Are Decisionmakers at Home on the Range? Communicating Uncertainties in Cost-Benefit Analyses

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Resources for the Future

Abstract

Better and more complete information does not necessarily lead to better policies. Complex information can confound rather than enlighten, or can lead to decision paralysis. Thus, any improvements in capturing uncertainty analytically needs to be matched by improvements in its communication – not only to those who make regulatory decisions on the basis of such information, but also to stakeholders, judges, the press and the general public. Accordingly, this paper presents the results of seven in-depth interviews conducted with former Presidential appointees at the EPA concerning the use of uncertainty analysis. Specifically, results of a case study involving future controls of NOx emissions from power plants was presented to the interviewees, using different visual approaches for displaying the uncertainties. They were asked to express preferences for different regulatory outcomes based on the alternative approaches used to present the information. Tables and probability density functions (PDFs) may be best suited for communicating to high-level decisionmakers, although PDFs tend to move respondents to tight spread options. Respondents also emphasized the importance of presenting technical analysis in context.

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Richard Morgenstern, Peter Nelson and Alan Krupnick[1]

I. Introduction

> "A big part of my frustration was that scientists would give me a range. And I would ask, 'Please just tell me at which point you are safe, and we can do that.' But they would give a range, say, from 5 to 25 parts per billion (ppb). And that was often frustrating."
> Christine Todd Whitman, quoted in Environmental Science and Technology Online, April 20, 2005

As the use of formal uncertainty assessment is becoming more common in many fields, including economics, finance, engineering, and certain scientific disciplines, it is not hard to see why examining uncertainties in Regulatory Impact Assessments (RIAs) is an important activity for improving public policy. Sole reliance on point estimates masks the underlying distribution of estimates of benefits and costs, gives a false sense of security to decisionmakers and the public, and can result in policies judged to have been ill-advised when uncertainties are realized after policy implementation. Consider, for example, two alternative policies that both yield the same net benefits but involve quite different variances. Absent formal uncertainty analysis, a decision maker would not have information on the nature or magnitude of the underlying uncertainties and, possibly, might choose an option that failed to meet key policy objectives, e.g., assure at least a minimal level of risk reduction or net benefits.

Despite the paucity of integrated assessment models or other relevant tools, the U.S. Environmental Protection Agency (EPA) started incorporating uncertainty analysis into its RIAs in the mid 1990s. In 1997 the Agency issued *Guiding Principles for Monte Carlo Analysis* (EPA, 1997a). The Agency also conducted at least some form of uncertainty analysis in several congressionally mandated studies, including both the retrospective and the prospective analysis of the Clean Air Act Amendments of 1990 (EPA, 1997b; 1999).[2]

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[1] Authors acknowledge financial support from US EPA for the underlying study (see Krupnick et al., forthcoming). Helpful comments were received from Alex Corrales at EPA and from our RFF collegues Michael Batz, Dallas Burtraw, Michael Hensler-McGuiness, and Jhih-Shyang Shih. The authors are responsible for any remaining errors.

[2] For example, our own review of four recent EPA RIAs for air pollution regulations (1999 The Benefits and Costs of the Clean Air Act 1990 to 2010 ("812 Study"); 2004 Final Control of Emissions from Nonroad Diesel Engines; 2005 Final Clean Air Interstate Rule; 2005 Final Clean Air Mercury Rule) suggests they do not adequately represent uncertainties around "best estimates," do not incorporate uncertainties into primary analyses, include limited uncertainty and sensitivity analyses, and make little attempt to present the results of these analyses in comprehensive way. The tendency of these RIAs is to discuss uncertainty qualitatively – to present tables and lists of sources of uncertainties in various

A recent NRC study (2002) calls for EPA to avoid false precision of point estimates, to move uncertainty analysis from secondary into primary analysis, to use formal uncertainty analysis procedures such as Monte Carlo simulations, to quantify uncertainties using expert judgment where appropriate, to identify driving uncertainties through importance assessment, and to use value-of-information (VOI) approaches to estimate the benefits of reductions in uncertainty.

The incorporation and sophistication of uncertainty analyses in RIAs will continue to grow as the EPA and other agencies respond to Circular A-4 issued by the US Office of Management and Budget in 2003, requiring quantification and analyses of the 'largest drivers' of uncertainty for RIAs involving annual costs and/or benefits in excess of $1 billion.

At the same time, better and more complete information does not necessarily lead to better policies. Complex information can confound rather than enlighten, or can lead to decision paralysis. Thus, any improvements in capturing uncertainty analytically needs to be matched by improvements in its communication – not only to those who make regulatory decisions on the basis of such information, but also to stakeholders, judges, the press and the general public.

Although a number of studies have considered the communication of uncertainty to decisionmakers (Thompson and Bloom, 2000), none has focused on political appointees occupying the most senior positions at the EPA. Accordingly, this paper presents the results of seven in-depth interviews conducted with former Presidential appointees at the EPA concerning the use of uncertainty analysis. Specifically, results of a case study involving future controls of NOx emissions from power plants was presented to the interviewees, using different visual approaches for presenting the uncertainties. They were asked to express preferences for different regulatory outcomes based on the alternative approaches used to display the information. In addition, the interviewees were asked a number of questions about the use of uncertainty analysis in regulatory decision-making.

Section II examines the audiences for communicating uncertainty about RIAs. Section III reviews the relevant literature on communicating risk and uncertainty to both the general public and to decisionmakers. Section IV summarizes the results of the seven in-depth interviews. Section V offers a series of conclusions.

II. Audiences for Uncertainty Analysis

If improved final point estimates were the only benefit of uncertainty analysis, the issue of communicating uncertainty to decisionmakers would not loom large. Uncertainty could operate in the background, as part of the modeling process with a final point estimate presented to decisionmakers for evaluation. But there are other reasons for conducting uncertainty analysis that crucially depend on successful communication of the

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component models and estimates – but to generally avoid quantitative inclusion or reporting of uncertainties in estimates.

results. Presenting policymakers with a distribution of potential outcomes from various policy options allows them to make judgments about the level of risk they are willing to tolerate regarding their choices, e.g., if they are focused on avoiding a specific outcome, a best estimate will be of limited use. Uncertainty analysis can provide policymakers with a picture of the state of knowledge underlying the research and prevent a false sense of confidence in the numbers. Additionally, helping decisionmakers understand the key sources of uncertainty can guide research priorities, so that the agency can efficiently devote resources to increase the confidence in the analysis.

Communicating uncertainty presents a major challenge, however. In addition to the massive amount of data generated in the course of the analyses, there are multiple layers of uncertainties involved, including uncertainty about the underlying science, the appropriate valuation of health improvements, behavioral responses, costs, and future trends. Presenting the results in an intelligible way unavoidably requires significant streamlining and simplification.

Further, there are a myriad types and sources of uncertainty, many of which are cognitively challenging, particularly if the audience lacks technical expertise. Perhaps the major challenge in presenting uncertainty is deciding what to include and what to leave out and doing so in a manner that is responsive to the needs and capabilities of the audience.

Typically, regulatory analyses have multiple audiences. The core function of a regulatory analysis is to improve government decisionmaking and the development of policy options. The audience in this context is agency policymakers, who generally face severe time constraints. Thus, the presentation to this audience will have to emphasize concision and clarity.

Another function of the regulatory analysis, embodied in the public release of the RIA, is to promote public confidence in government decisionmaking through transparency. The audience here is an outside audience, notionally the "public," but in practice technical experts located in academia, think tanks, and interest groups. These outsiders sometimes have as much technical expertise as agency staff and possibly more time to review the analysis than the agency decisionmakers. Thus a challenge for those preparing and communicating the regulatory analysis, as well as the internal decisionmakers receiving the analysis, is to direct attention to the issues that are likely to be of most interest to outsiders, including potential critics.

III. Research on the communication of uncertainty

Much of the relevant research on communicating uncertainty has been within in the context of risk communication, which overlaps with but is not identical to the problem of communicating uncertainty. A major orientation of risk communication research has been on finding ways of communicating well-defined probabilities so that a lay audience can put risks, particularly very small risks, in appropriate context. Research has shown that lay audiences are not very adept at interpreting probabilities in general and do an extremely poor job of assessing small probabilities (Tversky and Fox, 1995; Hammitt and Graham, 1999). In contrast, decisionmakers in federal agencies are usually facing decisions where the relevant possible outcomes have much larger probabilities; the issue of trying to interpret and properly contextualize very small likelihoods is not as relevant.

However, a separate strand of the research on risk communication is highly relevant to communicating uncertainty to policymakers. A large literature has developed that examines how the manner in which information is presented can affect its interpretation. In fact, researchers have found many situations that violate *decision invariance*, the principle that "different representations of the same problem should yield the same preference" (Tversky and Kahneman, 2000). For example, in the field of medical risk communication, telling a 37-year old patient that she has a 50 percent chance of regaining full joint mobility because she is under 40 will make her more optimistic about her outcome than telling her that she has the same probability of success because she is over 35. Similarly, it has also been shown that experts are just as susceptible to the cognitive biases associated with how an issue is framed as the general population. This means that it is possible-in fact, likely- that a presentation on uncertainty could inadvertently provide subtle cues that either increase or decrease the risk aversion of the audience (Slovic et al., 1982).

The challenges become greater when the issue is not simply risk and probabilities, but uncertainty about the nature of the probability distribution itself. Such uncertainty is inherent in most regulatory analysis, from model uncertainty to uncertainty about future trends. Here the decisionmaker looking for precision will be disappointed to find that questions about probability estimates and confidence bounds do not have straightforward answers.

Yet, owning up to uncertainty presents a major challenge. Research on risky decisionmaking has shown that people seek to avoid situations with ambiguous probabilities (Ellsberg, 1961). The reasons for this effect are not clear. One possibility is that making choices under conditions of ambiguity is cognitively demanding. Another possibility suggested by Curley et al. (1986) is that people may be concerned that their decisions will be subsequently evaluated and have a difficult time providing a rationale for their choices under conditions of ambiguity.

Discomfort with uncertainty may extend beyond ambiguity and include probabilistic decisionmaking itself. Gneezy et al. (2004) find individuals valuing a lottery less than its worst potential outcome. In one experiment they find the willingness to pay for a $50 gift certificate is substantially higher than the willingness to pay for a lottery with a high prize of a $100 gift certificate and a low prize of a $50 gift certificate. They term this phenomenon the "uncertainty effect." The fact that the value of the lottery lies outside of the range of possible outcomes violates the principles of most theories of decisionmaking under uncertainty (such as expected utility and prospect theory). The implications of this research for communicating uncertainty to policymakers are somewhat troubling, because it suggests that an increased emphasis on uncertainty may not produce the desired clarity in the decisionmaking process.

Approaches to communicating quantitative uncertainty

Three different approaches are generally used for presenting the results of quantitative uncertainty analysis: verbal descriptions, numeric presentations and graphical depictions. Presenting uncertainty may consist of simply showing outcomes from selected scenarios without reference to probabilities. Alternatively, it may involve confidence intervals or distributions for outcomes of interest (e.g. risk reductions, monetized benefits). Often a combination of approaches may be preferred, e.g. providing different scenarios with probabilities or confidence intervals for each (for example, probability distributions for net benefits given different assumptions about the value of a statistical life).

Verbal descriptions

In daily life, people frequently use verbal descriptions to convey probabilities. Statements like "I'm reasonably confident the statement is true" convey a sense of likelihood, albeit in an imprecise manner. Of course the lack of precision implied by using words also has its drawbacks. A number of empirical studies have attempted to translate verbal probability expressions into numerical equivalents (e.g. what probability is meant by the term "extremely likely"). In general, these studies have found that such translation cannot be done in a precise manner, given that interpretations of verbal expressions vary across individuals and contexts (see Budescu and Wallstein, 1995 for a review).

The IPCC Working Group I contribution to the Third Assessment Report (WGI-TAR) used a system of verbal descriptors for different findings and projections, with each term linked to a specific range of numerical probabilities. The term *virtually certain* was meant to imply a greater than 99% chance, *very likely* a 90-99% chance, *likely* a 66% to 90% chance, *unlikely* a 10-33% chance, *very unlikely* a 1-10% chance and *exceptionally unlikely* a less than 1 % chance (summarized in Manning, 2003). Patt and Schrag (2003) argue that this system is subject to misinterpretation, because individuals evaluate such descriptors as a combination of the probability of the event and the magnitude of its outcome. For example, people will tend to interpret the statement that snow flurries are "unlikely" as implying a higher numerical probability estimate than the statement, "A hurricane is unlikely." WGI-TAR rated the chances of substantial sea level rise in the 21 century as *very unlikely*, which by the above definition means a 1-10% chance, but is arguably open to misinterpretation by ordinary readers as a much smaller numeric probability.

Numeric presentations

The major numerical presentation format for uncertainty, familiar from most RIAs, is a table with means and confidence intervals (usually the 5th and 95th percentile) presented. Such a presentation has the advantage of presenting information in a concise and easy interpretable format. A normal distribution can be completely described with reference to its mean and standard deviation.

Another approach is to provide summary statistics that give a picture of the relative uncertainty of variables or predictions. Two such summary statistics are the *coefficient of variation* and the *uncertainty factor*. The coefficient of variation defined as the standard deviation over the mean, is particularly useful for putting uncertainties in context when different variables of interest have very disparate magnitudes.

Uncertainty factors are less common and are calculated as a percentile value of the distribution over either the mean or its corresponding value on the other side (e.g. the 95^{th} value over the 5^{th} or the 90^{th} over the 10^{th}). The uncertainty factor however is open to misinterpretation, because it is highly dependent on the underlying distribution-type.

There are numerous drawbacks to presenting uncertainty through tables or summary statistics. The foremost issue is that it may be hard to hold the audience's attention with tables and summary statistics for a large number of variables. Additionally, it should be noted that numeric probability estimates, although more precise than verbal descriptions, are not immune from misinterpretation or bias because of the framing impacts and other biases described above (Flugstad and Windschitl, 2003).

Graphical Displays

Graphical displays offer several advantages for communicating uncertainty (see Lipkus and Holland, 1999 for a discussion). First, graphics can reveal data patterns that are difficult to convey through other means. Second, for certain problems, e.g. comparing risks, graphs facilitate the processing of information better than numbers alone. Finally, graphs are more compelling than words and numbers and thus do a better job of holding an audience's attention.

The simplest graphical presentation of uncertainty is through scenarios that illustrate different outcomes under alternative assumptions, such as a high, medium, and low value for an input. When there is insufficient information to allow for the presentation of uncertainty in probabilistic terms, presenting scenarios may be the only viable option. Even when outcomes can be expressed in terms of probabilities, scenario presentations may be sufficient if the outcomes under all plausible assumptions are relatively homogenous, for example if under the range of all reasonable assumptions net benefits are assumed to be positive.

The obvious drawback with scenario approaches is that they provide little insight on the relative probability of occurrence. For displaying uncertainty in probabilistic terms, the three most common graphical techniques are whisker and box plots, probability density functions (PDFs) and cumulative density functions (CDFs).

Box and whisker plots are well suited for displaying summary statistics like means, medians, ranges, and fractiles. Research has shown that they are very effective ways of presenting this summary information to audiences, mainly because the information is labeled directly on the graph (Morgan and Ibrekk, 1987). While they provide no shape about the shape of the distribution, in many cases they may be sufficient for the needs of the policymaker (for example, if the issue is simply whether the confidence interval around a net benefit estimate excludes negative net benefits).

There may be cases where the policymaker seeks information that goes beyond summary statistics to the actual shape of the distribution. In these cases, PDFs and CDFs are preferred, with each having relative strengths and weaknesses. PDFs enable easy identification of the relative probabilities of different values as well as the mode of the distribution. They can be particularly helpful for highlighting multimodal distributions (e.g., net benefits gravitate around very low and very high numbers). A disadvantage of PDF is that they can be can be somewhat noisy and do not allow for easy interpretation of important elements of the distribution, such as means and factiles.

CDFs are far less noisy than PDF and are particularly helpful when what is of interest is the fractiles of the distribution (for example the probability that net benefits will be above a certain level). A downside is that it has been shown, as with PDFs, that audiences have a difficult time extracting summary information (like means) from a CDF plot.

Because of the complementary strengths and weaknesses of PDF and CDFs, Morgan and Ibrekk (1987) recommend using both a CDF and a PDF plotted directly above with the mean clearly labeled on both with a solid point.

Although less commonly used, pie charts can be helpful for emphasizing proportions and may be appropriate if a policymaker is interested in the probability of a high consequence event. For example, researchers at MIT have developed a roulette wheel to highlight the estimated probability of relatively large climate changes under different policies.

When uncertainty exists in two dimensions (for example uncertainty about both the dose-response functions and the values for a statistical life), there are a variety of approaches that can be used.

Research on the effectiveness of visual presentations of uncertainty

Two major strands of research relevant to the graphical presentation of uncertainty are: 1) studies of how well different graphical formats allow the accurate extraction of quantitative information, and 2) studies on the impact different graphical formats have on decisionmaking and whether different graphical presentations of the same information induce different responses. Of particular interest is whether different types of presentations will make an audience more or less risk averse.

The first question allows for an objective evaluation. One can test how accurately the audience extracts quantitative information from the visual display. Cleveland and McGill (1984) rank ten different elementary perceptual tasks in terms of the accuracy of quantitative extraction. Positions along a common scale (e.g. line graphs, bar charts), positions on common nonaligned scales (e.g. scatterplots) and angles (e.g. pie charts) performed best. Areas, volume, shading, and color saturation perform poorly. Cleveland and McGill also recommend against using curve-difference charts, as people have a hard time accurately judging the vertical length between the two curves.

Other research has shown that individuals exhibit biases in estimating physical magnitudes, and in particular tend to underestimate large areas and volumes (Stevens and Galanter, 1957). Lipkus and Holland (1999) recommend against using volume and area charts for presenting uncertainty because of these perceptual biases.

The issue of how different modes of presentation affect judgments is not testable in the same way as the question efficacy of communicating quantitative information. There is no one correct degree of risk aversion, and thus it is impossible to rank their performance based on an objective standard. Siebenmorgan et al. (2000) compared how the use of bar graphs and PDFs affected investors' interpretation of asset riskiness. Providing historical information on asset returns in the form of a density function rather than bar graphs led to greater estimates of asset volatility and risk. The density representations made respondents more conscious of the extremes. The authors conclude, "Given that nominally equivalent presentation formats lead to different impressions of asset risks, which translate into differences in investment behavior, and given that no gold standard exists to indicate a correct level of perceived risk, policymakers need to realize that decisions about the appropriate content and format of financial risk communication cannot be made in an objective or value-free fashion."

Similarly, in an examination of how well visual displays of risk communicated low probability events, Stone et al. (1997) found that adding graphics to the numeric presentations increased participants willingness to pay for risk reductions, in other words, it increased their level of risk aversion.

The effectiveness of graphical presentation can also be measured through audience evaluation, for example how they judge the clarity and utility of the format. The most relevant research on this topic for our purposes is a Thompson and Bloom (2000) study based on interviews and focus groups with EPA risk managers in the early 1990s. Part of the exercises involved presenting different graphical displays of risk. They found a strong preference for graphics that were not too busy (for example, many found a tornado graph fairly confusing). The risk managers rated the PDF format most favorably, although some said they would have preferred a CDF (not included in the focus group presentation). Thompson and Bloom see the results as consistent with Morgan and Ibrekk's (1987) recommendation to present CDFs and PDFs jointly with the mean clearly labeled.

Presenting Qualitative Uncertainty

Heretofore, discussion has focused on presenting quantitative uncertainty around the outcomes of the analysis. Another important context for presenting uncertainty is characterizing the state of knowledge and the degree of confidence around key parameters and assumptions. In its most basic form, this can involve qualitative descriptions about the degree of knowledge about various inputs into the analysis. In other cases, there may be enough information to provide numerical or graphical presentations, e.g. a probability distribution around a well-sampled variable. In cases where data are sparse or it is impossible to generalize from past results (e.g. forecasting technological progress) expert elicitation techniques may be used to generate probability distributions.

Despite the growing sophistication in the state of the art of quantitative uncertainty analysis, qualitative evaluation remains a fundamental aspect of communicating uncertainty, particularly presenting the assumptions behind the analysis and the state of the knowledge underpinning the analysis. Verbal presentation is particularly well suited for this task, for example, giving policymakers an overview of the types of uncertainties around input variables. This can take the form of simple tables with the descriptions of various uncertainties around each relevant variable or it may include an assessment of the hypothesized directionality of the effect.

Importance Analysis

Finally, we present some approaches for conveying value the relative importance of uncertainties to policymakers. Communicating the linkages between uncertainty in input variables and uncertainty in outcomes is a key goal of this activity. With an understanding of these linkages, policymakers can gain insights into the importance of particular parameters or assumptions. This knowledge, in turn, can be useful in making judgments about policy options. It can also help identify and prioritize targets for further research.

Perhaps the most familiar technique is the tornado graph, simply a stacked bar chart. The bars can represent correlation coefficients for the input variables with the output variables or the effect on the output from changing the input variable by some amount, for example one standard deviation. The bars are stacked in descending order from the variable with the highest correlation or impact. Tornado graphs are useful for showing both the magnitude of the relationships and the directionality.

IV. Presentation of Uncertainty Information to High Level EPA Decisionmakers

As discussed above, the most sophisticated uncertainty analysis will go to waste if it is not effectively presented to the individuals making the policy choice. This means taking into account their background and familiarity with the material, as well as the advantages and disadvantages of different presentation techniques. Unfortunately, there remains much to learn about how best to present risk and uncertainty information to high-level policymakers.

In order to shed light on this question, we interviewed seven former high-level decisionmakers at EPA. The interviews were structured around a mock briefing, which included several different graphical presentations of uncertainty. The respondents were asked for their reaction to the different approaches, how the graphics influenced their decisionmaking, and for their general thoughts on the treatment of uncertainty in regulatory analyses.

All the interview subjects had served in senior positions at EPA at the level of Assistant Administrator or Deputy Administrator during the period 1989-2004. The decision was made to restrict the respondents to individuals at the highest level of the decisionmaking process both because these individuals were less likely to have detailed knowledge of the techniques of uncertainty analysis and because their interpretation of uncertainty could have potentially large ramifications. The sample was restricted to former decisionmakers on the grounds that current officials might be constrained in their answers, especially since the hypothetical regulatory decision presented is at least tangentially relevant to current policy debates.

The briefing was designed to elicit various types of information. The first is how well different graphical displays perform in conveying information about uncertainty to decisionmakers. On one level, this is a question of how easily the decisionmakers could process the information being presented in the visuals after a brief introductory explanation. On a more subjective level is the question of whether the policymakers felt the visuals aided their decisionmaking process.

A second area of inquiry is how uncertainty analysis (and technical analysis in general) is used by decisionmakers. In a real world situation, other factors would also play an important role, for example, the state of the economy, the political climate, and historical experience with regulating the pollutant. In the course of the presentation, decisionmakers were given an opportunity to indicate the other types of information they would rely upon when making a decision.

Third is the question of how policymakers make decisions under uncertainty. The policy choice was structured around two options with similar mean net benefits, but very different variances. The decision between the two policies therefore involved choosing between spending larger amounts of money for the potential of realizing very high net benefits or spending less money and averting the possibility of very high net costs. The discussion was geared to gaining insight into the sorts of frameworks and heuristics policymakers rely upon in making such choices.

Finally, the policymakers were asked for their perspectives on how uncertainty analysis should fits into the institutional decisionmaking structure of the Agency. Issues raised included how much of this type of analysis is necessary for top-level decisionmmakers to see and process refinements to improve the ability of the analysis to positively affect regulatory decisionmaking.

The interview subjects were asked for a decision on a hypothetical tightening of the NOx regulations for power plants beyond that planned under the Clean Air Interstate Rule (CAIR). They were presented with three options: 1) doing nothing; 2) an intermediate option of reducing the NOx cap by an additional 20 percent below the CAIR baseline in 2020; and 3) a more stringent option which reduced the NOx cap 40 percent from baseline in 2020. The decisionmakers were asked imagine they were making the decision in the 2012-2015 timeframe in order to reduce complications regarding discounting, future regulatory developments, and the like. The interviewees were told that their names would be listed (as a group), but that none of the responses would be attributed to individuals.[3] Although a formal script was not used in the actual interviews, a stylized version of the information presented and the questions posed is contained in Appendix A.

The presentation began with a brief overview of the goals of the project and recent developments regarding the incorporation of uncertainty in regulatory analysis. The decisionmakers were then given information on the role of NOx as an ozone and particulate matter precursor and the health consequences of the resulting pollution. They also received a brief description of the CAIR rule along with a summary of EPA's estimated benefits of the rule. They were then given a description of the three proposed options. (For more on the details of the case study see (Krupnick et al., forthcoming)

Graphical Material

The decisionmakers were presented with a series of slides containing either tables or figures and asked for their reaction to them. After each slide, they were asked if the material provided them with enough information to make a decision on which option to choose and if so what their decision was. The presentation included seven slides in total: two tables and five figures. Because of the small sample size, it was not feasible to alter the order of the slides among the interviewees.

Physical Effects

The first table showed the impacts of the two proposed policies in terms of physical health impacts and costs in 2025 (Table 1). As expected, the tighter option was more expensive but averted more mortality and morbidity. However, there was fairly wide uncertainty around the health estimates, with the confidence interval for mortality extending between 122 and 810 deaths for the stringent option and 65 and 443 deaths for the intermediate option. Because of modeling limitations, no uncertainties around costs were presented.

Table 1 was generally well received by all the respondents, but several said they would have liked to see cost-effectiveness calculations, such as the cost per life saved or the cost per ton reduced. In fact, a number of the decisionmakers made back of the envelope calculations for these numbers. Several of the respondents were troubled by the lack of uncertainty about costs and said it was their impression that costs were frequently overstated. Many respondents said the confidence intervals raised the question of what factors were driving the uncertainty and requested more information on this subject. Some of the interviewees were surprised that both benefits and costs were fairly linear; a doubling of required emissions reductions resulted in an approximate doubling of both costs and benefits. (It was then explained that this was an artifact of the modeling analysis. For other pollutants and other control options nonlinear outcomes might result.)

[3] The following individuals were interviewed: Don Clay, Terry Davies, Linda Fischer, David Gardiner, Lynn Goldman, Hank Habicht, and Tracy Meehan.

TABLE 1

	Comparison of Tight NOx Cap and Intermediate NOx Cap Policies					
	Averted Physical Impacts in 2025					
	Tight NOx Cap			Intermediate NOx Cap		
	Mean	95% CI lower bound	95% CI upper bound	Mean	95% CI lower bound	95% CI upper bound
Mortality	466	122	810	254	65	443
Cardiovascular Hospital Admissions Admissions/Year	409	47	771	230	27	434
Non-Fatal Heart Attacks Cases/Year	995	338	1652	543	187	900
Respiratory Hospital Admissions Admissions/Year	2611	1550	3672	841	512	1169
Cardiovascular Hospital Admissions Admissions/Year	338	204	471	197	123	272
Asthma Emergency Room Visits/Year	598	358	838	265	150	380
Cost (millions $)	1340			710		

Monetized Benefits

The second table presented the results from the cost-benefit analysis, showing total benefits, costs and net benefits in the year 2025. (Table 2). Although both options had very different total benefits and costs, they were virtually identical with respect to the best estimate for net benefits, $10 million for the intermediate option and $11 million for the tight option. However, the two policies had very different ranges for net benefits with the more stringent option ranging from negative $831 million to $854 million and the intermediate option ranging from negative $455 million to positive $474 million.

The reaction to this table was more mixed. Most respondents said that it was helpful but only in conjunction with Table 1. Two said they were skeptical of monetization and thought that it didn't provide much guidance on close calls like this decision. One respondent said that monetization is useful for making an "apples-to-apples" comparison, but it is hard to convey the concept to the general public and for purposes of selling the policy the information in Table1 was more useful. Two of the interviewees were surprised that the net benefits were so similar for the two policies. They noted that in their time at EPA they often felt presentations were structured around a pre-chosen option and one or more straw-men options, making the process almost pre-ordained. All the subjects said that in a close call like this decision other factors such as political considerations would loom large.

TABLE 2

	Comparison of Tight NOx Cap and Intermediate NOx Cap Policies					
	Net Benefits in 2025					
	Tight NOx Cap			Intermediate NOx Cap		
	Mean	95% CI lower bound	95% CI upper bound	Mean	95% CI lower bound	95% CI upper bound
Total Benefits ($ US millions)	1351	509	2194	720	255	1184
Costs ($ US millions)	1340			710		
Net Benefits ($ US millions)	11	-831	854	10	-455	474

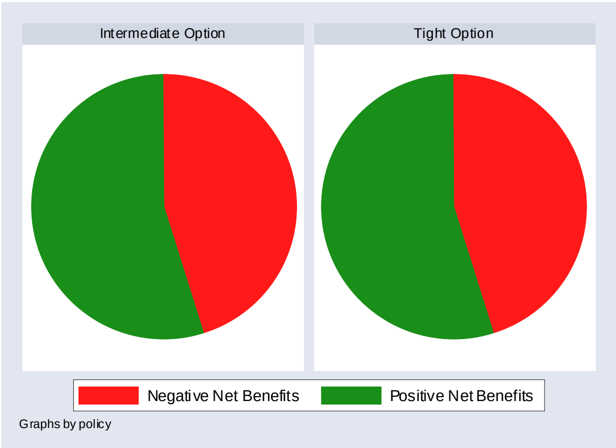
Pie Chart

The first figure shown to the policymakers was a simple pie chart displaying the probabilities that the policies would produce positive net benefits. The analysis showed that both policies had about the same probability of achieving net benefits (about 53%), so the charts were quite similar. Some of the interviewees found this chart helpful and said it gave them more confidence in their decision. Others found it too crude and said it did not provide much more information than was already contained in the tables. Some who said it was not helpful also said they could imagine cases where it might be helpful, for example, if the two policies differed greatly in there probability of achieving net benefits.

FIGURE 1

Probability that Policies Produce Net Benefits in 2025

Comparison of Tight and Intermediate NOx Caps

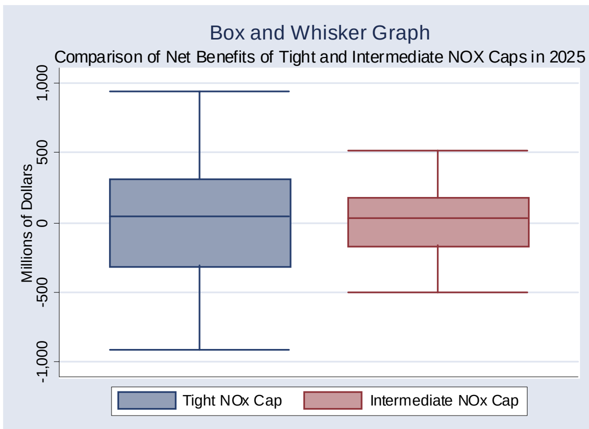


Box and Whisker, PDF, and CDF

The decisionmakers were then shown three of the most common graphical formats for presenting uncertainty: a box whisker plot, a probability density function, and a cumulative density function.

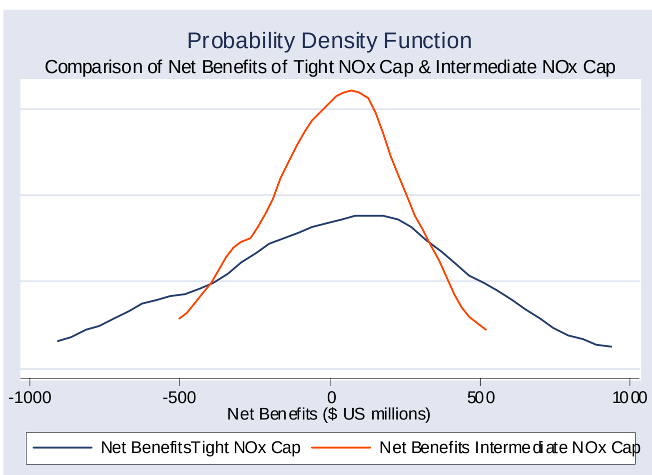
In general, the policymakers were not positive about the box and whisker diagram (Figure 2), with several saying it was repetitious and did not add much additional information from the tables. Some felt that the presentation focused their attention on the middle of the distribution and away from the extremes, although one noted that the plots showed that the policies could have large negative net benefits and opponents might seize on that number. Three interview subjects said they would have rather seen total benefits presented in the place of net benefits, as the latter bundled too much information into a single number.

FIGURE 2



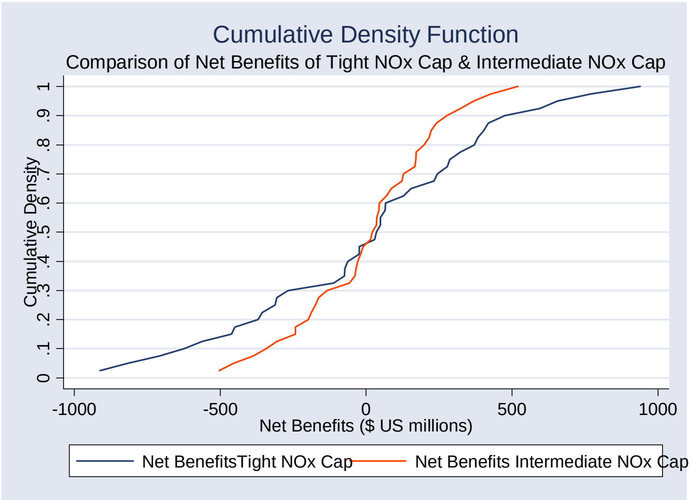
The interviewees responded much more favorably to the probability density function (Figure 3), saying it was more intuitive and persuasive. One respondent said the PDF was an easier graphic to frame a discussion around than the others. Interestingly, a majority of the respondents said the PDF made them gravitate toward the intermediate option. This is consistent with findings by Siebenmorgen et al. (2000) that PDFs make people more sensitive to extreme values and consequently more risk averse.

FIGURE 3



Only one of the interview subjects was familiar with a cumulative density function (Figure 4), and this graph seemed to require the most detailed explanation. Most of the decisionmakers did not find the CDF very helpful even after explanation. In fact, the sole individual who had prior experience with CDFs said they would not be inclined to present it to most decisionmakers because it was hard to explain. One decisionmaker, however, said they felt the CDF was a more neutral presentation than the PDF because, unlike the PDF, it did not push them toward the intermediate option.

FIGURE 4

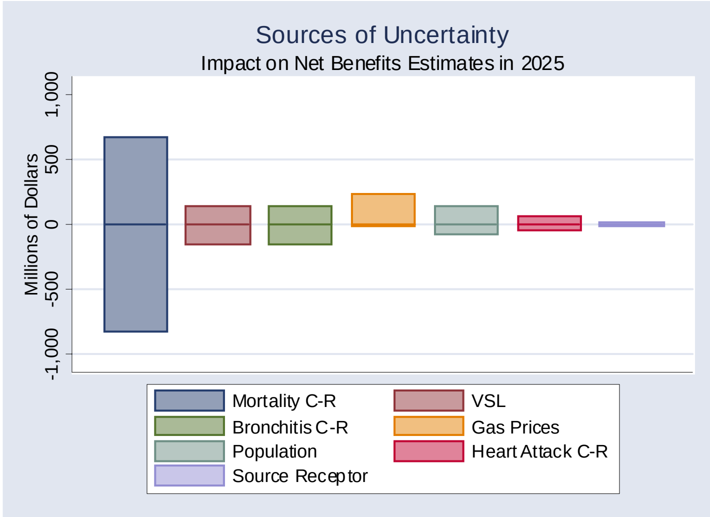


Sources of Uncertainty

The final figure was a graph showing the relative contributions of several key variables to the uncertainty associated with the estimate of net benefits (Figure 5). Four of the respondents found this very helpful; in fact, in several cases the graphic was moved up in the presentation in response to specific questions about the factors most responsible for the uncertainty. One of the interviewees said it was helpful because it identified different types of uncertainty: "If the uncertainty is coming from population projections, I can do something about that – choose which one I think is most reasonable. If it's coming from the science, I can't do much about that."

The two individuals who said the graph was not useful cited the fact that the mortality concentration-response function and the value of the statistical life were the biggest sources of uncertainty and this is what they had assumed going into the presentation. Also, one of the respondents who rated the graph as helpful said the wide band around mortality raised questions about the quality of the studies used in the analysis.

FIGURE 5



The policymakers decisions

All of the interview subjects said that, in practice, their decision would require much more information than was included in this presentation. Among the other factors cited were questions about distributional issues, the political balance of power, and the current state of the economy. With this caveat, all the respondents were willing to choose an option. One favored doing nothing and one favored the tight option. Three favored the intermediate option. One narrowed the choice to either the intermediate or the tight option and said the final choice would depend on political factors, such as the relative strength of EPA vs. OMB. The final decisionmaker said they would prepare both the tight and intermediate for review with a recommendation to go with the tight.

The decisionmaker who chose doing nothing cited the large uncertainties associated with both policies and the fact that the estimated net benefits for both were close to zero. The decisionmaker who chose the tight option said they were willing to trade off the possibility of large negative net benefits for the potential of achieving very large health gains. Reasons given for supporting the intermediate option included the tighter error bounds, the option to do more later, and the fact that omitted ecological benefits would push the net benefits into positive territory. Interestingly, five of the decisionmakers said the PDF graphic made the intermediate option seem more attractive.

Views on uncertainty in the process

After the presentation of the information drawn from the case study, the interviewees were queried on their overall views on the use of uncertainty information in decisionmaking. They were asked whether they felt the information aided their decisionmaking and for their degree of comfort in delegating to staff potentially significant technical decisions about the analysis.

All the respondents said they found the presentation of uncertainty helpful. Information on the sources of uncertainty was identified by many as an important component for decisionmaking. The presentation of uncertainty was also useful for giving decisionmakers insight on how confident they should be in their decision and some said it would be very useful in those cases where the ranges of net benefits were all positive or all negative. Additionally, some decisionmakers cited the need to see everything that potential critics might say so they are better prepared to defend the policy.

On the issue of delegation, interviewees said the complexity of the issues made delegation unavoidable. As one said, “If you weren’t comfortable with it, you would either quit or go insane. That’s why you have a staff.” Many favored building safeguards into the process, for example having different offices of EPA analyze the regulation separately or at least review the underlying details of the analyses. Another suggestion was to have outsiders like SAB bless the uncertainty techniques used. One respondent said that senior decisionmakers often don’t know what they have delegated: “They don’t know what they don’t know…I often find out more and more about what I didn’t know when I made a particular decision.”

Miscellaneous observations

In addition to the responses that came out in the structured interviews, respondents also made general observations on uncertainty and environmental decisionmaking in general.

- *The need for context*. Every decisionmaker said providing context was crucial to helping inform the decisionmaking process. Examples of the kinds of context that they wanted include information on the magnitude of the problem, how much had been done previously to address this problem, how the costs of the proposed regulations compared to other regulations, distributional issues around costs and benefits both geographically and across demographic groups, and political factors, such as where different interest groups stood on the proposal(s).

- *A preference for cost-effectiveness numbers.* Nearly all the decisionmakers seemed more comfortable thinking in terms of cost-effectiveness, e.g. dollar per life saved or dollar per ton reduced rather than in cost-benefit terms. Although none were hostile to the concept of monetization many felt that presenting information in terms of net benefits collapsed too much information into a single number.

- *Different styles of decisionmaking.* Several interviewees also noted that there are likely to be important differences in the responses to the formal presentation of uncertainty analyses based on the background of decisionmakers. Those with a technical background are more comfortable with the kind of presentation that was used in this project. However, several respondents observed that many EPA decisionmakers have legal training and that lawyers tend to be more comfortable with an argument-based approach that lays out the pros and cons of the different options. One decisionmaker said they liked to have a debate on the proposed policy, and “I can remember being moved by how strongly someone made their case.”

- *The importance of political considerations.* Many of the decisionmakers framed their discussion around how the analysis would help or hinder their ability to sell the policy to the White House or to outsiders. One noted that uncertainty analysis had a downside in that it armed critics, like OMB, who would be tempted to seize on lower bound numbers." One decisionmaker said they might be tempted to select the tight option even though they favored the intermediate option, because they would rather negotiate with OMB starting from a more stringent standard. This policymaker likened developing a regulation to running a gauntlet and lamented the adversarial nature of the process. One policymaker cautioned against placing too much emphasis on politics first: "Get the facts first before you bring on the politics….If you do the politics first, you will get confused. In the end, you want to know how far you had to move from the most analytically defensible options."

V. Conclusions

Obviously, no robust conclusions can be reached from interviewing such a small number of decisionmakers. Nevertheless, their different backgrounds and decision-making styles make the group fairly heterogeneous, so these views may cover most decisionmakers in very senior positions within a regulatory agency. With this caveat, we offer the following observations.

It appears that tables and PDFs are best suited for communicating to high-level decisionmakers. One caveat is that only two options were presented in this exercise. As the number of options or scenarios increases, PDFs tend to look fairly busy and comparative box and whisker plots might be a cleaner way to convey the information. In addition, because there appears to be a tendency for PDFs to move respondents to tight spread options, additional explanation about the implications of different choices (e.g. foregoing the opportunity for higher risk reductions in exchange for avoiding the possibility of higher net costs) is warranted.

One clear message from this exercise is the importance of presenting technical analysis in context. The respondents were quite forthcoming about the kinds of additional material they would need to make an informed decision. As one put it, "The answer is not in these graphs." The policymakers were particularly interested in the regulatory history of the pollutant and a comparison of how the current proposal compared to past efforts, particularly in terms of cost-per-ton and cost-per-health-improvement. In addition, they were interested in more information on the size of the current problem. Other types of contextual information requested included how the current proposals compared with other regulatory options, the degree of political opposition to the initiatives, a description of non-monetized benefits, and impacts on vulnerable groups.

The mock policy options themselves represented something of a close call. Both had best estimates of around $10 million in net benefits, but very different spreads. The more aggressive policy offered the potential for very high net benefits if NOx emissions turn out to have a strong impact on mortality. Conversely, the policy also has the possibility of high net costs if the actual health impacts are small and the increased expenditure produces little in the way of additional health benefits.

There was not unanimity around the policy choices. In general, there was a stronger inclination toward the intermediate option, and only one of the policymakers favored doing nothing. The reduced possibility of making a major error was the main reason given for the attractiveness of the intermediate option. But beyond this it is hard to generalize about the policymakers' decisionmaking processes.

Incorporating uncertainty into the decisionmaking process

Several respondents said that in order for uncertainty analysis and technical analysis in general to be most credible, an internal system of checks and balances should be created. This could be accomplished by having multiple offices within EPA look at the analysis or by establishing an external peer review process. Additionally, some argued for a presentation format that took the form of arguments pro and con for different regulatory options. One policymaker said that it might be better to have input from OMB at an early stage of the process, so that potential points of controversy could be identified earlier.

While the literature on communicating uncertainty is voluminous, it is particularly weak with respect to communicating to decisionmakers. Additional research on the relative effectiveness of techniques for communicating the complex issues incorporated in RIAs to high-level agency officials is warranted.

But communicating uncertainty involves more than just choosing the right mode of presentation. There is a need to be aware of subtle cues in the presentation that may bias interpretations. In fact, the possibility that different methods of presentation may induce different decisions is troubling. Under conditions of uncertainty, the rational decision depends on the decisionmaker's degree of risk aversion. But there is no "right" level of risk aversion and therefore is no objective criteria for ranking presentation methods along this dimension.

As a final note, much of the work on communicating uncertainty has focused on the communicators and finding ways to improve presentation methods. Given the importance of correctly appreciating the implications of uncertainty, perhaps more work needs to be done on the audience side. Agencies should consider providing their decisionmakers training on how to think about the complex issues associated with uncertainty in regulatory analyses.

Appendix A: Stylized Version of the Script
Used for Discussions with Senior EPA Officials

Thank you for agreeing to participate in this EPA-sponsored project on the presentation of risk, cost and benefit information to high-level decisionmakers at EPA. As you may know, a 2002 National Research Council (NRC) study recommended that EPA incorporate greater information about the uncertainties associated with risk, cost and benefit information into the regulatory decision framework. Most recently, OMB has mandated the use of formal uncertainty analysis in Regulatory Impact Analyses (RIAs) for extremely large rules -- those with annual economic impacts in excess of $1 billion.

While part of the RFF study is quite technical, we are here today to get your ideas on the most useful way of presenting the results to senior decisionmakers. Our approach is to display the results of a case study based on a hypothetical rule change – namely, further tightening the NOx standard starting around 2020. After providing you some background information on NOx we are going to present the estimates of the risks, costs and benefits of the hypothetical rule, along with some alternative visual ways of conveying the uncertainties associated with these estimates. We will ask you to react to these different formats. Following these displays, we will also ask you a series of broader questions about the whole area of uncertainty analysis. Based on your responses and those of other senior decisionmakers we will prepare a summary report for EPA without identifying individual responses.

As you know, NOx is an air pollutant of concern because it contributes to the formation of fine particles, including $PM_{2.5}$, as well as ozone. $PM_{2.5}$ has been linked to premature mortality, chronic bronchitis, heart attacks and respiratory problems. Ozone causes changes in lung function and respiratory symptoms, aggravation of asthma and other respiratory conditions. Recently published studies suggest that ozone may also contribute to premature mortality. In addition, nitrogen deposition has broad-scale ecological impacts but since we're focusing on health impacts they are also excluded from the analysis.

Recent regulatory actions affecting both mobile and stationary sources are projected to reduce NOx emissions substantially by 2018 – roughly 40-50 percent below 2001 levels. In the electric power sector, which contributes almost a quarter of total NOx emissions, EPA estimates that after full implementation of the Clean Air Interstate Rule (CAIR), total emissions will still be about 2.4 million tons per year in 2018/2020.

In terms of health impacts, EPA's so-called 'best estimates' of the effects of the CAIR rule – which includes major SO_2 and NOx reductions – are that premature mortality would be reduced by 17,000 deaths per year, 22,000 nonfatal heart attacks, 12,300 hospital admissions, and 1.7 million lost work days. Although they have not officially broken out the NOx component of those reductions, somewhere on the order of 10 percent is likely attributable to NOx. Overall, EPA has estimated that by 2015 the annual benefits of the rule, mostly in the form of reduced mortality, will be about $100 billion per year – more than 25 times the estimated costs.

Our hypothetical regulatory option involves further NOx reductions in the power sector – likely the most cost-effective source of such reductions -- starting in 2020. As noted, annual emissions from the electric power sector are projected to be about 2.4 million tons in 2020. Our most stringent option involves reducing NOx by another 900,000 tons, or about 40% below the expected baseline. Our intermediate option involves emission reductions of about half that level, or about 20% below baseline.

It is important to note that with some minor differences we are relying on standard EPA assumptions about both the health effects and control costs.[4] Yet, even within this framework, there are many uncertain factors that figure into the estimation of risks, costs and benefits. For example, there are uncertainties about dose-response functions, the size and spatial distribution of the affected population in the future, the expected change in future natural gas prices, and other factors. There are also uncertainties about the economic valuation of mortality and morbidity effects.[5] The results we will show you focus on the uncertainties in all these factors and how they could affect the overall estimates.

Clearly, there are other uncertainties we are not considering in our analysis. For example, further research could increase (or decrease) our concern about ozone mortality effects. Alternatively, new, lower cost NOx control technologies may become available. Although there are undoubtedly uncertainties with respect to the costs of the regulation, we have not included them in the analysis for this presentation.

Consistent with the OMB requirements, our presentation today will focus primarily on estimated costs and benefits of alternative regulatory options. However, as noted, uncertainty can also be presented in terms of physical effects such as mortality and morbidity. At the end of this presentation we will seek your views on the usefulness of presenting uncertainty information for physical effects as well as monetized values of benefits.

Text for Table1. Now that you have an understanding of the approach we are pursuing, I want to show you an initial table for one of the options. The table presents the best estimate for the net benefits' of the tight NOx policy in 2025, along with a 90% confidence interval. Based on our modeling assumptions this can be interpreted that there is a 90% chance that the net benefits will fall between these two numbers. The numbers are uncertain for the reasons outlined above, including questions about dose-

[4] Cost estimates are developed from RFF's HAIKU model (Paul and Burtraw, 2002), which has been shown to track closely the outputs of the model EPA typically uses for such estimates (EPA, 2002)
[5] The estimates of health effects and their valuation come from runs of RFF's Tracking and Analysis Model (Bloyd et al., 1996), which features concentration-response functions and valuation estimates typically used by the USEPA in RIA's, with the notable exception that a central estimate of the Value of Statistical Life is based on Mrozek and Taylor (2002), which is lower than that used by EPA by greater than that found in several more recent studies (Alberini et al., 2004)

response functions, the size of the affected population, the valuation of human health effects and other factors.

We can compare this with similar information for the other policy (also shown in table 1). Looking at this information, how would you choose between the options A, B, or doing nothing. Do you feel you have enough information to make a decision?

Table 1: Comparison of alternative policy options for post-CAIR Rule

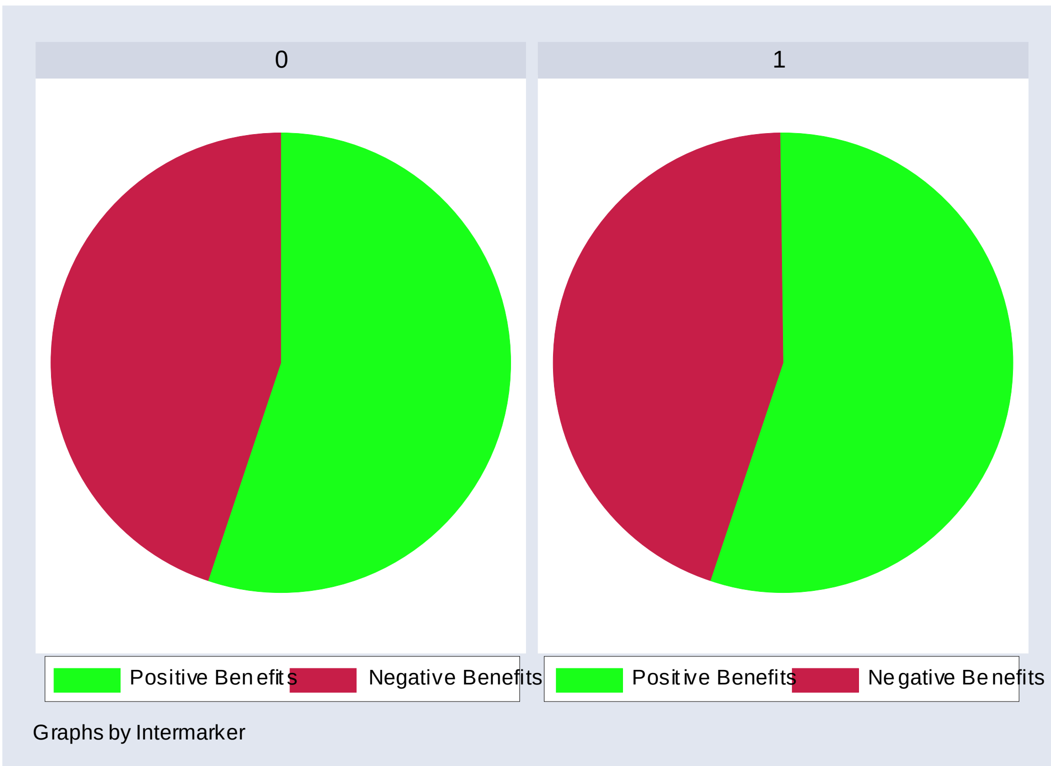
Net Benefits in 2025 (millions of dollars annually)

	Mean	25th Percentile	75th Percentile
Tight NOx Standard	11.2	-307.5	296.2
Intermediate NOx Standard	9.6	-165.7	170.9

Text for Figure 1

Here is a very simple pie chart that shows the probabilities that net benefits are above zero for each of the two options. The area highlighted in green represents the probabilities that net benefits are above zero. The probability that each policy will produce net benefits is virtually identical as you can see from this graph. The information here is somewhat limited, but do you find it helpful as a way of focusing your attention on the probabilities? In combination with the simple tabular information does this chart add any value? Please explain. Does it change your decision?

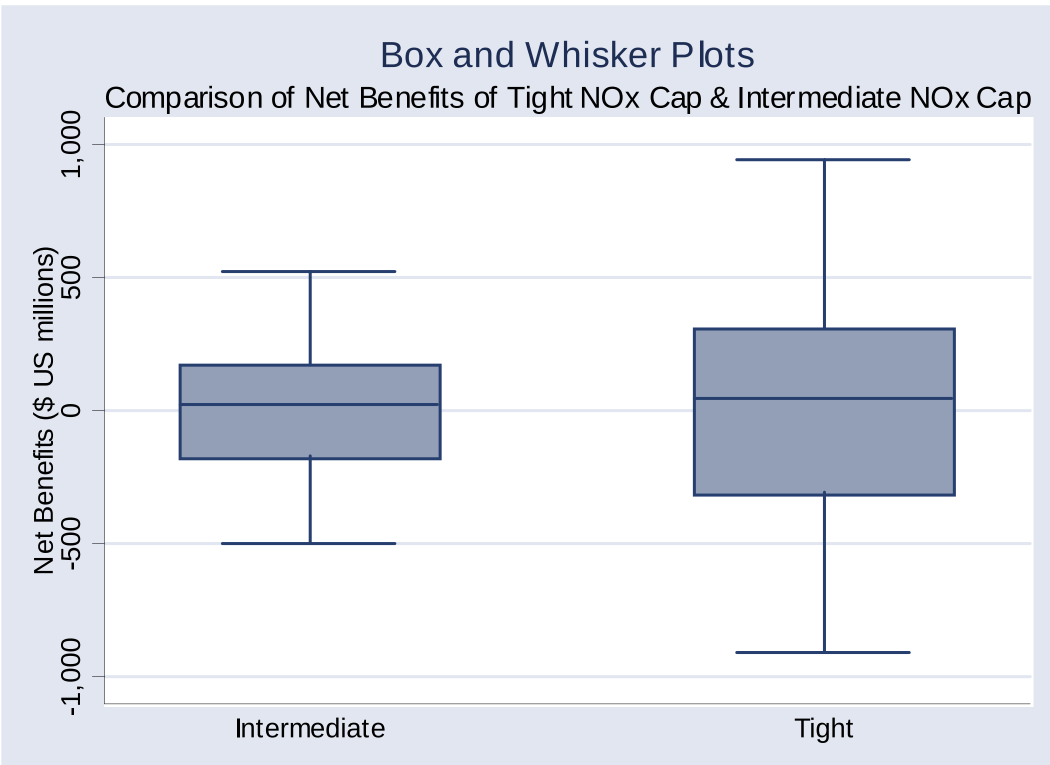
Figure 1:



Text for Figure 2

Now I would like to show you the same information presented in a slightly different format. These are known as box and whisker plots, you may be familiar with them. We present the same two different policy options shown above. Here the median is labeled on the graph. The box represents the middle 50 percent of the distribution and the end of the whiskers delineate the minimum and maximum of our estimates. Thus, the chart breaks the distribution into quartiles. As you can see the graph demonstrates that both options have similar median expected net benefits, but the tighter standard generates a wider range of potential outcomes. Compared to the table, how well does this sort of graphic convey the issue to you? How does it affect your decision?

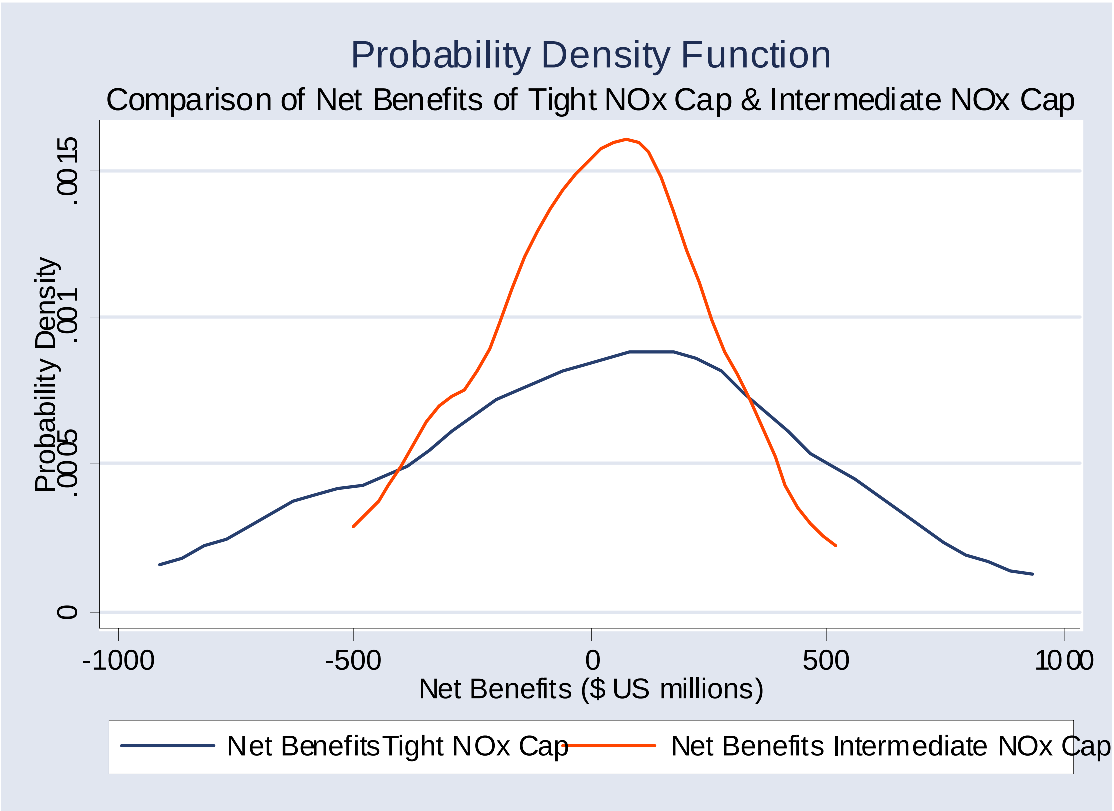
Figure 2:



Text for Figure 3

Here is more detailed graphic that conveys more information. These are known as probability density functions of our estimates of the net benefits of the two policies. Along the horizontal axis are the values of our net benefit estimates. The vertical axis shows the relative probability of each of these results occurring. For both policies, the highest probabilities are around the midpoints but, as we saw above, the tighter policy has a wider distribution. In other words, the central tendency for both policies is the same, but the tighter policy has a higher potential for both much larger net costs and much larger net benefits. How do rate this graphic in terms of clarity and amount of information provided? How does it affect your decision?

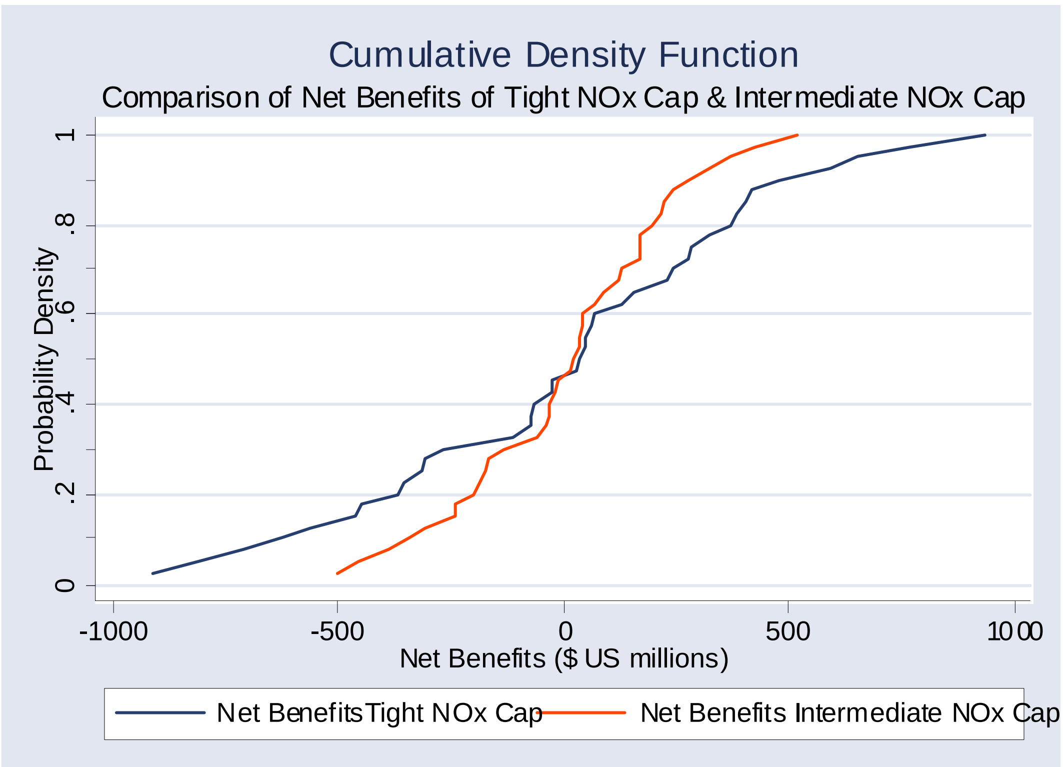
Figure 3:



Text for Figure 4

A similar graphic is the cumulative density function. This shows the probability that the value is below each level along the horizontal axis. So for example, we can see that there for both policies there is about a 50% chance that net benefits are negative and a 50 percent chance they are positive. For the tight policy, there is about a 10% net benefits are less than minus $500 million dollars a year, but an equivalent probability that the policy generates over $500 million in net benefits. This graph highlights the chance that net benefits will be over or under a certain value; do you find this informative? How does it affect your decision?

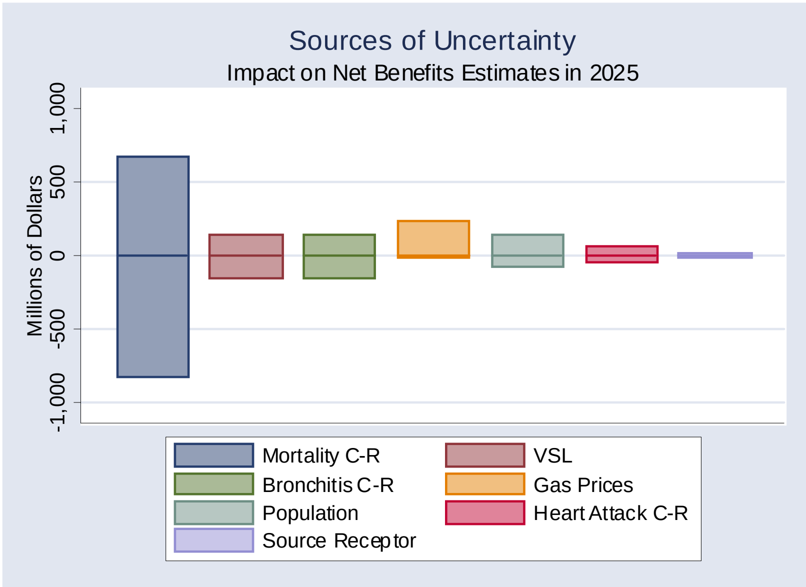
Figure 4:



Text for Figure 5

The preceding presentations have focused solely on the uncertainty around the net benefits. Now we would like to show you a graph that demonstrates some of the drivers of the uncertainty. This graph shows the impacts on the final net benefits estimation from the uncertainties associated with the different factors. As you can see, uncertainty about the mortality concentration-response function has by far the largest impact on the net benefits estimate. Is this information and useful to you? How does it affect your thinking?

Figure 5



Review of graphics and policy options

Now thinking about what you have seen, two policies with mean benefits close to zero, but with different spreads, would you choose the same policy as before? What were the reasons that guided your choice?

Additional thoughts on uncertainty

First, is this of interest to you at all or would just rather get point estimates? In general, how interested are you in this issue?

We have only presented a small sliver of the uncertainty that is involved in an analysis of this type. By necessity, the presentation has to be streamlined and as a consequence a decision-maker like yourself will have to rely on staff to make judgment calls as to what to included and leave out. Are you comfortable relying on staff to make the judgments about the uncertainty analysis? Are there steps you would like to take to increase your level of confidence in staff decisions?

Thank you for your help on this project.

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