DISCUSSION PAPER

February 2010 ■ RFF DP 10-04

The Treatment of Uncertainty in EPA's Analysis of Air Pollution Rules

A Status Report

Arthur G. Fraas

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

The Treatment of Uncertainty in EPA's Analysis of Air Pollution Rules: A Status Report

Arthur G. Fraas

Abstract

An understanding of the uncertainty in benefit and cost estimates is a critical part of a benefit–cost analysis. Without a quantitative treatment of uncertainty, it is difficult to know how much confidence to place in these estimates. In 2002, an NRC report recommended that EPA move toward conducting probabilistic, multiple-source uncertainty analyses in its RIAs with the specification of probability distributions for major sources of uncertainty in the benefit estimates. In 2006, reports by GAO and RFF found that EPA had begun to address the NRC recommendations, but that much remained to be done to meet the NRC concerns. This paper provides a further review of EPA's progress in developing a quantitative assessment of the uncertainties in its health benefits analyses for the RIAs for four recent NAAQS rulemakings. In conclusion, EPA's recent RIAs present the results of its uncertainty analyses in piecemeal fashion rather than providing an overall, comprehensive statement of the uncertainty in its estimates. In addition, its recent RIAs continue to focus on the concentration-response relationship and largely fail to address the uncertainty associated with the other key elements of the benefits analysis.

Key Words: benefit–cost analysis, uncertainty analysis

JEL Classification Numbers: B41, D61, D80, I18, Q50

Contents

The Treatment of Uncertainty in EPA's Analysis of Air Pollution Rules: A Status Report

Arthur G. Fraas*

Introduction

In a 2002 report titled *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*, the National Research Council (NRC) of the National Academy of Sciences raised specific and detailed concerns with the U.S. Environmental Protection Agency's (EPA) treatment of uncertainty in its health benefits analysis.[1, 2] While previous recommendations varied over the best way to address uncertainty, the 2002 report was unequivocal in recommending that EPA conduct a more comprehensive quantitative assessment of uncertainty in its primary analysis as presented in the executive summary and main chapters of its regulatory analyses. The NRC report specifically stated that this change would require that EPA conduct probabilistic, multiple-source uncertainty analyses and make available a presentation of the uncertainty analysis that would be clear and transparent to decisionmakers and to other interested readers.

Analysis of benefits for EPA air rules typically requires a complex chain of analyses, including establishing baselines like the demographics and health status of the exposed population, estimates of the change in emissions with regulatory action, the effect of emissions changes on air quality, the resulting changes in the exposure of the population, and the resulting effect of changes in exposure on health. Because of the potential compounding of high-end or low-end assumptions in developing benefit estimates, the analyst, decisionmakers, and the public cannot know without a quantitative uncertainty analysis whether the benefit estimates provided by a regulatory impact analysis (RIA) are within the ballpark of likely effects—particularly

* Art Fraas is a visiting scholar at Resources for the Future; fraas@rff.org. I am grateful to John D. Graham, Randall Lutter, Richard Morgenstern, and Margo Schwab for their advice and comments. The views and errors in this paper are my own.

[1] Earlier NRC reports raised similar concerns. These earlier reports found that proper characterization of uncertainty is essential and most have expressed the concern that health benefits analyses understate the uncertainties in the analyses and leave decisionmakers with a false sense of confidence in the health benefits estimates.

[2] While the 2002 NRC report focused its attention on the uncertainty in the analysis of health benefits of air pollution regulations, the report recommended that EPA should also perform a similar quantitative uncertainty analysis for the valuation of health benefits and for the regulatory cost analysis. (NRC 2002, 127 and 148).

where conservative assumptions or defaults are used. By developing probability distributions for each of the key components and combining these distributions for the primary estimate, a quantitative uncertainty analysis places the benefit estimates in the context of a comprehensive probability distribution to provide a better representation of the uncertainty in the estimates.[3]

A July 2006 U.S. Government Accountability Office (GAO) report found that EPA had started to address a number of the NRC recommendations in its draft RIA for the 2006 National Ambient Air Quality Standard (NAAQS) for particulate matter (PM), but that a "continued commitment and dedication of resources will be needed if EPA is to fully implement the improvements endorsed by the National Academies" (GAO 2006, 15). Other recent reports and studies have also urged EPA to make further progress in the treatment of uncertainty.[4]

This paper provides a further assessment of EPA's progress in developing a quantitative assessment of the uncertainties in its health benefits analyses by examining the RIAs for four recent proposed and final NAAQS rulemakings—Ozone, Lead, Nitrogen Dioxide (NO_2), and Sulfur Dioxide (SO_2).[5] Each of these four RIAs included options with estimated benefits that exceed one billion dollars per year. The RIAs for these recent NAAQS rulemakings are "state-of-the-art" for EPA's regulatory analysis that reflect key changes in the benefits methodology applied to the recent NAAQS RIAs and in the RIAs for other major stationary and mobile source rulemakings.

Background

EPA's Approach to Uncertainty Analysis at the Time of the NRC Review

EPA used a two-part approach to provide a quantitative assessment of the uncertainty in the health benefits analyses for the four RIAs reviewed by the 2002 NRC report. First, EPA prepared a primary analysis that provided a probability distribution for each health outcome evaluated. These probability distributions incorporated only one source of uncertainty--the

---

[3]Throughout this discussion, the term "uncertainty" refers to both "variability" that reflects the statistical variation in estimates as well as to the uncertainty associated with a more fundamental lack of knowledge.

[4] For example, see Krupnick et al. 2006. See also NRC 2007a, 114-117 ; NRC 2007b, 6-8; Keohane 2009, 45-47.

[5] The NAAQS establish ambient standards for key air pollutants and are the flagship rules of the Clean Air Act (CAA). While the CAA prohibits the consideration of cost in setting the NAAQS, EPA prepares a regulatory analysis (RIA) in order to satisfy the requirements of Executive Order 12866 and to inform the public about the potential benefits and costs of alternative standards.

random sampling error associated with the effect estimates from the selected health studies--in its analysis. Second, EPA also prepared ancillary uncertainty analyses in an appendix to the RIA. These analyses included alternative and supplementary calculations for some uncertainties and sensitivity analyses for others. Typically, these ancillary analyses only examined one source of uncertainty at a time.

NRC Committee: Estimating the Public Health Benefits of Proposed Air Pollution Regulations

The 2002 NRC report was critical of EPA's approach in evaluating the uncertainty in its health benefits analysis. With respect to the primary analysis, the report stated that "…no estimate can be considered best if only one of the large number of uncertainties is included in the analysis producing that estimate."[6] (NRC 2002, 138) In addition, the NRC report found "…that the mean of the distributions should not be interpreted as 'best' estimates, and the intervals between the 5th and 95th percentiles of the distributions should not be interpreted as '90 percent credible intervals,' within which 'the true benefit lies with 90 percent probability' (U.S. EPA 1999a, p. 3-26.)" (NRC 2002, 134).

With respect to EPA's ancillary sensitivity analysis in the appendices to these RIAs, the NRC report observed that by limiting the analyses to focus on one source of uncertainty at a time that these analyses "…do not adequately convey the aggregate uncertainty from other sources, nor do they discern the relative degrees of uncertainty in the various components of the health benefits analysis." (NRC 2002, 10-11). The report recommended that (NRC 2002, 11):

> EPA should move the assessment of uncertainty from its ancillary analyses into its primary analyses to provide a more realistic depiction of the overall degree of uncertainty. This shift will entail the development of probabilistic, multiple-source uncertainty models based not only on available data but also on expert judgment. EPA should also continue to use sensitivity analyses but should attempt to include more than one source of uncertainty at a time.

It also identified a number of specific areas of uncertainty in the analysis of health benefits that deserve to be evaluated in a quantitative uncertainty analysis. The NRC identifies

[6] The NRC report also noted that "Because of the lack of consideration of other sources of uncertainty, the results of the primary analysis often appear more certain than they actually are." (NRC 2002, 11).

many factors that are important to such analysis, not all of which are discussed here. My review focuses on the following critical components to a quantitative uncertainty analysis.

Boundaries and Baselines

1. Population Demographics and Heterogeneity: Predictions about future populations, such as predicted population growth and changes in age distribution are important elements of EPA's benefits analyses. The NRC recommended that EPA should evaluate the uncertainty involved in these predictions and the effect of these uncertainties on the benefits estimates. (NRC 2002, 6)
2. Health Baseline: Projections of baseline health status are important aspects of EPA's benefits analyses. The NRC suggested that EPA should also evaluate the uncertainty associated with its estimates of baseline health status. (NRC 2002, 6)

Exposure Assessment

3. Estimated Changes in Emissions: The NRC reported that "…current emissions models fail to provide an assessment of uncertainty associated with the emissions predictions for the baseline and control scenarios." For example, there is uncertainty with the extent of compliance and the effectiveness of projected control requirements. (NRC 2002, 5-6)
4. Air Quality Modeling: Air quality modeling—that is, the effect of emissions on ambient air quality—represents another critical step in estimating the benefits of proposed air pollution regulations. Without evaluating the uncertainty in air quality modeling, the NRC reported that "…it is difficult to know how much confidence to place in the predictions." (NRC 2002, 6)
5. Ambient Air Concentrations Adequately Represent Actual Exposure: EPA analyses also assume that predicted ambient concentrations of a pollutant adequately represent human population exposures. (NRC 2002, 7)

Health Outcomes

6. The assumption of causality between pollutant exposures and adverse health outcomes is a critical part of EPA's benefits analysis and the NRC noted that it is important to assess the uncertainty associated with this assumption. (NRC 2002, 8)
7. Validity and Precision of the Concentration-Response Functions**:** The benefits analysis should reflect the plausibility and uncertainty of the concentration-response

function, such as imprecision of exposure and response measures, functional form (and threshold), lag structures, potential confounding factors, and extrapolation from the study population to the target population in the benefits analysis. (NRC 2002, 9)

8. Toxicity of PM Components: Because scientific information on PM toxicity is incomplete, EPA has typically made the assumption that all particle types are equivalent in potency. The NRC recommended that EPA should evaluate a range of alternative assumptions regarding relative particle toxicity in its uncertainty analyses. (7)

OMB' Circular A-4

In 2003, the Office of Management and Budget (OMB) issued Circular A-4 to provide guidance to the Federal agencies on the development of regulatory analysis required by Executive Order 12866 and the Regulatory-Right-to-Know-Act.[7] Circular A-4 included an expanded discussion on the treatment of uncertainty in a regulatory analysis and specifically requires a formal quantitative uncertainty analysis for rules with benefits or costs that exceed one billion dollars per year.[8]

GAO's Report to Congress

GAO issued its July 2006 report "EPA Has Started to Address the National Academies' Recommendations on Estimating Health Benefits, but More Progress Is Needed" on the extent to which EPA had responded to the NRC recommendations in its January 2006 draft RIA for the proposed rule revising the particulate matter NAAQS. GAO found that EPA fully "applied" eight of the recommendations and that EPA partially responded to another 16 recommendations—approximately two-thirds of the Academies' recommendations--in its January 2006 regulatory impact analysis. (GAO 2006, 7) However, many of the EPA responses addressed

[7]Circular A-4 revised OMB's earlier 1996 "best practices" document and a revised version issued as an OMB guidance in 2000.

[8]Circular A-4 also included other requirements. For example, it requires that the analysis should consider both the statistical variability and the uncertainty associated with incomplete knowledge about relevant relationships. It also provides that the treatment of uncertainty must be guided by the same principles of transparency and full disclosure that apply to other elements of the regulatory analysis.

recommendations for changes to the RIA that were not related to the development of a quantitative uncertainty analysis.[9]

Of the eight components identified above (from the 2002 NRC report) as key elements of a quantitative uncertainty analysis, GAO found EPA had fully applied only two recommendations—both associated with the assumption of causality and the concentration-response relationship between PM exposure and premature mortality--and partially addressed one in the draft 2006 RIA for the PM NAAQS.[10] GAO specifically noted that even with EPA's expert elicitation study "…the health benefits analysis does not similarly assess how the benefit estimates would vary in light of other key uncertainties as the Academies had recommended." (GAO [2006], p. 3.) With respect to other key uncertainties, GAO cited, for example, uncertainty about the effects of age and health status of people exposed to particulate matter and estimates of exposure to particulate matter. For these reasons, GAO reported that "EPA's responses reflect a partial application of the Academies' recommendation." (GAO 2006, 9).

2006 RFF Study

In 2006, Krupnick et al. also published a report, *Not a Sure Thing: Making Regulatory Choices Under Uncertainty*, providing guidance and recommendations to EPA on developing a formal uncertainty analysis in its RIAs. As a part of this project, the authors reviewed four recent EPA RIAs and concluded that EPA had made some progress in improving its uncertainty analysis, but that "considerable opportunities" remained. The study reported that (Krupnick et al. 2006, 7.)

> In general, EPA RIAs do not adequately represent uncertainties around "best estimates", do not incorporate uncertainties into primary analyses, include

---

[9]Of GAO's eight fully "applied" recommendations, for example, only two were directly related to developing a quantitative uncertainty analysis. Of the remaining recommendations, three suggested further EPA review of the basis for estimated health effects in the primary analysis (e.g., using C-R functions from acute studies that integrate over multiple days or weeks, rather than rely on studies with a lag of 1 or two days) and two addressed presentation (e.g., rounding to fewer significant digits) and transparency (e.g., providing clear and accurate references to the technical supporting documents) issues. Finally, GAO reported that EPA decided not to adopt one of the eight recommendations—i.e., providing an estimate of health benefits for the current population resulting from the expected change in emissions—because it would not provide meaningful information to the analysis. (GAO 2006, Appendix II, 20-28).

[10] See Appendices II & III of the GAO report for NRC report recommendations "applied" and "not applied" to the 2006 draft RIA. (GAO 2006, Appendix II and III, 20-28 and 29-38).

> limited uncertainty and sensitivity analyses, and make little attempt to present the results of these analyses in a comprehensive way.

Krupnick et al. also presented a case study of a hypothetical rule as a way of developing a quantitative uncertainty analysis for other sources of uncertainty (beyond those associated with the concentration-response relationship and the valuation of effects). They reported their success in modeling population uncertainties and the uncertainties associated with the source receptor estimates associated with air quality modeling. (Krupnick et al. 2006, 221.) Finally, the report provided some conclusions and recommendations for next steps in developing a formal uncertainty analysis in EPA's RIAs.

Status of EPA Uncertainty Analysis in Recent RIA's

EPA's recent RIAs acknowledge the NRC critique of its uncertainty analysis in the RIA discussion of Limitations and Uncertainties, as follows (U.S. EPA 2009a, 5-34):[11]

> The National Research Council (NRC) (2002) highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA's Office of Air and Radiation (OAR) is developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates. Components of that strategy include emissions modeling, air quality modeling, health effects incidence estimation, and valuation.

EPA's efforts to date to provide a quantitative uncertainty analysis—both before and after the 2002 NRC report—have focused on the concentration-response relationship between exposure to air pollution and the associated health outcomes. (See Table 1.) In particular, EPA's Office of Air and Radiation (OAR) completed an expert elicitation study in 2006 in response to the NRC report to better characterize the concentration-response relationship between fine PM exposure and premature mortality. (Roman et al., 2008; IEc, 2006) In this study, the experts addressed some of the key concentration-response related issues identified by the 2002 NRC report: causality, functional form, threshold, and magnitude of effect. EPA is now presenting the results of this expert elicitation study in RIAs for regulations that achieve significant fine PM reductions.

[11] See also EPA 2008a 6-5, 6-6 and EPA 2009b, 5-55.

With the exception of the addition of the results from this expert elicitation study, EPA continues to use—largely unchanged--the basic approaches reviewed by the 2002 NRC report in presenting a quantitative uncertainty analysis for its benefits estimates. In particular, these RIAs present a “primary” or “core” estimate with “confidence intervals” for the estimated health effects based on the standard error in the effect estimates from the selected health studies and a separate sensitivity analysis—conducted by considering one element at a time--for some of the other factors that contribute to uncertainty in developing health effects estimates. (See Table 2.) EPA also provides a qualitative discussion for the variety of factors for which it is unable to provide a quantitative analysis. Each of these approaches deserves further discussion.

Alternate Concentration-Response Functions for PM Mortality (Expert Elicitation Study)

As its most significant response to the NRC report, EPA conducted an expert elicitation study to provide a better understanding of the relationship between fine PM and premature mortality. EPA now presents an array of information from the expert elicitation study in its RIAs. This includes a representation of the results for each of the 12 experts as well as estimates based on the most recent epidemiological-based estimates from the American Cancer Society study (Pope 2002) and from the six-city study (Laden 2006). A panel of EPA’s Science Advisory Board—the Advisory Council on Clean Air Compliance Analysis (Council)—strongly endorsed EPA’s application of the study results to the assessment of PM benefits.[12]

The expert elicitation study represents an important experimental effort—but one that is attended by significant limitations and that raises some important methodological issues. One area requiring additional attention is the development of a usable probability distribution from the expert elicitation to represent the concentration-response relationship between exposure to air pollution and adverse health effects. For the PM expert elicitation, EPA has chosen to present the views of each of the experts separately—an approach consistent with the best practices in the field. Because of the issues associated with aggregating the views of the experts, EPA has

[12] The Council responded as follows as to whether EPA’s benefits assessment responded to the NRC recommendation (U.S. EPA-SAB 2008, ii): “… to 'move the assessment of uncertainties from its ancillary analysis into the primary analysis by conducting probabilistic, multiple-source uncertainty analysis.’ (NRC, Estimating the Health-Risk-Reduction Benefits of Proposed Air Pollution Regulations, 2002). Our answer is yes.”

declined to present an aggregate estimate.[13] As a result, the current approach falls short of the goal of formal decision analysis—that is, a rigorous and theoretically justified approach for combining information about uncertainty in the form of a probability distribution. In addition, the selection of experts and the composition of the panel also continue to be an area of concern. A number of the experts on the panel, for example, have decades of work invested in epidemiological studies showing an association between PM exposure and adverse health effects. On the other hand, only three members of the panel came from the toxicological community—a discipline that may have a somewhat different perspective on the effects of fine PM. For example, this community might be more likely to adopt a threshold below which exposure to fine PM would not have a significant adverse health effect.[14] While one would expect such panels to include experts in the epidemiology field, the selection and composition of expert elicitation panels to assure an appropriate balance remains an area of continuing concern in applying expert elicitation methods to a quantitative uncertainty analysis.

The presentation of the results from the expert elicitation study, then, provides a separate perspective—independent of the primary analysis—on the uncertainty associated with the concentration-response relationship between exposure to fine PM and premature mortality. However, the application of the results from this initial expert elicitation study falls far short of yielding the more comprehensive, quantitative representation of uncertainty in the health benefits estimates envisioned by the NRC committee. And, of course, the expert elicitation study applies only to the fine PM–premature mortality relationship and does not address the uncertainty in the concentration-response relationship for the other criteria pollutants subject to the NAAQS (ozone, lead, NO_2, and SO_2).

EPA's "Primary" Analysis for Health Effects with Monte Carlo Methods

EPA continues to develop a primary analysis presenting incidence estimates based on concentration-response functions from selected studies (or groups of studies). These estimates include "95th percentile confidence intervals" based on the standard errors of the effect estimates

---

[13] On this question, The Council supported EPA's approach by responding that the best approach depended on the context and results of the expert elicitation. Where the experts have a wide range of views, it is important to provide separate estimates for each expert; but where experts share similar views, it would be appropriate to provide a single distribution (or point estimate with uncertainty bounds). (U.S. EPA-SAB 2008, ii.)

[14] For example, see Industrial Economics, Inc. 2006, 3-26.

taken from the selected studies for each of the health endpoints.[15] EPA uses Monte Carlo methods to generate the confidence intervals around the health incidence estimates and the monetized benefit estimates.[16]

In discussing this approach, the NRC report found that "…no estimate can be considered best if only one of the large number of uncertainties is included in the analysis producing that estimate" (NRC 2002, 138). Further, the committee also found the intervals between the 5th and 95th percentiles of the distributions should not be interpreted as "90 percent credible intervals," or interpreted as a range within which "the true benefit lies with 90 percent probability" (U.S. EPA 1999a, p. 3-26)" (NRC 2002, 134).

In EPA's most recent RIAs, health benefits from reduced exposure to PM has represented an important co-benefit of regulatory action—accounting for more than 90 percent of estimated benefits in most cases--for rules establishing other NAAQS (e.g., ozone, lead and nitrogen dioxide). In these rulemakings, EPA has adopted a benefits-per-ton methodology for estimating the co-benefits of PM control. The adoption of this approach in these RIAs has made it impossible for EPA to provide confidence limits on the monetized PM co-benefit estimates because EPA has not developed a quantitative uncertainty analysis of the other critical components that underlie these benefit-per-ton estimates. (U.S. EPA 2009a, 5-35.) Instead, these RIAs present point estimates of the benefits using effect estimates from Pope, et al and Laden, et al as its core or primary estimates.[17] In addition, to provide perspective on these two estimates, these RIAs also present the Pope and Laden benefit results with the corresponding estimated co-benefits using the 12 effect coefficients for each of the experts from the EPA expert elicitation study on PM mortality. Most of the individual expert-based estimates fall between the estimates from these two epidemiological studies.

---

[15] For example, see EPA SO2 2009, 5-21.

[16]Monte Carlo analysis involves the random sampling from the probability distribution functions for the various elements that comprise a "model" (in this case relating changes in emissions to health outcomes like increased risk of mortality). This process generates thousands of possible outcomes that allow the development of a probability distribution function for the outcome of interest (for example, mortality). EPA also uses the health effects distributions for the individual health end-points in conjunction with a distribution of the value of reducing the risks of these effects in a Monte Carlo analysis to generate a distribution for monetized benefit estimates.

[17] EPA adopted this approach in response to the Council concern that the array of estimates from the 12 experts and the use of a range based on the lowest and highest mean estimates for these experts did not identify the Agency's best estimate of PM mortality benefits and is not the best way to present information from the expert elicitation. (U.S. EPA-SAB 2008, 5-6.)

In summary, despite the NRC critique, EPA has not changed its basic methodology for its primary analysis for the specific pollutant subject to regulation (ozone, NO_2, or SO_2)—that is, a primary estimate with "confidence intervals" based solely on the use of the standard error in the effect estimates. The only cases where EPA does not use the confidence interval approach are its recent RIA for the lead NAAQS and, as discussed above, in developing co-benefit estimates based on a per-ton methodology for PM reductions.

Sensitivity Analysis

In addition, EPA performs sensitivity analyses to identify the effect of specific assumptions on the primary benefit estimates. For the draft regulatory analysis for the 2009 SO_2 NAAQS proposal, for example, these sensitivity analyses suggested that the benefit estimates are relatively more sensitive to alternative threshold assumptions in the PM-mortality relationship and less sensitive to alternative assumptions on the discount rate. (U.S. EPA 2009, 5-57.)

The NRC report recognized that sensitivity analysis helped to describe the uncertainty in the analysis, but found that EPA's approach was not sufficient. The major problems identified by the NRC report with EPA's approach included: (1) the sensitivity analyses are contained as ancillary analyses in the Appendices to the RIA, rather than integrated into the primary analysis; (2) the sensitivity analyses consider only one element of uncertainty at a time; and (3) EPA does not offer any judgment on the relative plausibility of the various scenarios, leaving to the reader the task of integrating the information from the sensitivity analyses on the various sources of uncertainty.

EPA's most recent RIAs for lead, nitrogen dioxide, and SO_2 NAAQS respond to the first of these concerns by presenting the basic results from EPA's sensitivity analysis in the body of the benefits chapter. However, in other respects, EPA's approach to and treatment of sensitivity analysis is largely unchanged from the approach reviewed by the NRC committee in 2002. In particular, EPA's sensitivity analyses continue to consider only one element of uncertainty at a time.[18] And, EPA presents the alternative scenarios without providing any judgment on the relative plausibility of the alternatives. As a result, the reader must integrate the information from

[18] Because OMB's Circular A-4 requires the agencies to present benefit and cost estimates using discount rates of 3 percent and 7 percent, the RIA sensitivity analyses will sometimes present estimates that also include both discount rates. In these analyses, the benefits estimates are not very sensitive to the discount rate. For example, the draft SO2 RIA presents benefit estimates using Pope and Laden with the two alternative discount rates. Sensitivity analyses for other key elements are presented for a single discount rate. (EPA 2009, 5-57.)

the sensitivity analyses—as well as the other quantitative analyses developed in the RIA—in assessing the uncertainty in the health benefits estimates.

Qualitative Discussion of Other Areas of Uncertainty

EPA continues to provide a qualitative discussion of other factors that contribute to uncertainty in its health benefits analysis.[19] In the final RIA for the PM NAAQS, for example, EPA included both an extensive qualitative discussion of uncertainties in the benefits analysis and a table providing a list of key areas of uncertainty.[20] Other recent RIAs provide a similar qualitative discussion. While this qualitative discussion recognizes the importance of other sources of uncertainty in the health benefits estimates, there is little evidence of further progress in providing a quantitative uncertainty analysis for these critical areas, such as population demographics and heterogeneity, health baselines, projected changes in emissions, and air quality modeling.

The projected changes in emissions used in these RIAs represent one critical area deserving quantitative analysis. In its RIAs, EPA provides point estimates for the emissions reductions used in the analysis. For example, the draft RIA for the SO_2 NAAQS proposal presents emissions reduction estimates for individual nonattainment counties—so, a required emissions reduction of 6100 tons in Morgan County (Indiana) and 450 tons in Greene County (Missouri) for an SO_2 standard of 50 ppb. The aggregate estimate for the SO_2 emission reductions required to meet the 50 ppb option across all nonattainment counties is 1,061,000 tons.

The RIA identifies some of the uncertainties and limitations associated with the estimated reductions. First, these RIAs present an analysis of "illustrative control strategies" because the actual control strategies will be determined through the State Implementation Plan process and could differ substantially—with a different mix of emissions reductions and sources—from the approach evaluated by the RIA. In addition, there are uncertainties associated with the use of air quality monitoring to develop these emissions reduction estimates and with the effectiveness of the identified controls.

[19] The NRC committee recommended that "…EPA should emphasize even more than it has in the past the sources of uncertainty that remain unaccounted for in the primary analysis. These uncertainties should continue to be described as completely and realistically as possible" (NRC 2002, 147).

[20] Available at www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

Changes in control strategies could introduce substantial uncertainty in the benefits estimates because of the heterogeneity across sources and locations in the benefits of control. For example, a recent article suggests a substantial variation in PM co-benefits across sources—including negative PM co-benefits for mobile source NOx control in all of the three eastern regions considered in the analysis (Atlanta, Chicago, and New York/Philadelphia) (Fann et al. 2009; see Table 3). Because PM co-benefits dominate the benefit estimates for recent NAAQS revisions, a shift in NOx control strategy involving mobile sources could substantially alter the estimated benefits (for example, a change in emissions dictated by the SIP process in response to violations at roadway monitors). However, RIAs for the recent NAAQS do not present any information on the effects of heterogeneity across sources and locations.

Another critical area is the development of a quantitative uncertainty analysis for the exposure assessment, including the underlying air quality modeling. For example, a recent NRC report provided estimates of the benefits per ton associated with controlling emissions of SO_2, NOx, and fine PM from coal-fired power plants that are substantially smaller than EPA's recent estimates (in some cases an order of magnitude smaller; see Table 4). Although a portion of this difference is attributable to a difference in the threshold assumption for the concentration-response, much of the difference in the estimates arises from differences in the air quality modeling used in the NRC report and by EPA[21] (NRC 2009, 73). Such differences could significantly alter estimated benefits.

Summary

Seven years after the 2002 NRC report, EPA's primary response to the report has been limited primarily to the completion of an expert elicitation study of the causal relationship between fine PM exposure and premature mortality. EPA has also responded to some of the NRC report recommendations by changing the presentation of its uncertainty analysis—for example, moving its sensitivity analysis into the main RIA health benefits chapter and rounding the estimates to fewer significant digits. But, in all other respects, EPA's basic approach to presenting the uncertainty in its health benefits estimates remains largely unchanged.

[21] Krupnick et al. (2006) examined the effect of adopting two alternative source-receptor models and reported that there was a 3.5 fold difference in the mean benefit estimates for the two models (97).

First, the array of information presented in EPA's recent RIAs continues to place on the reader of the RIA the responsibility of assessing the relative weighting and plausibility of alternative assumptions and combine this assessment across uncertainty sources to provide an overall estimate of the uncertainty in the estimates. Second, the quantitative treatment of uncertainty in EPA's recent RIAs focuses on the concentration-response relationship and largely fails to address the uncertainty associated with other key elements in the benefits analysis, such as population demographics and heterogeneity, health baselines, and exposure, including air quality modeling. Third, while the expert elicitation study provides a separate perspective on the fine PM–premature mortality relationship, it falls far short of yielding the more comprehensive, quantitative representation of uncertainty in the health benefits estimates envisioned by the NRC report. Finally, the expert elicitation study applies only to the fine PM–premature mortality relationship, and does not address in a similar way the uncertainty in the concentration-response relationship for the other criteria pollutants subject to the NAAQS.

The development of a good quantitative uncertainty analysis is clearly a difficult effort—perhaps more difficult than recognized by the 2002 NRC report. It is made all the more difficult by limited budget and staff resources and by the continuing stream of major rulemakings.[22] In the last two years, for example, EPA has developed RIAs for four final or proposed NAAQS rules—ozone, lead, nitrogen dioxide, and sulfur dioxide. With this heavy workload under tight deadlines and limited resources, it is difficult to improve the uncertainty analysis.

Nevertheless, EPA's recent RIAs provide only a qualitative discussion for many of the sources of uncertainty in the analysis, even though outside panels and studies continue to call for improved quantitative uncertainty analysis.[23] To paraphrase the NRC report, no estimate can be considered best until the quantitative analysis includes the major sources of uncertainty in the analysis producing that estimate. The examples cited above on the potential uncertainty in emissions estimates and air quality modeling point to the uncertainty that attends current RIA benefits estimates. Because the same questions with respect to uncertainty analysis arise repeatedly with the periodic review of the NAAQS required by the CAA, and with the

[22] In response to the 2006 GAO report, EPA staff indicated that budget and staff to devote to the RIA effort were limited. In addition, they reported that some of the recommendations require a long-term research and development effort. For example, EPA has such research underway to assess the relative toxicity of different components of particulate matter. They also suggested that the cost of doing the work necessary to meet some of the recommendations might outweigh the value of the added information. (GAO 2006, 10-11and 30-36.)

[23] NRC 2007a, 116-117; NRC 2007b, 6-8; Krupnick et al. 2006, 224-227, Keohane 2009, 45-47.

application of these NAAQS RIA effect estimates to RIAs for other rules (for example, mobile source rules), it would seem imperative for EPA to develop a better quantitative uncertainty analysis.

Tables

Table 1. Quantitative Uncertainty Analysis for Key Elements in Estimating Health Benefits for Rules Revising Recent NAAQS

	GAO Assessment, 2006	Final 2006 PM NAAQS RIA	Recent EPA Regulatory Analysis
I. Boundaries and Baselines			
Population demographics and heterogeneity	Not applied.	No further progress.	No further progress.
Health baselines	Not applied.	No further progress.	No further progress.
II. Exposure Assessment			
Estimated changes in emissions	Not applied; R&D under development.	No further progress.	No further progress.
Air quality modeling	Not addressed.	No further progress.	No further progress.
Ambient air measures adequately reflect actual exposure	Partially applied. However, EPA has not yet assessed how human-time activity patterns affect exposure to PM.	No further progress.	Sensitivity analysis on the geographic scope of exposure estimates for lead, NO_2, and SO_2 RIAs (e.g. exposure within a 30 km radius v. exposure within a 15 km radius).
III. Health Outcomes			
Assumption of causality	Applied. RIA refers readers to prior RIA for information.	Same plus EPA completed expert elicitation study.	No additional progress.
Validity and precision of C-R function	Applied. EPA is undertaking an expert elicitation study to evaluate C-R function for fine PM.	EPA completed expert elicitation study for C-R function for fine PM.	See Table 2.
Toxicity of PM components	Not applied; R&D underway.	Same	Not applicable for criteria pollutant of concern in rule.

Sources: U.S. EPA 2006, 2008a, 2008 b, 2009a, and 2009b.

Table 2. Quantitative Uncertainty Analysis in Developing a Concentration-Response Function for Estimating Health Benefits for Recent NAAQS Rules

	Ozone NAAQS	Lead NAAQS	NO2 NAAQS	SO2 NAAQS
Primary Analysis				
Mean Based on Effect Estimate	Yes [a]	Yes [b]	Yes [b]	Yes [b]
95% Confidence Interval using std. error of selected studies	Yes [a]	No	Yes [b]	Yes [b]
Sensitivity Analysis/Primary Analysis	None	Yes [c]	Yes	Yes
One factor at a time	n/a	Yes	Yes	Yes
Presentation in Appendix only	n/a	Analysis in the benefits section.	Analysis in the benefits section.	Analysis in the benefits section.
Types of Sensitivity Analysis/Primary Analysis				
Exposure estimate scope	n/a	Yes	Yes	Yes
Threshold	n/a	No	Yes	No
Selection of studies	n/a	Yes	Yes	Yes
Simulated attainment	n/a	No	Yes	No
PM Co-Benefits				
Expert Elicitation Study	Yes	Yes	Yes	Yes
Confidence Intervals	No	No	No	No
Sensitivity Analysis	Only in Appendix.	None	Analysis in the benefits section.	Analysis in the benefits section.
Presentation in Executive Summary	No, only qualitative discussion.	No, only qualitative discussion.	No, only qualitative discussion.	No, only qualitative discussion.

[a] Premature mortality and morbidity

[b] Morbidity only

[c] Sensitivity analysis also included the effect of different air-to-blood ratios and non-air background lead levels.

Sources: U.S. EPA 2006, 2008a, 2008 b, 2009a, and 2009b.

Table 3. Monetized Reductions in Fine PM Precursor Emissions by Source and Location

	Area source carbon	Mobile source carbon	EGU & Non-EGU carbon	Area source SOx	EGU SOx	Non-EGU SOx	VOC	Area source NH3	Mobile source NH3	EGU NOx	Non-EGU NOx	Mobile source NOx
National	$720,000	$550,000	$460,000	$40,000	$82,000	$59,000	$2,400	$38,000	$95,000	$15,000	$9,700	$10,000
Atlanta	$670,000	$590,000	$620,000	$48,000	$15,000	$42,000	$1,200	-$4,100	$56,000	$7,900	-$4,500	-$4,100
Chicago	$510,000	$580,000	$600,000	$29,000	$18,000	$15,000	$3,100	$36,000	$100,000	$1,100	$2,000	-$8,700
Dallas	$1,100,000	$790,000	$1,100,000	$140,000		$29000	$600	$16,000	$36,000	$34,000	$920	$370
Denver	$280,000	$450,000	$220,000	$75,000	$6,400	$19,000	$1,400	$10,000	$58,000	$3,200	$3,800	$2,700
NY/Phi	$570,000	$710,000	$780,000	$14,000	$74,000	$50,000	$4,300	$53,000	$140,000	$1,500	-$2,600	-$8,200
Phoenix	$2,500,000	$1,700,000	$980,000	$73,000		$550,000	$2,000	$15,000	$43,000	$11,000	-$2,100	-$680
Salt Lake	$140,000	$150,000	$65,000	$15,000		$9,100	$2,600	$29,000	$43,000		$4,200	$1,500
San Joaquin	$910,000	$560,000	$720,000	$140,000	$350,000	$46,000	$5,700	$36,000	$140,000	$28,000	$28,000	$43,000
Seattle	$500,000	$570,000	$720,000	$54,000	$6,300	$52,000	$560	$18,000	$49,000	$120,000	-$2,300	-$8,100

Source: Fann et al. 2009, 174. Figure 4.

Table 4. Benefit per Ton Estimates for Emissions of Direct PM and Precursor Pollutants from EGUs

	2009 NRC Report[a]		NO2 NAAQS[b]	SO2 NAAQS[c]
	Mean	*50th percentile*		
Direct PM2.5	$9,500	$7,100	$280,000	$230,000
PM2.5 Precursor Pollutants				
SO_2	$5,800	$5,800	NA	$42,000
NO_x	$1,600	$1,300	$7,600	$7,600

[a] Benefit per ton estimates for the reduction of direct PM and for precursor emissions from the mean and 50th percentile EGUs over the distribution of 406 coal-fired plants considered in the NRC report (NRC 2009, 65).

[b] Benefit per ton estimates from the draft RIA for the proposed NO_2 NAAQS rule (U.S. EPA 2009a, Table 5.7, 5-28).

[c] Benefit per ton estimates from the draft RIA for the proposed SO_2 NAAQS rule (U.S. EPA 2009b, Table 5.9, 5-31).

References

Fann, Neal, Charles M. Fulcher, and Bryan J. Hubbell. 2009. The influence of location, source, and emissions type in estimates of the human health benefits of reducing a ton of air pollution. *Air Quality, Atmosphere & Health* 2(3): 169–176. http://www.springerlink.com/content/1381522137744641/

GAO (U.S. Government Accountability Office). 2006. *Particulate Matter: EPA Has Started to Address the National Academies' Recommendations on Estimating Health Benefits, but More Progress is Needed*. GAO-06-780. Washington, DC: U.S. GAO. www.gao.gov/cgi-bin/getrpt?GAO-06-780

Industrial Economics, Inc. 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Washington, DC: U.S. EPA, Office of Air Quality Planning and Standards, September. www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf

Keohane, Nathaniel O. 2009. The Technocratic and Democratic Functions of the CAIR Regulatory Analysis. In *Reforming Regulatory Impact Analysis*, edited by W. Harrington, L. Heinzerling, and R. Morgenstern. Washington, DC: Resources for the Future.

Krupnick, Alan, Richard Morgenstern, Michael Batz, Peter Nelson, Dallas Burtraw, Jhih-Shyang Shih, and Michael McWilliams. 2006. *Not a Sure Thing: Making Regulatory Choices under Uncertainty*. Washington, DC: Resources for the Future.

Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. Reduction in Fine Particulate Air Pollution and Mortality. *American Journal of Respiratory and Critical Care Medicine* 173: 667–672.

NRC (National Research Council). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: National Academies Press.

———. 2007a. Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution. Washington, DC: National Academies Press.

———. 2007b. Models in Environmental Regulatory Decision Making. Washington, DC: National Academies Press.

———. 2009. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. Washington, DC: National Academies Press.

OMB (U.S. Office of Management and Budget). 2003. Circular A-4. Washington, DC: OMB.

Pope, C.A., R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association* 287: 1132–1141.

Roman, Henry A., Katherine D. Walker, Tyra L. Walsh, Lisa Conner, Harvey M. Richmond, Bryan J. Hubbell, and Patrick L. Kinney. 2008. Expert Judgment Assessment of the Mortality Impact of Changes in Ambient Fine Particulate Matter in the U.S. Environmental Science and Technology 42(7): 2268–2274.

U.S. EPA (U.S. Environmental Protection Agency). 2006. Regulatory Impact Analysis, 2006. National Ambient Air Quality Standards for Particulate Matter, Chapter 5. Research Triangle Park, NC: Office of Air Quality Planning and Standards, October. www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf

———. 2008a. Regulatory Impact Analysis, March 2008. National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Research Triangle Park, NC: Office of Air Quality Planning and Standards. www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf

———. 2008b. Regulatory Impact Analysis of the Proposed Revisions to the Air Quality Standards for Lead, October. Research Triangle Park, NC: Office of Air Quality Planning and Standards. www.epa.gov/ttn/ecas/regdata/RIAs/finalpbria.pdf.

———. 2009a. Proposed NO_2 NAAQS Regulatory Impact Analysis (RIA). Research Triangle Park, NC: Office of Air Quality Planning and Standards. www.epa.gov/ttn/ecas/regdata/RIAs/proposedno2ria.pdf

———. 2009b. Proposed SO_2 NAAQS Regulatory Impact Analysis (RIA), November 2009. Research Triangle Park, NC: Office of Air Quality Planning and Standards. atwww.epa.gov/ttn/ecas/regdata/RIAs/pso2full11-16-09.pdf

U.S. EPA – SAB (U.S. Environmental Protection Agency – Science Advisory Board). 2008. *Characterizing Uncertainty in Particulate Matter Benefits Using Expert Elicitation*. EPA-COUNCIL-08-002. Washington, DC: U.S. EPA.