR 33474	Y
2060-AK27	Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel	June 29, 2004	69 FR 38958	Y
2060-AG52	National Emission Standards for Hazardous Air Pollutants: Plywood and Composite Wood Products; Effluent	July 30, 2004	69 FR 45944	N

	Limitations Guidelines and Standards for the Timber Products Point Source Category; List of Hazardous Air Pollutants, Lesser Quantity Designations, Source Category List			
2060-AG69	National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers and Process Heaters	September 13, 2004	69 FR 55218	Y
2060-AL76	Rule to Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions to Acid Rain Program; Revisions to the NOX SIP Call	May 12, 2005	70 FR 25162	Y
2060-AJ65	Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam Generating Units	May 18, 2005	70 FR 28606	Y
2060-AJ31	Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations	July 6, 2005	70 FR 39104	Y
2060-AM82	Standards of Performance for Stationary Compression Ignition Internal Combustion Engines	July 11, 2006	71 FR 39154	Y
2060-AI44	National Ambient Air Quality Standards for Particulate Matter	October 17, 2006	71 FR 61144	Y
2060-AK70	Control of Hazardous Air Pollutants from Mobile Sources	February 26, 2007	72 FR 8428	Y
2060-AK74	Clean Air Fine Particle Implementation	April 25, 2007	72 FR 20586	Y
2060-AN24	National Ambient Air Quality Standards for Ozone	March 27, 2008	73 FR 16436	Y
2060-AM06	Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder	May 6, 2008	73 FR 25098	Y
2060-AN72	Standards of Performance for Petroleum Refineries	June 24, 2008	73 FR 35838	Y
2060-AM34	Control of Emissions from Nonroad Spark-Ignition Engines and Equipment	October 8, 2008	73 FR 59034	Y
2060-AN83	National Ambient Air Quality Standards for Lead	November 12, 2008	73 FR 66964	Y
2060-AO79	Mandatory Reporting of Greenhouse Gases	October 30, 2009	74 FR 56260	N
2060-AP36	National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines	March 3, 2010	75 FR 9648	Y
2060-AO38	Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines	April 30, 2010	75 FR 22896	Y

Continued

Table A1
Continued

RIN	Rule	Date	*Federal Register*	Monetized Benefits?
2060-AO48	Primary National Ambient Air Quality Standard for Sulfur Dioxide	June 22, 2010	75 FR 35520	Y
2060-AP36_10	National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines	August 20, 2010	75 FR 51570	Y
2060-AO15	Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry	September 9, 2010	75 FR 54970	Y
2060-AP50	Federal Implementation Plans: Interstate Transport of Fine Particulate Matter and Ozone and Correction of SIP Approvals	August 8, 2011	76 FR 48208	Y
2060-AP61	Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles	September 15, 2011	76 FR 57106	Y
2060-AP52	National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units	February 16, 2012	77 FR 9304	Y
2060-AP76	Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews	August 16, 2012	77 FR 49490	N
2060-AN72_12	Standards of Performance for Petroleum Refineries; Standards of Performance for Petroleum Refineries for Which Construction, Reconstruction, or Modification Commenced after May 14, 2007	September 12, 2012	77 FR 56422	Y
2060-AQ54	2017–2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards	October 15, 2012	77 FR 62624	Y

2060-AO47	National Ambient Air Quality Standards for Particulate Matter	January 15, 2013	78 FR 3086	Y
2060-AQ58	National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines; New Source Performance Standards for Stationary Internal Combustion Engines	January 30, 2013	78 FR 6674	Y
2060-AR13	National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters	January 31, 2013	78 FR 7138	Y
2060-AQ86	Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards	April 28, 2014	79 FR 23414	Y
2060-AP93	Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces	March 16, 2015	80 FR 13672	Y
2060-AR33	Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units	October 23, 2015	80 FR 64662	Y
2060-AP38	National Ambient Air Quality Standards for Ozone	October 26, 2015	80 FR 65292	Y
2060-AP69	NESHAP for Brick and Structural Clay Products Manufacturing; and NESHAP for Clay Ceramics Manufacturing		80 FR 65470	Y
2060-AS30	Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources	June 3, 2016	81 FR 35824	Y
2060-AS23	Emission Guidelines and Compliance Times for Municipal Solid Waste Landfills	August 29, 2016	81 FR 59276	Y
2060-AS16	Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2	October 25, 2016	81 FR 73478	Y
2060-AS05	Cross-State Air Pollution Rule Update for the 2008 Ozone NAAQS	October 26, 2016	81 FR 74504	Y
2060-AT67	Repeal of the Clean Power Plan; Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guidelines Implementing Regulations	July 8, 2019	84 FR 32520	Y

Note: RIN = regulation identifier number. Where the Environmental Protection Agency used the same RIN more than once, we have modified the second instance by adding an extension that represents the two-digit year of rule promulgation.

Endnotes

Author email addresses: Aldy (joseph_aldy@hks.harvard.edu), Kotchen (matthew.kotchen@yale.edu). This article was prepared for inclusion in the Environmental and Energy Policy and the Economy conference and publication, sponsored by the National Bureau of Economic Research (NBER). We are grateful to Sofia Caycedo and Tim Bialecki for valuable research assistance while students at Yale. We thank participants at the NBER Environmental and Energy Policy and the Economy conference, Sally Atwater, and Bill Hogan for constructive feedback on an earlier draft. The authors gratefully acknowledge financial support from the NBER and the External Environmental Economics Advisory Committee. For acknowledgments, sources of research support, and disclosure of the authors' material financial relationships, if any, please see https://www.nber.org/books-and-chapters/environmental-and-energy-policy-and-economy-volume-2/co-benefits-and-regulatory-impact-analysis-theory-and-evidence-federal-air-quality-regulations.

1. A major rule is one that has an impact of $100 million or more in at least 1 year. Only a small fraction of final rules are considered major. For example, according to OMB (2019), only 609 of 36,255 final rules published in the *Federal Register* from FY 2007 to FY 2016, or 1.7%, meet the criterion for major designation.

2. The calculation includes four rules jointly promulgated by the EPA and the Department of Transportation (DOT; OMB 2019, table 1-1).

3. We use the term cobenefits throughout the article, though other terms are frequently used as well in the literature and government analyses in reference to the same concept. Impacts may be characterized as "secondary," "indirect," and "ancillary," among others. When referring to cobenefits, we also assume implicitly the possibility for negative benefits—that is, cocosts.

4. In spring 2020, the EPA drafted revisions to its economic guidelines and commissioned their review by a panel convened by the agency's Science Advisory Board (EPA 2020a). The topic of cobenefits (ancillary impacts) and its treatment in the economic guidelines elicited substantial public comment (in writing and during oral remarks in the public comments of the panel meetings) and feedback from panel members. Two coauthors of this article, Aldy and Levinson, are members of that review panel.

5. Refer to Section 2 of the Energy Policy and Conservation Act, Public Law 94-163, December 22, 1975, https://www.govinfo.gov/content/pkg/STATUTE-89/pdf/STATUTE-89-Pg871.pdf.

6. Refer to Sections 102 and 105 of the Energy Independence and Security Act of 2007, Public Law 110-140, December 19, 2007. https://www.govinfo.gov/content/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf.

7. Refer to Section 1501 of the Energy Policy Act of 2005, Public Law 109-58, August 8, 2005. https://www.congress.gov/109/plaws/publ58/PLAW-109publ58.pdf.

8. Refer to Section 202 of the Energy Independence and Security Act of 2007.

9. The database and documentation can be accessed at https://doi.org/10.7910/DVN/J2HWDA.

10. Although the RIAs for some rules mention nonmonetized benefits, given the nature of our analysis, we necessarily restrict attention to monetized benefits and costs.

11. We use regulation identifier numbers to identify each regulation we describe in the text. The appendix table lists all regulations with their RINs, publication dates, and *Federal Register* cites that we have compiled for this analysis.

12. We note that the choice of discount rate is less of a concern for this analysis because of the way that benefits and costs are reported for a given snapshot year. There are two categories of exceptions. First, some RIAs present latent fine PM premature mortality risks. These RIAs estimate the present value of these risks over 5 years from the snapshot year. Second, joint EPA-NHTSA regulations addressing fuel economy provide the present value of the benefits from vehicles regulated in the snapshot year.

13. We accessed the GDP Implicit Price Deflator annual series from the St. Louis Federal Reserve Economic Data website on May 11, 2020, https://fred.stlouisfed.org/series/A191RI1Q225SBEA.

14. Refer to table 4-1 in EPA (1998).

15. In the lead NAAQS RIA, the lower-bound benefits exceed the lower-bound costs estimated with a 7% discount rate. Under a 3% discount rate, the lower and upper bounds of the monetized benefits exceed their corresponding scenario's costs.

16. We recognize other potential decision criteria, such as distributional equity, employment, or export promotion. Indeed, some are mentioned explicitly in the executive orders mandating RIAs, and most RIAs include chapters analyzing these other economic outcomes. Our focus here, though, is on whether cobenefits belong in calculations of net benefits.

17. That is, the numbering indicates a pollutant's relative centrality to the particular regulation's intended goal, not necessarily to the timing of regulation. Later in this section, we consider the important case of when copollutant 2 has already been regulated and the EPA is analyzing the net benefits of regulating target pollutant 1.

18. Note that a technology standard—for example, setting $x_1 = k_1$—in lieu of a performance standard would also yield cobenefits in this case.

19. This assumes the benefits can be added together—that is, they are additively separable, which is an implicit assumption typical of EPA regulatory analyses.

20. Fullerton and Karney (2018) evaluate such cobenefit rebounds in a general equilibrium model in which the regulator chooses between tax and cap-and-trade instruments for two pollutants. Also note that this is similar to the overlapping policies problem, where one policy instrument sets a quantitative emissions limit, as described in Levinson (2011) and Goulder and Stavins (2011).

21. For example, consider the relationship between SO_2 (pollutant 1) and CO_2 (pollutant 2). Reducing SO_2 emissions at a coal-fired power plant with a scrubber would yield no CO_2 reductions ($\gamma_2 = 0$), and technically it could result in a modest increase in CO_2 emissions due to the energy penalty associated with operating a scrubber. In contrast, reducing CO_2 emissions by dispatching a natural gas power plant in lieu of the coal-fired power plant would reduce both CO_2 and SO_2 emissions.

22. This finding is common beyond economics. Refer to Castle and Revesz (2019) for a discussion of how federal courts have typically ruled in favor of consideration of ancillary impacts of regulations.

23. Thanks to Don Fullerton and Al McGartland for helpful suggestions on these topics.

24. Refer to Evans et al. (2021) for further discussion of this issue.

References

Aldy, J. 2018. "Promoting Environmental Quality through Fuels Regulations: Lessons for a Durable Energy and Climate Policy." In *Lessons from the Clean Air Act: Building Durability and Adaptability into US Climate and Energy Policy*, ed. A. Carlson and D. Burtaw, 159–99. New York: Cambridge University Press.

Aldy, J., M. Kotchen, M. Evans, M. Fowlie, A. Levinson, and K. Palmer. 2019. "Report on the Proposed Changes to the Federal Mercury and Air Toxics Standards." E-EEAC Committee Report. https://www.e-eeac.org/mats-report.

———. 2020. "Deep Flaws in Mercury Regulatory Analysis." *Science* 368:247–48.

Blackwell, A. G. 2017. "The Curb-Cut Effect." *Stanford Social Innovation Review* Winter:28–30.

Boardman, A. E., D. H. Greenberg, A. R. Vining, and D. L. Weimer. 2018. *Cost-Benefit Analysis: Concepts and Practice*. Cambridge: Cambridge University Press.

Burtraw, D., A. Krupnick, K. Palmer, A. Paul, M. Toman, and C. Bloyd. 2003. "Ancillary Benefits of Reduced Air Pollution in the US from Moderate Greenhouse Gas Mitigation Policies in the Electricity Sector." *Journal of Environmental Economics and Management* 45 (3): 650–67.

Castle, K. M., and R. L. Revesz. 2019. "Environmental Standards, Thresholds, and the Next Battleground of Climate Change Regulations." *Minnesota Law Review* 103:1349–437.

CEA (Council of Economic Advisers). 2019. *The Economic Effects of Federal Deregulation since January 2017: An Interim Report*. Washington, DC: Executive Office of the President. https://www.whitehouse.gov/wp-content/uploads/2019/06/The-Economic-Effects-of-Federal-Deregulation-Interim-Report.pdf.

Dudley, S. 2012. "Perpetuating Puffery: An Analysis of the Composition of OMB's Reported Benefits of Regulation." *Business Economics* 47 (3): 165–76.

EO (Executive Order) 12291, Federal Regulation, 46 *Federal Register* 13193, February 17, 1981.

EO (Executive Order) 12866, Regulatory Planning and Review, 58 *Federal Register* 51735, October 4, 1993.

EO (Executive Order) 13771, Reducing Regulation and Controlling Regulatory Costs, 82 *Federal Register* 9339, February 3, 2017.

EPA (Environmental Protection Agency). 1973. Regulation of Fuels and Fuel Additives, 38 *Federal Register* 1254, January 10.

———. 1976. Lead National Ambient Air Quality Standard, 41 *Federal Register* 14921, April 8.

———. 1997. The Benefits and Costs of the Clean Air Act, 1970 to 1990. Report to Congress, EPA-410-R-97-002, October. https://www.epa.gov/sites/production/files/2017-09/documents/ee-0295_all.pdf.

———. 1998. Regulatory Impact Analysis for the NOx SIP Call, FIP, and Section 126 Petitions, Volume I: Costs and Economic Impacts. EPA-452/R-98-003, September.

———. 2014. *Guidelines for Preparing Economic Analyses*. May 2014 Update. Washington, DC: EPA/National Center for Environmental Economics. https://www.epa.gov/sites/production/files/2017-08/documents/ee-0568-50.pdf.

———. 2015. Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units. 80 *Federal Register* 64662, October 23, RIN 2060-AR33. https://www.govinfo.gov/content/pkg/FR-2015-10-23/pdf/2015-22842.pdf.

———. 2018a. Increasing Consistency and Transparency in Considering Costs and Benefits in the Rulemaking Process. 83 *Federal Register* 27524, June 13, RIN 2010-AA12. https://www.govinfo.gov/content/pkg/FR-2018-06-13/pdf/2018-12707.pdf.

———. 2018b. Strengthening Transparency in Regulatory Science. 83 *Federal Register* 18768, April 30, RIN 2080-AA14. https://www.govinfo.gov/content/pkg/FR-2018-04-30/pdf/2018-09078.pdf.

———. 2019a. Oil and Natural Gas Sector: Emissions Standards for New, Reconstructed, and Modified Sources Review. 84 *Federal Register* 185, September 24, RIN 2060-AT90. https://www.govinfo.gov/content/pkg/FR-2019-09-24/pdf/2019-19876.pdf.

———. 2019b. Repeal of the Clean Power Plan; Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guidelines Implementing Regulations. 84 *Federal Register* 32520, July 8, RIN 2060-AT67. https://www.govinfo.gov/content/pkg/FR-2019-07-08/pdf/2019-13507.pdf.

———. 2020a. *Guidelines for Preparing Economic Analyses*. Review Copy Prepared for EPA's Science Advisory Board's Economic Guidelines Review Panel. April 3. https://yosemite.epa.gov/sab/sabproduct.nsf/0/30D5E59E8DC91C2285258403006EEE00/$File/GuidelinesReviewDraft.pdf.

———. 2020b. Increasing Consistency in Considering Benefits and Costs in the Clean Air Act Rulemaking Process. 85 *Federal Register* 35612, June 11, RIN 2060-AU51. https://www.govinfo.gov/content/pkg/FR-2020-06-11/pdf/2020-12535.pdf.

———. 2020c. National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units—Reconsideration of

Supplemental Finding and Residual Risk and Technology Review. 85 *Federal Register* 31286, May 22, RIN 2060-AT99. https://www.govinfo.gov/content/pkg/FR-2020-05-22/pdf/2020-08607.pdf.
———. 2020d. Review of the National Ambient Air Quality Standards for Particulate Matter. 85 *Federal Register* 24094, April 30, RIN 2060-AS50. https://www.govinfo.gov/content/pkg/FR-2020-04-30/pdf/2020-08143.pdf.
EPA (Environmental Protection Agency) and NHTSA (National Highway Traffic Safety Administration). 2020. The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks. 85 *Federal Register* 24174, April 30, RIN 2060-AU09. https://www.govinfo.gov/content/pkg/FR-2020-04-30/pdf/2020-06967.pdf.
Evans, M., K. Palmer, J. Aldy, M. Fowlie, A. Levinson, and M. Kotchen. 2021. "The Role of Retrospective Analysis in an Era of Deregulation: Lessons from the U.S. Mercury and Air Toxics Standards." *Review of Environmental Economics and Policy* 15 (1), forthcoming.
Fowlie, M., E. Rubin, and C. Wright. 2020. "Declining Power Plant Emissions, Co-Benefits, and Regulatory Rebound." Paper presented at ASSA [sp out] meetings, San Diego, January 4, 2020.
Friedman, L., D. Hedeker, and E. Richter. 2009. "Long-Term Effects of Repealing the National Maximum Speed Limit in the United States." *American Journal of Public Health* 99 (9): 1626–31.
Fullerton, D., and D. H. Karney. 2018. "Multiple Pollutants, Co-Benefits, and Suboptimal Environmental Policies." *Journal of Environmental Economics and Management* 87:52–71.
Goulder, L. H., and R. N. Stavins. 2011. "Challenges from State-Federal Interactions in US Climate Change Policy." *American Economic Review* 101 (3): 253–57.
Gray, C. B. 2015. "EPA's Use of Co-Benefits." *Engage* 16 (2): 31–33.
Hansman, C., J. Hjort, and G. León. 2018. "Interlinked Firms and the Consequences of Piecemeal Regulation." *Journal of the European Economic Association* 17 (3): 876–916.
Karlsson, M., E. Alfredsson, and N. Westling. 2020. "Climate Policy Cobenefits: A Review." *Climate Policy* 20 (3): 292–316.
Kotchen, M., M. Moore, F. Lupi, and E. Rutherford. 2006. "Environmental Constraints on Hydropower: An Ex-Post Benefit-Cost Analysis of Dam Relicensing in Michigan." *Land Economics* 82:389–403.
Levinson, A. 2011. "Belts and Suspenders: Interactions among Climate Policy Regulations." In *The Design and Implementation of US Climate Policy*, ed. D. Fullerton and C. Wolfram, 127–40. Chicago: University of Chicago Press.
Linn, J. 2008. "Technological Modifications in the Nitrogen Oxides Tradable Permit Program." *Energy Journal* 29 (3): 153–76.
Lutter, R., and J. Shogren. 2002. "Tradable Permit Tariffs: How Local Air Pollution Affects Carbon Emissions Permit Trading." *Land Economics* 78 (2): 159–70.
Napolitano, S., G. Stevens, J. Schreifels, and K. Culligan. 2007. "The NOx Budget Trading Program: A Collaborative, Innovative Approach to Solving a Regional Air Pollution Problem." *Electricity Journal* 20 (9): 65–76.
Nichols, A. L. 1997. "Lead in Gasoline." In *Economic Analyses at EPA: Assessing Regulatory Impact*, ed. R. D. Morgenstern, 49–86. Washington, DC: Resources for the Future.
OMB (Office of Management and Budget). 2003. "Circular A-4: Regulatory Analysis." Washington, DC: Executive Office of the President. September 17. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf.

———. 2005. “Validating Regulatory Analysis: 2005 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities.” Executive Office of the President. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/assets/OMB/inforeg/2005_cb/final_2005_cb_report.pdf.

———. 2017. Memorandum M-17-21, Guidance Implementing Executive Order 13771, Titled “Reducing Regulation and Controlling Regulatory Costs,” April 5. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/memoranda/2017/M-17-21-OMB.pdf.

———. 2019. “Report to Congress on the Benefits and Costs of Federal Regulations and Agency Compliance with the Unfunded Mandates Reform Act.” https://www.whitehouse.gov/wp-content/uploads/2019/12/2019-CATS-5885-REV_DOC-2017Cost_BenefitReport11_18_2019.docx.pdf.

Schmalensee, R., and R. Stavins. 2013. “The SO_2 Allowance Trading System: The Ironic History of a Grand Policy Experiment.” *Journal of Economic Perspectives* 27 (1): 103–22.

Sigman, H. 1996. “Cross-Media Pollution: Responses to Restrictions on Chlorinated Solvent Releases.” *Land Economics* 72: 298–312.

Smith, A. 2011. “An Evaluation of the $PM_{2.5}$ Health Benefits Estimates in Regulatory Impact Analyses for Recent Air Regulations.” Final Report NERA Economic Consulting. https://www.nera.com/content/dam/nera/publications/archive2/PUB_RIA_Critique_Final_Report_1211.pdf.