# The Cost of Nothing Trumps the Value of Everything: The Failure of Regulatory Economics to Keep Pace with Improvements in Quantitative Risk Analysis

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# THE COST OF NOTHING TRUMPS THE VALUE OF EVERYTHING: THE FAILURE OF REGULATORY ECONOMICS TO KEEP PACE WITH IMPROVEMENTS IN QUANTITATIVE RISK ANALYSIS

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*The entire U.S. federal regulatory apparatus, especially that part devoted to reducing (or deciding not to reduce) risks to the environment, health, and safety (EHS), relies increasingly on judgments of whether each regulation would yield benefits in excess of its costs. These judgments depend in turn upon empirical analysis of the potential increases in longevity, quality of life, and environmental quality that the regulation can confer, and also of the economic resources needed to "purchase" those benefits—analyses whose quality can range from extremely fine to disappointingly poor. The quality of a risk analysis (from which the benefits of control are derived) or of an economic analysis depends on attributes they share in common, such as the complexity and rigor of the data collection and mathematical modeling, the transparency by which the assumptions used are disclosed, and the humility of the conclusions drawn (particularly the care taken to acknowledge uncertainty in the estimate). This Article is part of a series of investigations by a multidisciplinary team of scholars, examining whether regulatory cost analysis may be systematically less rigorous, transparent, and humble as compared to the corresponding analyses of risk upon which regulations are jointly based. In this particular study, I contrast the attention paid to depicting uncertainty on the "cost side" versus the "risk side" of cost-benefit analysis, and show that regulatory economics has steadily remained about ten to fifteen years behind risk analysis with respect to this important attribute of analytic quality. Various sections of the Article explain why overconfident pronouncements about cost or risk can thwart sensible decisionmaking, demonstrate how an unbalanced approach to analyzing risks versus cost is untenable, and trace the history of attempts to improve the estimation of regulatory cost uncertainty both inside and outside the major federal EHS regulatory agencies. The core of this Article is a combination of a statistical analysis and a set of case studies, showing how much improvement remains to be made on the "cost side" of regulatory uncertainty analysis, and providing various sets of reasons why this particular deficiency arose and persists. If decisionmakers and the public are not informed that the true magnitudes of regulatory cost may be much higher or (more likely) much lower than the overconfident estimates provided with current regulatory analyses, they*

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*cannot express their desires for more or less regulatory stringency in light of the resulting uncertainty in net benefit.*

## INTRODUCTION

What does it really mean for an individual, or a society, to undertake an action—or to leave well enough alone—because "it does more good than harm?" And how do we come to such a determination with some semblance of serious reflection? When the action involves trying to reduce risk to human health, safety, or the environment, increasingly this most basic formulation of a "moral algebra"[1] has acquired the structure and rigor of cost-benefit thinking. Even where regulatory agencies are not required by their organic statutes to try to estimate or maximize net benefits, the expectation that benefits and costs will at least be discussed for informational purposes has firmly taken hold.[2] Actions, or inactions that perpetuate the status quo, come with costs and benefits, and our society is devoting enormous effort to estimating the magnitude of these goods and harms and debating how we should act in light of them.[3]

The fundamental optimism (some would call it the fundamental hubris) of cost-benefit analysis (CBA) is that when we estimate quantitatively the goods and harms of a proposed policy, rational discussion can ensue about whether it is wise as well as whether it is ethical. Under an extremely "hard" version of cost-benefit balancing, the wisdom of any policy could be gauged by determining whether the point estimate for total benefit is larger than the point estimate for total cost; under a "softer" version of cost-benefit balancing, the estimates would be considered among other inputs.

*But what if we habitually estimate the benefits with greater or lesser care than we estimate the costs?* Any analysis, of course, can contain errors, no analysis can guarantee that a sound decision will flow from it, and no decision, no matter how sound, can guarantee a favorable outcome. An analysis in which the appraisal of one side of the cost-benefit ledger is routinely superior to

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1.  KERRY S. WALTERS, BENJAMIN FRANKLIN AND HIS GODS 124 (1999).

2.  *See, e.g.*, Amy Sinden, *Formality and Informality in Cost-Benefit Analysis*, 2014 UTAH L. REV. (forthcoming 2015), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id =2442357.

3.  *See, e.g.*, OFFICE OF MGMT. & BUDGET, 2014 DRAFT REPORT TO CONGRESS ON THE BENEFITS AND COSTS OF FEDERAL REGULATIONS AND UNFUNDED MANDATES ON STATE, LOCAL, AND TRIBAL ENTITIES (2014).

the other side, however, makes decisions more precarious than they should be. This Article, the capstone publication in a series of papers from a multidisciplinary project team studying the treatment of economics and science in CBA,[4] explores the possibility that the estimates of regulatory[5] cost developed for actions contemplated by the U.S. federal and state governments *may be systematically less rigorous, transparent, and humble*[6] than the estimates of risk reduction (regulatory benefit) they accompany.

As I will discuss, the strong possibility that regulatory cost economics is the weakest link in CBA is more than a bit ironic, given that some of the salutary changes in quantitative risk assessment (QRA) over the past thirty years have been impelled by criticism from economists.[7] But the "poaching" by economists onto scientific turf has also led QRA into some of its blind alleys and backwaters, in my opinion, including the pursuit of less "conservative" risk estimates without regard to the accuracy of this charge or the usefulness of less precautionary—and perhaps less accurate—estimates in decisionmaking.[8] Which propitious changes might occur if scientists with

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4.     The project was funded by the Human and Social Dynamics of Change program, National Science Foundation (NSF), under grant #0756539. I gratefully acknowledge the support and advice provided by NSF, and that of my colleagues on the project at Resources for the Future, Applied Biomathematics, Decision Research, Clark University, University of California-Riverside, and Texas A&M University. Able research assistance in preliminary scoring of the 25 EPA rules (*see* Part VIII *infra*) was provided by Penn Law students Alison Bonelli, Catherine Courcy, Matthew Lee, and Julie Xu, and expert editorial assistance was provided by Ben Meltzer. Published versions and pre-publication drafts of the 19 articles written for this project are available at http://www.tinyurl.com/finkelnsf; the site also contains the table of contents for the book DOES REGULATION KILL JOBS?, partially funded by this NSF grant.

5.     This Article will concentrate on traditional regulatory instruments; however, henceforth the term "regulation" should be taken to also mean other types of interventions that governments require or encourage. Cap-and-trade systems, labels and other information-disclosure programs, voluntary programs enrolling excellent firms for special recognition, and the like, all are intended to confer benefits on society, and all may come at a cost.

6.     *See* CLINTON J. ANDREWS, HUMBLE ANALYSIS: THE PRACTICE OF JOINT FACT-FINDING (2002).

7.     For example, the long-awaited "unification" of non-cancer and cancer risk assessment by making the former mimic the latter and produce estimates of probability-of-harm rather than "bright lines" was in large part spurred on by economists who complained, with good reason, that bright-line assessments do not lend themselves to benefits valuation. *See, e.g.*, Proceedings of the Workshop on the Convergence of Risk Assessment and Socio-Economic Analysis to Better Inform Chemical Risk Management Decisions 42-44 (May 1-2, 2000), http://www.riskworld.com/Nreports/2000/RA-EAWorkshopMay2000.pdf; *see also* RICHARD B. BELZER, MERCATUS CENTER, RISK ASSESSMENT, SAFETY ASSESSMENT, AND THE ESTIMATION OF REGULATORY BENEFITS 21 (2012).

8.     *See, e.g.*, OFFICE OF MGMT. & BUDGET, REGULATORY PROGRAM OF THE UNITED STATES GOVERNMENT: APRIL 1, 1990—MARCH 31, 1991, 13-26 (the principal author of the chapter on risk assessment was economist Richard Belzer); Kenny S. Crump and Robin Gentry, *A*

economics training were to turn the tables, and begin to shine a light on the possible deficiencies on the "cost side" of CBA? The Sermon on the Mount contains this admonition: "And why beholdest thou the mote that is in thy brother's eye, but considerest not the beam that is in thine own eye?"[9] This project is in some sense an attempt to help remove one of the "beams" while we continue to worry about the various "motes" that also plague the regulatory analysis process.

The central theme of this Article is that *costs matter*. That proposition should be uncontroversial, even for readers who reject the entire enterprise of comparing benefits to costs. Even for the most rigid forms of the "precautionary principle,"[10] it is sensible to try to achieve our goals in the least expensive way possible. And because costs matter, we should have some clue what they really are—or, less pejoratively, how uncertain they are, who bears them, what second-order consequences they set in motion, etc. And yet, time after time, *leaders in CBA scholarship and practice gloss over this half of the ledger as if it is a solved problem*. For a recent and representative quote to introduce this Article, consider one of the first writings of Cass Sunstein after he left his position as Administrator of the Office of Information and Regulatory Affairs (OIRA), also known as the "Regulatory Czar":

> It is true that even if we accept cost-benefit analysis, serious questions remain. Some of those issues are scientific. If we cut emissions of certain air pollutants, what, exactly, are the public-health benefits? Other questions are economic. Suppose that a rule would save 30 lives a year. How do we turn that figure into monetary equivalents? These and other issues have a philosophical dimension. How should we deal with values that are hard or impossible to quantify, such as human dignity? And should our valuations change if a rule would mostly benefit members of future generations?[11]

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*Response to OMB's Comments Regarding OSHA's Approach to Risk Assessment in Support of OSHA's Final Rule on Cadmium*, 13 Risk Analysis, 487-89 (1993).

9.     *Matthew* 7:3.

10.     *See, e.g.*, *Environmental Justice Requires Precautionary Action: Hearing before the California Environmental Protection Agency Advisory Committee on Environmental Justice* (2003) (statement of Peter Montague, Director of Environmental Research Foundation); Adam M. Finkel, *I Thought You'd Never Ask: Structuring Regulatory Decisions to Stimulate Demand for Better Risk Science and Better Cost Economics*, Eur. J. of Risk Res. (forthcoming 2015) (discussing a rigid precautionary principle as one of the lowest rungs on a ladder of analytic sophistication).

11.     Cass R. Sunstein, *The Stunning Triumph of Cost-Benefit Analysis*, Bloomberg, Sept. 12, 2012, http://www.bloomberg.com/news/2012-09-12/the-stunning-triumph-of-cost-benefit-analysis.html (last visited Dec. 22, 2014).

So one of the leading national scholars on CBA believes that there are "scientific" and "economic" problems left to solve—but notice that all the problems Sunstein mentions[12] are on the benefits side of the ledger (see Part I *infra* for a definition parsing benefits and costs). What about the process, discipline, and art of estimating regulatory costs? In this Article, I explore how scientists may tiptoe in where economists fear to—or choose not to—tread.

## I.  Definitional Preface

There are many ways to define "benefits" and "costs," some of which would introduce enormous confusion into this series of explorations of how analysts work across the two domains. Some attempts to parse the two terms lead to double-counting, the failure to count important things, or both. For a recent example of such a conceptual muddle, consider this paragraph from economist Eduardo Porter:

> The government has to predict how much climate change will cost us in the future—through lost agricultural productivity, poorer health, bigger hurricanes and the like—to figure out how much we should spend today. It does so through a measure called the "social cost of carbon," which captures the added damage that will be caused by adding one more ton of $CO_2$ into the air. The government's estimate of the cost to our society covers a wide range of $5 to $68 a ton and increases over time. Several economists have concluded that cutting carbon emissions via fuel-efficiency standards may be even more expensive.[13]

Here, Porter uses "cost" to mean the damage done by an externality, and then only briefly switches gears to refer to the cost of *averting* that damage as possibly "expensive." There is nothing per se illogical about saying "it will cost us a lot to avoid these costs," but such an approach doesn't really encourage cost-benefit thinking (any more than the phraseology "we could benefit by buying these benefits" would).

Another common way of parsing the two areas is to colloquially define "costs" as any unfavorable consequences and "benefits" as any favorable

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12.   A major theme of this Article will be the irony that much of the cost-benefit apparatus (scholars, practitioners, and policy stakeholders) seems to regard the estimation of regulatory costs as a "solved problem," when in fact it may be the weakest analytic link of all.

13.   Eduardo Porter, *Taxes Show One Way to Save Fuel*, N.Y. Times, Sept. 11, 2012, www.nytimes.com/2012/09/12/business/fuel-efficiency-standards-have-costs-of-their-own.html.

ones.[14] This can be a coherent way to divide the ledger while avoiding double-counting. However, it also blinds the discussion to two important concepts—the notion of "disbenefit" and the notion of "negative cost"—that can greatly clarify the role and the turmoil of CBA.[15]

In this project, our team has defined these terms so as to place on the "benefit" side of the ledger *all* the changes—both positive and negative—in outcomes not traded in markets. In other words, the health, safety, environmental, and other conditions that are altered by a regulation—once monetized—constitute the regulation's "benefits." Note that, under this definition, some non-market benefits can be negative,[16] and the intervention as a whole may even have negative total benefit, not just negative net benefit. On the "cost" side of the ledger, we place all of the changes, impelled by the regulation, in resources that are traded in markets. In other words, the costs are the resources that are consumed or reallocated so that society can "buy" the benefits. As I will discuss in detail, these changes involve much more than the monetary resources some may be required expend in order to comply with the regulation. These "compliance costs" are a central part of the concept of regulatory cost, but, as with benefits, any given component of total cost can be positive or negative. Producers or consumers whose economic welfare decreases as a result of a regulation incur positive costs, while those whose welfare increases incur negative costs. If the latter outweigh the former, the regulation as a whole may have negative costs along with positive benefits.

More simply put, the benefits are the results of the intervention and the costs are the resources marshaled to attain them. For the purpose of examining analytic activity in the federal and state regulatory systems, our definition has the advantage of usefully dividing the work and responsibilities of analysts in two different ways: (1) regulatory economists estimate regulatory costs (in dollars, although the dollars are conceived of as opportunity costs), while risk scientists estimate regulatory benefits (in "natural units" such as lives saved, quality-adjusted life-years (QALYs) conferred,

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14.     *See, e.g.*, Regulatory Improvement Act, S. 746, 106th Cong. §621 (1999) (defining "cost" as "the reasonably identifiable significant adverse effects, quantifiable and nonquantifiable, including social, health, safety, environmental, economic, and distributional effects, that are expected to result from implementation of, or compliance with, a rule").

15.     An example of a "disbenefit" is an increase in one risk set in motion by the attempt to reduce another risk. *See infra* note 16. An example of a "negative cost" is the economic good fortune to some that often accompanies, or offsets, or dwarfs, the monetary "hits" that others must bear when society intervenes to correct a market failure.

16.     This is the case especially if the regulation exacerbates one or more risks in pursuit of the reduction of other risks. *See, e.g.*, RISK VERSUS RISK: TRADEOFFS IN PROTECTING HEALTH AND THE ENVIRONMENT (John D. Graham & Jonathan Baert Wiener eds., 1995); *infra* Part VI.

habitat preserved, visibility improved, etc.); and (2) economists also work on the "benefits side," because traditionally the act of monetization (converting benefits from natural units to dollars, in order to compare benefits to costs) is carried out by economists. Table 1 presents a hypothetical regulation, where a variety of costs and benefits are parsed according to this preferred structure.

TABLE 1.  A COHERENT PARSING OF BENEFITS AND COSTS

| Benefits | Costs |
|---|---|
| *Reduced emissions of $CO_2$ and air toxics, leading to "lives saved" (and benefits from reduced morbidity), slower trajectory of climate change* (note: perhaps slightly offset by "rebound" effect of more miles driven) | Plastic costs more than steel (reduced consumer and producer surplus in car sector) |
| | Steel plant closures |
| Increased highway traffic fatalities | *Unemployed workers hired by plastics sector* |
| *Reduced dependence on imported oil* | "Innovation drag" as automakers are forced to divert resources to making cars so as to address an externality rather than profit |
| | Managerial time diverted to externality |
| | *Innovations in design having unanticipated positive effects on consumer and producer surplus* |

Note: This table depicts the costs and benefits of a hypothetical (fanciful) proposal to require car bodies to be made of lightweight materials such that every model achieves an additional three miles per gallon. *Italicized* ("good") entries are either positive benefits or negative (offsetting) costs; non-italicized entries are positive costs or negative (offsetting) benefits. There are effects that "spillover" across any conceptual firewall one might draw—for example, foregone agricultural productivity if climate *does not* warm as much as predicted is either a "negative benefit" of the policy or a positive cost.

   This Article will remark only peripherally on the rigor with which risk-reduction benefits, once they are estimated, are then monetized. By parsing terms this way, we will essentially be contrasting the analytic work of scientists (who estimate benefits, albeit in "natural units" rather than in dollars) and of economists (who, among other functions, estimate costs).[17]

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   17.    No single way to parse benefits and costs is wholly satisfactory. In particular, there is spillover between the two categories. For example, non-market benefits can impel changes in market outcomes, as in the increased productivity (leading to increased economic growth, which is a "negative cost") of persons whose health is improved via the regulatory benefits

The remainder of this Article will discuss four fundamental ways in which the estimation of costs and benefits can proceed with vastly different degrees of rigor, care, and transparency. It will present results from an analysis of several dozen major U.S. federal health, safety, and environmental regulations, exploring to what extent the analytic treatment of costs—as opposed to benefits—has in fact been markedly or systematically less rigorous, primarily with respect to the first of the four phenomena—uncertainty. It will explore why these differences may have arisen and may persist, and will make specific recommendations for harmonizing the analytic treatment of costs and benefits where solid reasons do not exist for any discrepancies. Finally, it will sketch out a program of additional research to expand our results and explore their implications for public perception of risks, costs, and decisions. The goal of this project is to suggest that cost-benefit analysis as currently performed may be *incompatible with itself,* and to suggest improvements to remedy this situation.

## II. Four Phenomena that Surround both Risk Assessment and Cost Assessment

The larger project to which this Article is a contribution considers four areas where QRA has faced (and to some extent, surmounted) analytical and ethical challenges. Risk assessors and regulatory economists must confront these four phenomena but tend to confront them differently. We hope that comparing these perspectives will help improve the practice of regulatory economics, and thence CBA more generally. The four phenomena that both risk and cost assessment must confront include:

- *Uncertainty*: should total benefit (or total cost) be quantified and communicated as a single point estimate, a range, a probability density function (pdf), or multiple pdfs?
- *Interindividual Variability*: should benefit (or cost) be disaggregated so as to depict the variation in benefits (or costs) that different individuals or different segments of society will actually face, or should analysts implicitly assume that we all face the same risk (or that we all bear the same cost)?[18]

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attained. Note also that both benefits and costs are flows that persist over time, rather than static events.

18.    Once a regulatory system acknowledges interindividual variability, the two remaining phenomena (utility and equity) must be dealt with, although they are dealt with by default if variability is ignored. This results in linear valuation and uniform weighting, which is of course a form of weighting like any other. *See* Carl Cranor & Adam M. Finkel, Toward Recognizing Individual Benefits and Costs in Cost-Benefit Analysis (2014) (in review, Journal of Benefit-Cost Analysis).

- *Utility*: should the implicit function relating the magnitude of risk (or of cost) to the magnitude of harm or disutility it causes be linear throughout the entire range of individual risk (or cost) levels? Alternatively, should de minimus individual risks (or de minimus costs) be treated differently, and/or should extremely large (i.e., intolerable) individual risks (or costs) be treated differently?

- *Equity*: should we aggregate the benefits (or costs) to each individual in the population—having implicitly or explicitly converted them into units reflecting disutility—by imposing equal weights on each person without regard to covariates such as age, race, socioeconomic status, etc., or should we apply non-uniform weights?

This Article concentrates on the first of the four phenomena—uncertainty. Although there are areas of overlap, the nineteen articles and one edited volume produced under the auspices of this National Science Foundation (NSF) project can be categorized as addressing uncertainty,[19]

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19.     Adam M. Finkel, *Emitting More Light than Heat: Lessons from Risk Assessment Controversies for the 'Job-Killing Regulations' Debate,* in DOES REGULATION KILL JOBS? 128 (Cary Coglianese, Adam M. Finkel, & Chris Carrigan eds., 2014); Finkel, *I Thought You'd Never Ask*, *supra* note 10; Adam M. Finkel, *Harvesting the Ripe Fruit: Why Is it so Hard to Be Well-Informed at the Moment of Decision?*, in THE VALUE OF INFORMATION: METHODOLOGICAL FRONTIERS AND NEW APPLICATIONS (Molly Macauley & Ramanan Laxminarayan eds., 2011); Jack Siegrist, *Mixing Good Data with Bad: How to Do It and When You Should Not*, in VULNERABILITY, UNCERTAINTY, AND RISK: ANALYSIS, MODELING, AND MANAGEMENT 368 (Int'l Conference on Vulnerability and Risk Analysis and Mgmt., Bilal M. Ayyub ed., 2011), *available at* http://ascelibrary.org/doi/abs/10.1061/41170%28400%2945; Scott Ferson & Jack Siegrist, *Statistical Inference Under Two Structurally Different Approaches to Interval Data*, in VULNERABILITY, UNCERTAINTY, AND RISK: ANALYSIS, MODELING, AND MANAGEMENT, 368 (Int'l Conference on Vulnerability and Risk Analysis and Mgmt., Bilal M. Ayyub ed., 2011), available at http://cedb.asce.org/cgi/WWW-display.cgi?274101; Sandra Hoffmann, *Overcoming Barriers to Integrating Economic Analysis into Risk Assessment*, 31 RISK ANALYSIS 1345 (2011); Jack Siegrist, Scott Ferson & Adam M. Finkel, Ravnoprochnost: Avoiding Unnecessary Uncertainty in Cost–Benefit Calculations (2013) (unpublished manuscript); Jack Siegrist, Scott Ferson & Adam M. Finkel, Advanced Bias Correction: Factoring Out Misestimation and Overconfidence (2013) (unpublished manuscript); Scott Ferson et al., Natural Language of Uncertainty: Numeric Hedge Words (2015) (forthcoming Int'l Journal of Approximate Reasoning); Dale B. Hattis & Adam M. Finkel, Barriers to a More Even-Handed Treatment of Uncertainties in Projected Economic Costs and Health Benefits of Environmental Regulations (2013) (unpublished manuscript).

variability,[20] utility,[21] or equity.[22]

## III. Why is Complexity Valuable?

In Part IV *infra*, I argue that *analytic imbalance*—substantially more complexity or rigor in some large portions of the CBA than in other portions, particularly when risks are analyzed with rigor and costs are not—creates unstable situations with undesirable consequences. There are, of course, two basic ways to resolve such an imbalance: add complexity and rigor to the weak link(s), or *discard* the extra complexity that encumbers the more detailed portions of the analysis. So, why might it be preferable to impel the production of more complex information about risks or costs, rather than to truncate or produce a "least common denominator" analysis?

If we were contemplating gathering more information to enrich the analysis, it might be easier to think logically about the pros and cons. The quantitative treatment of the value of information (VOI) has a well-developed body of literature supporting it,[23] and is founded on the premise that, although new information can be costly to obtain and can erode net benefits through delay, its value comes from its ability to reduce the probability or the magnitude of decision errors.[24] In this Article, I am referring not to *new* information, but to the complexity with which we can choose to describe

20.    Victoria Salin, *Variability in the Impact on Industry of Food Safety Regulation: A Review of Ex Post Analyses*, Agribusiness, Food, and Consumer Economics Research Center Commodity Market Research Report No. CM-03-12 (March 2012); Winston Harrington, Elena Safirova, Conrad Coleman, Sébastien Houde, & Adam M. Finkel, Distributional Consequences of Public Policies: An Example from the Management of Urban Vehicular Travel, Penn Law: Legal Scholarship Repository (2014) (unpublished manuscript); Victoria Salin & Adam M. Finkel, Variability in Costs to Comply with Regulations: An Application to Food Safety (2013) (unpublished manuscript).

21.    Does Regulation Kill Jobs? (Cary Coglianese, Adam M. Finkel, & Chris Carrigan eds., 2013); Adam M. Finkel, *Perceiving Others' Perceptions of Risk - Still a Task for Sisyphus*, 1128 Annals N.Y. Acad. Sci. (2008); Strategies for Risk Communication: Evolution, Evidence, Experience 121 (2008); Branden B. Johnson & Adam M. Finkel, Public Perceptions of Regulatory Costs, Their Uncertainty, and Their Distribution (2014) (in review, Risk Analysis); Adam M. Finkel & Branden B. Johnson, A "Top-Down" Elicitation of the Value of a Statistical Life: Results from a New Stated-Preference Survey (2013) (unpublished manuscript).

22.    *See, e.g.*, Adam M. Finkel, *Solution-Focused Risk Assessment: A Proposal for the Fusion of Environmental Analysis and Action*, 17 Hum. & Ecological Risk Assessment 75 (2011); Public Perceptions of Regulatory Costs, *supra* note 21; Cranor & Finkel, *supra* note 18.

23.    *See, e.g.*, Fumie Yokota & Kimberly M. Thompson, *The Value of Information in Environmental Health Risk Management Decisions: Past, Present, Future*, 24 Risk Analysis 635 (2004); Finkel, *Harvesting the Ripe Fruit*, *supra* note 19.

24.    Adam M. Finkel & John S. Evans, *Evaluating the Benefits of Uncertainty Reduction in Environmental Health Risk Management*, 37 J. Air Pollution Control Ass'n 1164, 1165-67 (1987).

information *we already have in hand* about risks and costs. It is tempting to resort to platitudes such as "details matter" or "one size doesn't fit all," but these are unsatisfying in light of the real potential for complexity to delay the completion of analysis, add costs, and foment public confusion.

So, in order to support the argument that complexity and rigor are desirable commodities (and therefore to advance the premise that, faced with an imbalance, we should first consider adding rigor where it is lacking rather than discarding it where it is present), I rely on an image of a "virtuous circle" of interaction between analysts (who can supply rigor) and decisionmakers (who can demand it). In a companion paper to this one, I constructed a hierarchy of complexity in cost-benefit decisionmaking consisting of ten distinct levels of detail.[25] The hierarchy depicts how information can be marshaled to gauge the harms caused by environmental, health, or safety hazards, as well as the pros and cons of actions to reduce them. Table 2 shows these levels as a series of equations in several variables; the companion paper goes into much more detail about the attributes of each level, and gives examples of contemporary decisions that resemble various rungs on this ladder of complexity.

The following summary discussion is intended to highlight the extremes and midpoint of this ladder: (1) the least complex decision rule I can imagine in this arena is to fixate exclusively on *either* a potential harm that society could eliminate, or on the potential costs of eliminating it, and invoke the precautionary impulse—if the harm or the cost might exist, treat it as if it does exist and must be avoided above all else; (2) just above the middle of the ladder (at Level 6) sits a cost-benefit decision rule that requires information about the probability density function (pdf) for total cost and total benefit, thereby allowing society to choose a control strategy that maximizes net benefit (monetized risk-reducing benefits less the cost of obtaining them) but that can consider different balances between underestimating and overestimating the virtues of each strategy; and (3) at the top of the ladder sits a decision rule that takes seriously not only uncertainty, but interindividual variability in both risk and cost, heterogeneity in individual preferences for changes in longevity or environmental quality and for changes in personal income, and a social welfare function that accounts for other attributes of those individuals who receive risk-reducing benefits and those who pay for those benefits (notably, their income and their baseline risk levels).

The point of a "virtuous circle" is conceptually simple: complexity helps decisionmakers see more clearly the true spectrum of available choices and

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    25.      Finkel, *I Thought You'd Never Ask*, *supra* note 10.

## TABLE 2. CHARACTERISTICS OF A TEN-RUNG LADDER OF COMPLEXITY IN REGULATORY DECISION-RULES

| Level | Verbal Description | Symbolic Description |
|---|---|---|
| 1 | Prevent or eliminate the most dire outcome | $NB > 0$ if $\Delta R > 0$ OR if $\Delta C > 0$ |
| 2 | Attain a "bright line" of safety | $NB > 0$ if $R < R^*$ |
| 3 | Pass a "double bright line" test | $NB > 0$ if $R < R^*$ and $C < C^*$ |
| 4 | Compare arbitrary point estimates of total benefit and total cost | $NB = (P \cdot \Delta R_? \cdot VSL) - C_?$ |
| 5 | Compare reconciled point estimates of total benefit and total cost (expected values, in this example) | $NB = (P \cdot \Delta \overline{R} \cdot VSL) - \overline{C}$ |
| 6 | Develop a probability density function (pdf) for net benefit | $pdf(NB) = [pdf(VSL) \cdot P] \cdot pdf(\Delta R) - pdf(C)$ |
| 7 | Develop a pdf for net risk minus net cost | $pdf(NB) = [pdf(VSL) \cdot P] \cdot pdf(\Delta R_{NET}) - pdf(C_{NET})$ |
| 8 | Compare pdfs of net risk and net cost with some attention to interindividual variability in each | $NB = \max(NB_i, NB_j)$ |
| 9 | Assess the uncertain net benefit to each individual (or subpopulation) separately, then aggregate | $pdf(NB) = \sum_{i=1}^{P} \{[pdf(\Delta r_i) \cdot v_i] - pdf(c_i)\}$ |
| 10 | Combine estimates of individual net benefit via any non-trivial social welfare function | $pdf(NB) = \sum_{i=1}^{P} w_i \{[pdf(\Delta r_i) \cdot v_i] - pdf(c_i)\}$ |

Key to Abbreviations:

NB = Net Benefit

P = number of persons in affected population

VSL = Value of a Statistical Life

$\Delta R$ ($\Delta C$) = change in total risk (total cost) that a policy impels

$\Delta r$ ($\Delta c$) = change in risk (cost) for a particular *individual*

Note: this table is greatly elaborated upon, with columns explaining the information needs at each level, in Finkel, *supra* note 10.

how each choice affects things we hold most dear. Monomaniacal precaution tends to lead to costly programs to reduce small or non-existent risks, or to policies of inaction that cater exclusively to the economic interests of a favored few.[26] Keeping an eye only on total costs and benefits, and the uncertainties therein, tends to attenuate these extreme mistakes, but ignores

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26.     *See* Peter Montague, *Two Friends Debate Risk Assessment and Precaution*, RACHEL'S DEMOCRACY & HEALTH NEWS, Aug. 13, 2007.

completely the dimension of individual cost and benefit, and thereby courts outcomes in which net benefit increases marginally but to the detriment of the majority of those affected.[27]

In a "vicious circle" of interaction, analysts *could* fail to describe costs or benefits with much complexity (and decisionmakers could passively accept what they are given), or decisionmakers *could* ask only for simplistic information. On the other hand, the decisionmaker could say to the analysts, "I want to know about uncertainty, the range and distribution of consequences to individuals, and the net risk reduction considering substitution effects or the net cost considering general-equilibrium effects." Similarly, "I think you need to know about . . ." is something the analysts could say to challenge the decisionmaker.[28] In the companion paper mentioned *supra*, I argue that *mediocre ambitions for the kind of decisions we wish to make beget mediocre information, which in turn begets mediocre decisions.* Conversely, I believe that if decisionmakers demand complexity, or if analysts proffer it with enthusiasm, we can master the difficult cost-benefit choices and not simply be carried along in their wake. To the extent that more complex decision rules yield better results, the unimproved weak links—where we are forced to discard some scientific or economic information to reach the lower common denominator of the two—become a proper, and indeed a compelling, subject of scrutiny.

## IV. Why is "Balance" Important?

Whether the analysis considers uncertainty, interindividual variability, non-linearities in valuation, or equity and social welfare, a common thread emerges: there is virtue in treating each phenomenon in a balanced way across the risk/cost divide. The two "sides" are mirror images of each other: from the point of view of decisionmakers, *the only reason to take action is because of risk, and the only reason not to take action is because of cost*. In another companion piece in the series, we examined quantitatively the disadvantages of an unbalanced treatment of uncertainty or variability in risk versus

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27.    *See* Winston Harrington et al., *Distributional Consequences of Public Policies: An Example from the Management of Urban Vehicular Travel*, U of Penn. Inst. for Law & Econ, Research Paper No. 14-21 (2014).

28.    In this discussion, I am presuming that added complexity is sincere, and not concocted to impress stakeholders or judges. *See, e.g.*, Wendy E. Wagner, *The CAIR RIA: Advocacy Dressed Up As Policy Analysis*, in Reforming Regulatory Impact Analysis 56, 60 (Winston Harrington, Lisa Heinzerling, & Richard D. Morgenstern, eds., 2009). Wagner points out helpfully that uncertainty analyses can sometimes be drummed up strategically to "prove" that benefits exceed costs no matter how pessimistic the assumptions used. It is important, however, to realize that even in such cases, this is not a drawback of uncertainty analysis per se, but of post hoc and self-serving uncertainty analysis.

cost.[29] Here, I will briefly summarize some of the qualitative principles that make balance a virtue.

First, the very concept of net benefit depends equally on benefit—i.e., risk reduction—and cost: that's what makes it "net." Of course, any one of the phenomena could apply more significantly to benefit than to cost—benefit may be more uncertain than cost, more variable, or better described with a non-linear valuation or social welfare function—but that would be an important special case, not the general one. More importantly, there is a paradox at work here: only through at least trying to address the phenomenon on both "sides" can we *determine* that the further pursuit of balance is not necessary! If uncertainty in cost is indeed small relative to uncertainty in benefit, that conclusion will arise out of some attempt to quantify uncertainty, or else it will be a rationalization of dubious provenance. Ignoring something important is a fundamental analytic error, and as a first principle, errors in risk are no more or less harmful than are errors in cost.

Second, imbalance creates, by definition, an instability: will we proceed to strengthen the weak link or not? As we explore in our piece regarding the Russian engineering principle of *ravnoprochnost* ("equi-sturdiness") as it applies to CBA,[30] the problem with the weak link in a designed product is not simply the creation of a vulnerability at which the entire product is most likely to fail catastrophically; less well-appreciated is the fact that, in hindsight, all of the time and expense spent on refining the stronger links beyond the quality of the weakest one were wasted. Until the imbalance is corrected by strengthening the weaker link, decisionmakers really only have two choices. As mentioned above, one option is to essentially *discard* much of the rigor previously gained in the stronger links, and choose a decision rule that corresponds to the least common denominator of the various inputs. For example, decisionmakers could pay no attention to the value of net benefit for any individual, because there is no information on individual cost (even though there may be a very detailed analysis of interindividual variability in risk and benefit). The other possibility is to *act as if* balance has been achieved, essentially concocting a false sense of confidence out of a half-baked analysis. This is perhaps easiest to see when uncertainty is the analytic phenomenon of interest: the temptation to not "waste" a complete uncertainty analysis of part of a problem may lead decisionmaker to act as if the partial uncertainty actually studied is the total uncertainty in the entire

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29.    Siegrist et al., Ravnoprochnost, *supra* note 19.

30.    *Id.*

problem.[31] This kind of underestimation of uncertainty is a serious pitfall, as the next sections will demonstrate.

## V.  WHY IS UNCERTAINTY IMPORTANT?

I now turn to the first and arguably most far-reaching of the four ways in which benefit and cost estimation can differ—the honesty with which uncertainty is explored and communicated. A vast and growing literature, initiated more than one hundred years ago but especially active during the 1980s and 1990s, attests to the intensity with which scholars and practitioners have explored the sources of uncertainty in quantitative policy analysis, and explains how inattention to uncertainty can frustrate sound decisionmaking.[32] All these discussions emphasize somewhat different features of the basic question "how can overconfidence poison decisionmaking?"[33] Here, with an appreciation of the details and alternative perspectives such a summary must omit, I attempt a very basic synthesis of how I have answered this question.

All of the important deficiencies of using a point estimate instead of a depiction that acknowledges the uncertainty of a quantity—in this context, risk, cost, or net benefit—fall into one or more of three overarching lapses:

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31.     It may also lead critics of a regulation to complain about an analysis as if the partial uncertainty actually studied is the only source of poor uncertainty analysis in the regulation—and so one secondary advantage of balanced treatment of uncertainty in risk and cost is that it helps "spread the targets" and reduce the paradoxical situation where the strongest portion of the analysis receives the most criticism and hence the most additional refinement.

32.     Among the most comprehensive book-length references specific to uncertainty in risk assessment and cost-benefit analysis are: M. GRANGER MORGAN & MAX HENRION, UNCERTAINTY: A GUIDE TO DEALING WITH UNCERTAINTY IN QUANTITATIVE RISK AND POLICY ANALYSIS (1992); ADAM M. FINKEL, CONFRONTING UNCERTAINTY IN RISK MANAGEMENT: A GUIDE FOR DECISION-MAKERS (1990); NATIONAL RESEARCH COUNCIL, SCIENCE AND JUDGMENT IN RISK ASSESSMENT (1994); ALISON CULLEN & H. CHRISTOPHER FREY, PROBABILISTIC TECHNIQUES IN EXPOSURE ASSESSMENT: A HANDBOOK FOR DEALING WITH VARIABILITY AND UNCERTAINTY IN MODELS AND INPUTS (1999); ALAN KRUPNICK ET AL., NOT A SURE THING: MAKING REGULATORY CHOICES UNDER UNCERTAINTY (2009); NASSIM NICHOLAS TALEB, THE BLACK SWAN: THE IMPACT OF THE HIGHLY IMPROBABLE (2010). But of course there are many others, and still more references from outside the fields of risk assessment and cost-benefit analysis that have much to impart.

33.     Less commonly explored, because it is less common a pitfall, is "underconfidence"—the conclusion that uncertainty is so large that nothing meaningful can be said or done. Sometimes a dauntingly broad range can emerge from a very rigorous analysis that pays special attention to one or both tails of the distribution, but often underconfidence, like overconfidence, can emerge instead from the most cursory or automatic of processes. Concern has been raised, for example, about the corrosive effect of EPA's boilerplate statement of underconfidence about carcinogenic potency—the agency routinely caveats its point estimate of potency with the clause "but it could be as low as zero" even in cases where theory and evidence makes it extremely unlikely that the substance has zero potency. *See* NATIONAL RESEARCH COUNCIL, SCIENCE AND DECISIONS: ADVANCING RISK ASSESSMENT 104 (2009).

(1) incorrectly assuming that a particular value for the quantity is, in fact, the "desired estimator" when that value and the estimator actually diverge from each other; (2) choosing a correct value of one particular estimator, when a different estimator would better serve the decision; or (3) failing to discern that no single estimator can optimize the decision, nor can it adequately communicate the reality of the situation to affected parties.

To see these three problems in their full light requires one to think about the reasons why we use estimators, and the notion that an estimator can become what I would clumsily term an "estimanacle." In his poem "London," William Blake wrote about "the mind-forg'ed manacles" we use to chain others and ourselves.[34] I start from the premise that, given a distribution of the true values of some quantity, *any* estimator can do no more than help the decisionmaker balance the adverse consequences of error, according to the exact and particular way that estimator strikes that balance. If the adverse consequences when the quantity turns out to be smaller than you estimate it to be are exactly as adverse as they are if the quantity turns out to be larger than you estimate it to be, then the median of the uncertainty distribution could well be the best possible estimator to use. Half of the time (with half of the probability), we would have to live with the consequences of one type of error, and half of the time with the other. Any estimator other than the median would strike a different balance, but in this hypothetical case we have already said that such a balance would not reflect this decisionmaker's true preferences as well as the median would.

The great value of a point estimate is that it can make sense of a distribution when the consequences of error are known and agreed upon. The estimator is a necessary manacle, because it forces us (indeed, allows us) to decide based on a particular set of preferences (one can't be risk-averse and risk-seeking at the same time, for the same decision). *But we can be led to paradise or to perdition, depending on whether the estimator is what we are told it is, and on whether it imposes upon us those preferences we would consciously choose ourselves.*

The first problem amounts to unacknowledged and uncorrected bias: a good decision could have been made with an accurate depiction of a particular estimator, but inattention to uncertainty resulted in garden-variety misestimation. Suppose, for example, that the analyst and decisionmaker agree that they are interested in the expected value or mean, a quantity that has strong and broad appeal.[35] It is easy to imagine arriving at a grossly erroneous estimate of the mean of some quantity when it is modeled as the sum or

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34.   WILLIAM BLAKE, *London*, in SONGS OF INNOCENCE AND EXPERIENCE (1794).
35.   *See* Albert L. Nichols & Richard J. Zeckhauser, *The Perils of Prudence: How Conservative Risk Assessments Distort Regulation*, REGULATION, Nov./Dec. 1986, at 13.

product of several uncertain components—the short-cut of combining esti-
mates of each mean value may bear little resemblance to the overall mean if
one or more components are omitted, or if the components do not combine
in the way that the model predicts.

Less well-understood, but potentially far more important, is the fact
that even random sampling from existing data (as opposed to estimation via
modeling) may not yield a precise or even an unbiased estimate of the
mean.[36] More generally, the distribution of uncertainty in the mean derived
via sampling from an asymmetric distribution is itself asymmetric.[37] This
has profound implications for analysis and management. Expected-value
decisionmaking is supposed to be a way to *bypass* uncertainty—proponents
say it shouldn't matter whether the distribution is broad or narrow when
you know how it behaves on average.[38] But if you need to study the uncer-
tainty *in order to estimate the mean properly*, this short-cut becomes an excur-
sion straight into a minefield. *When the tails determine the mean, there is no
substitute for studying the tails directly, at which point the "short-cut" has become
moot.*[39]

The second problem exposes the weaknesses of expected-value, or any
other one-size-fits-all prescription for social decisionmaking. In my experi-
ence, many advocates of expected-value decisionmaking are oblivious, will-
fully or otherwise, to the powerful value judgments it imposes upon society.
At the same time, advocates of decision rules whose ethical underpinnings
are more blatant tend to dismiss other equally valid judgments that could be
made. Elementary decision theory teaches that any estimator (for purposes
of this discussion, think of "estimator" as "percentile point on an uncertainty
distribution") will be optimal for one particular relationship between the

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36.     See the discussion of "Level 5" in the analytic hierarchy developed in Finkel, *I
Thought You'd Never Ask*, *supra* note 10.

37.     *See* Adam M. Finkel, *A Simple Formula for Calculating the "Mass Density" of a
Lognormally-Distributed Characteristic: Applications to Risk Analysis*, 10 RISK ANALYSIS 2291
(1990).

38.     *See, e.g.*, Ralph M. Perhac, Jr., *Does Risk Assessment Make a Case for Conservatism?*, 7
RISK: HEALTH, SAFETY, AND ENV'T 297, 302 (1996).

39.     Although for clarity this example uses variability rather than uncertainty as the
source of incertitude, the importance of non-normal populations should be easy to discern.
Suppose you need an unbiased estimate of the mean income of the U.S. population. If one in
every 10,000 Americans was a billionaire, the average wealth even of a "large" sample of
10,000 could quite possibly be an underestimate (in the common case [its probability ap-
proaches $1/e$, or 37%] where no billionaires were randomly selected among the first 10,000),
but could be a gross overestimate (in the less common case where two billionaires, rather
than the expected number of one, were picked).

consequences of underestimation and those of overestimation.[40] The mean minimizes the expected amount of deviation between the actual value of the uncertain quantity and the value (the estimator) we use as if it applies, *without regard to the sign of the error*. This is why I have often used the parable that, faced with an uncertain distribution of travel times to get to an airport to catch a plane, the expected value is ideal for someone who would prefer being four minutes late to being five minutes early (!), but deeply misleading to anyone who has any other calculus in mind.[41] A particular percentile estimator other than the median may be the only ideal choice for any decision where the consequences of one type of error exceed the other; these sorts of "precautionary" (in either direction) estimators force the parties to confront their values (which may not lead to harmony), whereas expected-value estimators tend to impose the constraint of equal weighting of outcomes upon the users. I think we would never consider an analysis successful if it didn't provide an answer to the question being asked, but that is quintessentially what a point estimate does: it is a guide to one way of deciding, which may not be the way that all or any of the decisionmakers actually prefer. Only the uncertainty gives possible access to *the estimator that is right for the person(s) using the estimate.*

The third way in which a point estimate tends to thwart sensible regulatory decisionmaking is more difficult to explain, but involves the inherent limitations of reducing uncertain possibilities to any single value. Although it may be a superhuman feat to map a distribution of possibilities onto a binary or finite set of choices, sometimes no one estimator—even one consciously chosen to reflect the decisionmaker's attitude towards errors of under- and over-estimation—can tell the whole story of what we are actually gambling with. A particular decision may be preferable to another because it is far superior if net benefit turns out to be at its expected value, clearly better if net benefit turns out to be much greater than average, and only slightly worse if net benefit turns out to be much lower than average. Needless to say, no single point estimate can show how difficult this choice truly is, and also how robust a particular decision might be when one considers the true spectrum of uncertainty.[42]

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40.     Kimberly M. Thompson and John D. Graham, *Going Beyond the Single Number: Using Probabilistic Risk Assessment to Improve Risk Management*, 2 HUM. ECOLOGICAL RISK ASSESSMENT 1008 (1996).

41.     Adam M. Finkel, *A Second Opinion on an Environmental Misdiagnosis: The Risky Prescriptions of Breaking the Vicious Circle*, 3 N.Y.U. ENVTL. L.J. 295, 335-40 (1995).

42.     When the pivotal quantity exhibits interindividual variability rather than uncertainty, looking at the whole distribution can reveal creative and superior disaggregation, via multiple simultaneous decisions. For example, given how the health benefits of ingesting Omega-3 fatty acids change with age and sex, and how the risks of ingesting mercury also do

Therefore, the *specific* folly of marrying a pdf for risk to a point estimate for cost is overwhelming.[43] Not only is this practice guaranteed to underestimate the actual uncertainty in net benefit, but:

- with this combination, one can't reliably even estimate expected net benefit;
- even with good luck and a reliable estimate of expected net benefit, that output is ample only in an impoverished decision context (risk-neutrality with respect to the magnitude of net benefit); and
- because the uncertainty that is acknowledged is one-sided (i.e., it contains no information about uncertainty in cost), the normal rules of value-of-information theory are out the window: one can't even begin to think systematically about whether more information on cost would improve the decision.

Not everyone agrees that more information about uncertainty is salutary, I hasten to add.[44] Of course uncertainty analyses cost money and take time, and should only be refined consistent with the value they have in light of their costs—that is, if the refinement could reduce the expected opportunity loss (i.e., regret) of the decision by an amount greater than the cost of the refinement.[45] Some observers fear that more information about uncertainty can confuse decisionmakers and the public, can falsely imply that all values within a range are equally likely, or can politicize decisions (i.e., by encouraging the "look at the tail but don't divulge how far out it goes" strategy of insulating decisions from public pressure).[46] Although the second of these concerns can easily be handled by explaining that this is not usually how one interprets a range,[47] I sympathize with these concerns.

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(in different ways), agencies could set (say) six different guideline levels for how much fish of which varieties are safe to consume, each applying to males or females in three broad age categories (child, adult, elderly). Here the decision-maker is not balancing different kinds of errors, but minimizing all of them by increasing (here, "individualizing") the number of interventions.

43.     *See* Siegrist et al., Ravnoprochnost, *supra* note 19.

44.     Presidential/Congressional Commission on Risk Assessment and Management (PCCRAM): Risk Assessment and Risk Management in Regulatory Decision-Making (1997), at 89-90 (finding that mathematical assessments of uncertainty are not always helpful when "risk-related decisions are routine, made at the local level, and do not involve large stakes"); National Research Council, Science and Decisions, *supra* note 33, at 103-04 (discussing EPA's approach to deciding how much uncertainty analysis to deploy).

45.     National Research Council, Science and Decisions, *supra* note 33, at 82-87; Finkel, *Harvesting the Ripe Fruit*, *supra* note 19.

46.     PCCRAM, *supra* note 44, at 171.

47.     M. Granger Morgan et al., Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Climate Decision Making 20 (Nat'l Oceanic and Atmospheric Admin. ed., 2009).

However, I believe that the human and financial costs of misestimation and decisions that backfire are far larger than the costs of "too much information." Although their article (like so many others to be discussed *infra*) dealt only with uncertainty in risk and ignored uncertainty in cost, no one has ever said it better than Wilson, Crouch, and Zeise: "a decision made without taking uncertainty into account is barely worth calling a decision."[48]

## VI. WHICH IS LARGER: RISK UNCERTAINTY OR COST UNCERTAINTY?

Before proceeding to examine in detail the treatment of uncertainty across the risk/cost divide, we need to confront honestly a precondition for uncertainty analysis—where there is little or no uncertainty, there is little or no need to quantify or communicate it. This is a limiting case of the more general issue of symmetry; if risks are far more uncertain than costs, more attention to risk uncertainty relative to cost uncertainty may actually be the proper response to the raw materials—a "feature rather than a bug." Although I will explore many other reasons for treating the two kinds of uncertainty differently, the relative size of the two is so fundamental to their treatment that it must be dealt with at the outset.

Unfortunately, "how uncertain are risks (or costs)?" is a very hard question to answer, in large part because of the inherent Catch-22—*estimates* of uncertainty may be a terrible guide to how uncertain the observer actually is. This is especially so when the person(s) doing the estimating have an incentive to appear more confident than they have a right to be. In any event, there are very few examples of a priori estimates of uncertainty to compare on both sides of any particular risk/cost problem, simply because there are so few rigorous attempts to quantify cost uncertainty. We can, however, exploit two other kinds of information to explore the possibility that costs are better understood (i.e., less uncertain) than risks are: data on the uncertainty in various *components* of risk or cost, and specific instances of surprise or corroboration when we have been able to measure either risk or cost ex post and compare it to predicted values.

Both kinds of information need to fit into a coherent template that defines and circumscribes uncertainty. As a working definition that facilitates a fair comparison, I suggest the following four principles:

- *For this narrow purpose, we should be interested in estimates of population risk and total cost, as opposed to estimates of risk or cost for identified or hypothetical individuals.* Misestimation of risk or cost

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48.    Richard Wilson et al., *Uncertainty in Risk Assessment*, in RISK QUANTITATION AND REGULATORY POLICY 133, 133 (David G. Hoel et al. eds., 1985).

because of inattention to variability (or mistakes in ascribing variability) is important in its own right, but focusing on population measures isolates the performance of the uncertainty analysis. Furthermore, individual risk can, by definition, never be proven or disproven. If, say, one million people each face a predicted risk of approximately 1 in 1000, and we say that uncertainty means that somewhere between 900 and 1100 people are predicted to succumb to the risk, then the discovery that 100, or 1900, people actually succumbed would reveal overconfidence. On the other hand, an estimate of a "reasonable worst-case" risk of 1 in 100 for certain highly exposed people can neither be corroborated nor refuted by the death of any particular person—by chance, any person could either succumb or not, at any true probability.

- *We should measure uncertainty, bias, or surprise in multiplicative rather than additive terms.* Measures like the coefficient of variation, the ratio of predicted to observed values, or the ratio of the 95th and 5th percentiles of a set of estimates are scale-invariant, which makes them preferable to absolute measures for comparing different sets of results.

- *We should compare results so as to either include or ignore model uncertainty, rather than mixing different types of results.* Both risk estimates and cost estimates are complicated by parameter uncertainty and model uncertainty. For example, consider the decision of whether to require firms to install pollution control devices to reduce emissions of a substance found to cause cancer in rodents. The uncertainty in the number of "lives saved" by the devices is a function of uncertainty in numerous parameters, including binomial sampling uncertainty in the rodent dose-response experiments, imprecision in the value of the exponent used to scale by allometry from rodents to humans, inability to precisely specify the capture efficiency of the devices, etc. Here the parameters are not known precisely, but we can choose to assume that the equation we use to model their relationship to risk [that is, lives saved equals (fraction of emissions reduced) x (potency in rodents) x (rodent:human scaling factor) x (number of exposed persons)] is known to be correct. On the cost side, we could assume that a different simple linear equation applies: cost equals [(the current price of one device) x (total number of devices installed to comply with the regulation) x (factor by which current price will drop due to economies of scale and/or technological learning)]. As in the "risk equation," each parameter can

be assigned an uncertainty, and the uncertainty in cost is estimated as the convolution of these distributions. But for both risk and cost, the models themselves may be incorrect. For example, there may be a significant probability, according to expert judgment, that the rodent carcinogen acts via a mechanism that is irrelevant to or inoperative in humans. The uncertainty distribution for the risk can thus either be expressed as the previous parameter-uncertainty distribution (under the "default" model), as the degenerate distribution (probably a point estimate at zero) under the alternative assumption, as a weighted combination of the two distributions, informed by expert elicitation,[49] or as two or more separate distributions with a narrative explanation of the ambiguity and of the weights that could be assigned to each.[50] The cost model might also be incorrect; according to the "Porter Hypothesis," for example, considering only the firm's outlays for pollution-control devices neglects the consequent savings in materials, labor, and production efficiency these devices often create, resulting in cost over-estimation of substantial and uncertain magnitude.[51] Although there exists a spectrum of views on whether and how to account for model uncertainty,[52] any comparison of uncertainty in risk and cost needs to take care not to treat model uncertainty differently within the same analysis. Of course one side of the ledger will *look* more uncertain than the other if its distribution incorporates the additional ambiguity contributed by multiple model assumptions, but capturing all uncertainties is, in my opinion, less important than accounting for and comparing uncertainty in a systematic and symmetric way.

- *We should strive to assess net risk and net cost—rather than putting to the side the direct trade-offs that accompany risks and costs—but, in any event, we should assess net effects on both sides or neither, not one without the other.* There is a compelling but largely unrecognized parallel between risk assessment and cost assessment:

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49.    UNCERTAINTY MODELING IN DOSE RESPONSE: BENCH TESTING ENVIRONMENTAL TOXICITY 177 (Roger Cooke ed., 2009).

50.    For a discussion of the pros and cons of each approach to model uncertainty, *see* Chapter 8 of Science and Judgment, *supra* note 32, at 144-159, *and* Chapter 4 of Science and Decisions, *supra* note 33, at 93-126.

51.    Michael E. Porter & Claas van der Linde, *Toward a New Conception of the Environment-Competitiveness Relationship*, 9 J. ECON. PERSP. 97 (1995); *contra* Karen Palmer et al., *Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm?*, 9 J. ECON. PERSP. 119 (1995).

52.    *See Uncertainty Modeling in Dose Response*, *supra* note 49, at 1.

in both arenas, countervailing effects of policy interventions can diminish, offset, or even exceed the direct effects.[53] The subfield of "risk vs. risk"[54] challenges conventional or myopic assessment to admit that reducing one risk can often create, increase, or concentrate some other risk (see Figure 1 for my adaptation of Graham and Wiener's influential 2x2 typology of risk-risk tradeoffs). *But at the same time, a powerful set of "cost versus cost" trade-offs perturbs the economics of regulation*[55]—and we should see these effects as wholly analogous to the indirect-risk issues. Economists know this as the distinction between the simplistic analysis of compliance costs to the directly regulated firms, which they call "partial equilibrium," and the more complete analysis of these plus the other changes in prices charged, quantities demanded, labor employed, and capital amassed as the direct result of the compliance changes, which they call "general equilibrium."[56] Viewed as a conceptual oversimplification, the failure to consider the economic benefits of regulation is exactly parallel to the failure to consider the health harms of risk reduction.

FIGURE 1. GRAHAM-WIENER TYPOLOGY WITH EXAMPLES

*Risk*

|  | *Same Type* | *Different Type* |
|---|---|---|
| *Same* | Risk Offset<br><br>Stronger car roofs (reduced severity, increase (?) probability of a rollover) | Risk Substitution<br><br>Chlorination/cholera |
| *Different* | Risk Transfer<br><br>Intermedia pollutant transfers | Risk Transformation<br><br>CAFE standards/crashes |

*Population* (row label spanning *Same* and *Different*)

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53.    *See, e.g.*, Adam M. Finkel, *Emitting More Light than Heat*, *supra* note 19, at 131-32.

54.    *E.g.*, RISK VERSUS RISK, *supra* note 16; Samuel Rascoff & Richard Revesz, *The Biases of Risk Tradeoff Analysis: Towards Parity in Environmental and Health-and-Safety Regulation*, 69 U. CHI. L. REV. 1763 (2002).

55.    *See generally* Michael Hazilla & Raymond J. Kopp, *Social Cost of Environmental Quality Regulations: A General Equilibrium Analysis*, 98 J. POL. ECON. 853 (1990).

56.    *Id.* at 855.

## A. *Estimates of Risk Uncertainty*

Although a meta-analysis of the existing fragments of information relevant to quantifying the typical extent of risk uncertainty is beyond the scope of this Article, it is clear that uncertainty abounds in risk science.[57] The nature of risk estimates makes it unusual to be able to contrast predicted with observed human health outcomes. On the other hand, the uncertainty in some components of risk assessment can be estimated. Parameter uncertainty in population dose-response estimation, a key element in human health risk assessment, is amenable to some quantification. Perhaps the most informative such study was conducted more than twenty-five years ago by Allen et al., who estimated for various carcinogenic substances the potency uncertainties due to the imprecision either inherent in epidemiologic studies or toxicologic experiments.[58] Their study also shed further light on the accuracy of both methods by comparing the two different kinds of predictions for each substance to one another, for the twenty-three cases where evidence from both humans and laboratory animals exists to conduct the comparison.[59] Figure 2 (reproduced from Allen et al.[60]) shows that the 90th percentile confidence intervals for the potencies derived from epidemiology—the vertical error bars—range from about one order of magnitude to six or seven orders of magnitude. The confidence intervals from toxicology—the horizontal error bars—are generally somewhat narrower, but one or two of them also span nearly five orders of magnitude. In the same figure, the distance from the intersection point of each pair of error bars to the dashed, forty-five-degree line is a measure of the *additional* uncertainty contributed by the inability of investigations on one species (human or rodent) to predict the potency in the other species. This rodent-human uncertainty (notwithstanding decades of complaints about the folly of rodent toxicology, as in Whelan[61]) actually happens to be quite modest—perhaps a factor between five and twenty at most, and much less so on average given the rather remarkable pattern of scatter on both sides of the forty-five-degree line (the two parallel dashed lines I added to the Allen et al. diagram represent a rodent:human uncertainty of ten-fold). With this important set of chemicals as a template, the uncertainty in the potency of a

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57.     *See supra* note 32.

58.     Bruce C. Allen et al., *Correlation between Carcinogenic Potency of Chemicals in Animals and Humans*, 8 Risk Analysis 531 (1988).

59.     *Id.* By definition, this meta-analysis could not assess the model uncertainty due to the possible human irrelevance of rodent carcinogenicity findings, since it considered only substances with positive results in both rodents and humans.

60.     Allen et al., *supra* note 58, at 539.

61.     Elizabeth M. Whelan, *Stop Banning Products at the Drop of a Rat*, Insight, Dec. 1994, at 18.

new substance assessed either by epidemiology or toxicology might be approximated as roughly a factor of the geometric mean of (depending) the widths of the vertical or horizontal error bars, inflated further by a rough estimate of the uncertainty in the interspecies comparison.[62]

FIGURE 2. CENTRAL ESTIMATES AND UNCERTAINTY RANGES FOR
CARCINOGENIC POTENCY OF THE TWENTY-THREE
SUBSTANCES WHERE HUMAN AND ANIMAL
ESTIMATES ARE BOTH AVAILABLE
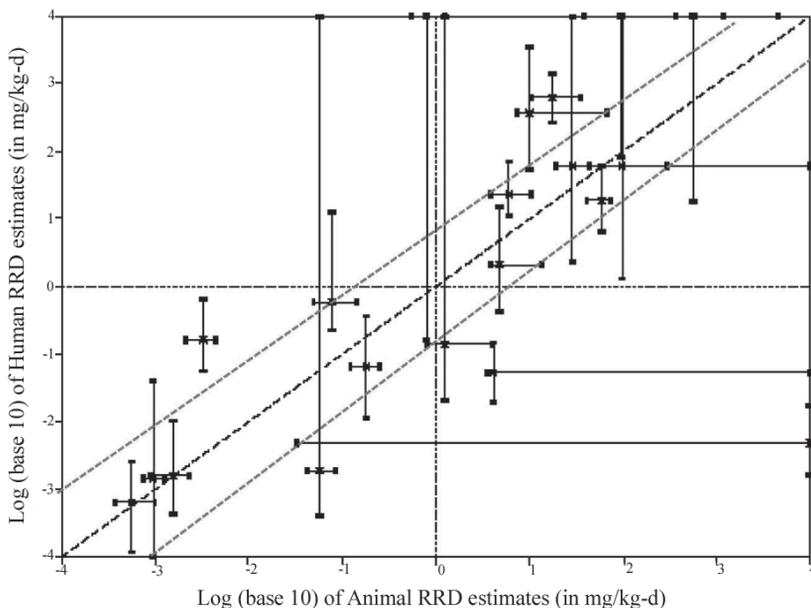


Note: The original figure first appeared in Allen et. al, *supra* note 58, at 539. The adapted version depicted here first appeared in Adam M. Finkel, *EPA Underestimates, Oversimplifies, Miscommunicates, and Mismanages Cancer Risks by Ignoring Human Susceptibility*, 34 RISK ANALYSIS 1785, 1789 (2014). The author thanks Allen et al. and the journal RISK ANALYSIS for allowing its reproduction here.

For clarity, the labels naming each substance have been removed; for example, the substance in the lower left corner and far above the 45-degree line is cadmium, for which both the confidence limits from toxicology and from epidemiology are rather small.

Much of this uncertainty presumably stems from the rather small sample sizes in epidemiologic studies of chemical carcinogens, and from the

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62.     If the underlying distributions from which these confidence intervals come are lognormal, then the correct way to propagate the two types of uncertainty would be to add the squares of their logarithmic standard deviations, and take the square root of the sum. For a lognormal whose 95th percentile is X-fold greater than its 5th percentile, the logarithmic standard deviation is (ln X/3.29).

even smaller samples inherent in laboratory bioassays. For a recent example of a thorough uncertainty analysis in human health that takes advantage of large human studies (and multiple such investigations), consider the U.S. Environmental Protection Agency's (EPA) report on the benefits of the 1990 Clean Air Act (CAA) Amendments.[63] That report concluded that for the year 2020, the 95th percentile estimate of avoided mortality (and to a much lesser extent, avoided morbidity) benefits from all CAA controls on fine particulate matter and other criteria air pollutants was $5.7 trillion, with a lower-bound (5th percentile) estimate of $250 billion.[64] This "factor of twenty-five" uncertainty comes predominantly from uncertainty in the concentration-response functions for $PM_{2.5}$ and some of the other pollutants, but also includes a smaller component of uncertainty (roughly a factor of two) due to the spectrum of reasonable estimates from stated-preference and revealed-preference studies of the value of a statistical life.

Examples such as these attest to the fact that there is substantial parameter uncertainty in risk science, but neither too little uncertainty to be safely ignored, *nor* so much uncertainty that we cannot make reasonable risk-based decisions. Larger, qualitative errors of course also plague risk assessment, with our evolving understanding of model uncertainty in specific cases suggesting that some prior beliefs were false positives (such as the initial concern that the artificial sweetener saccharin was a human carcinogen[65]), while others may have been false negatives (such as the growing concern that non-ionizing radiation from power transmission lines or cellphones may in fact be capable of causing adverse health effects[66]). Even larger errors may occur in risk assessment, if one accepts the view that small exposures to certain toxic substances may be beneficial to the health of some individuals,[67] and therefore that an estimate of positive benefit from a particular exposure reduction may mask a true effect that is actually of the opposite sign. As mentioned *supra*, when reducing one risk causes a different risk to increase, "errors of sign" can also occur. Graham and Wiener's 1995 book suggests a dozen or so cases where risk-reduction benefits may have been overstated,

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63. U.S. Envtl. Prot. Agency, The Benefits and Costs of the Clean Air Act from 1990 to 2020 (2011).

64. *Id.* at 7-9, tbl. 7-5.

65. *See* United States Department of Health and Human Services, National Toxicology Program, Report on Carcinogens 466-68 (2011).

66. *See* Press Release, World Health Organization, IARC Classifies Radiofrequency Electromagnetic Fields as Possibly Carcinogenic to Humans (May 31, 2011), http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf.

67. *See* Edward J. Calabrese & Linda A. Baldwin, *Hormesis: The Dose-Response Revolution*, 43 Ann. Rev. of Pharmacology and Toxicology 175 (2003); *but see* Kristina Thayer et al., *Fundamental Flaws of Hormesis for Public Health Decisions*, 113 Envtl. Health Persp. 1271 (2005).

and in a few of these cases—such as the asbestos remediation example—of the wrong sign.[68] As I will discuss in detail, risk assessors have worked diligently over the past twenty-five years to continually improve the honesty and transparency with which they strive to incorporate these various types of uncertainty into their work.

## B. *Estimates of Cost Uncertainty*

The raw material for cost estimation makes this side of the ledger more amenable than risk assessment is to retrospective evaluation; unlike changes in longevity, changes in wealth can be measured at the population and individual levels, and can often to a large extent be causally attributed to specific policy actions. There have only been a handful of surveys comparing ex ante predictions of regulatory cost to realized ex post values, however, and they reveal substantial uncertainty and potential for surprise. Probably the most comprehensive of these was a meta-survey conducted by Harrington, Morgenstern, and Nelson, who looked at twenty-five cases previously generated from roughly fifteen researchers or committees (notably, the eight OSHA cases developed by the Congressional Office of Technology Assessment in 1995[69]).[70] They found that the ratio of total predicted costs to total realized costs ranged from roughly one to one up to roughly twenty to one.

Unlike the case for risk assessment, the concept of false negatives and positives doesn't really apply to cost estimation, as zero risk (i.e., is the substance benign or harmful?) is not paralleled by a dichotomy of "zero cost" (i.e., does a policy intervention cost nothing or something?) However, the concept of "super uncertainty" (estimates of the wrong sign, yielding confidence limits with ratios less than zero), applies equally or more so in economics as compared to risk science. In some cases, industries have realized savings from regulations that required them to purchase pollution-control devices that improved production efficiency by more than the investment cost.[71] More generally, a partial-equilibrium analysis of regulatory cost can easily conclude that an intervention decreased overall economic welfare (that is, before health and environmental benefits are weighed against this negative change), whereas a general-equilibrium analysis of the same intervention might conclude that the policy increased overall

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68.     *See* Risk versus Risk, *supra* note 16, at 16.

69.     U.S. Congress, Office of Technology Assessment, OTA-ENV-635, Gauging Control Technology and Regulatory Impacts in Occupational Safety and Health: An Appraisal of OSHA's Analytic Approach (1995).

70.     Winston Harrington, Richard D. Morgenstern & Peter Nelson, *On the Accuracy of Regulatory Cost Estimates*, 19 J. Pol'y Analysis & Mgmt. 297 (2000).

71.     Eban Goodstein & Hart Hodges, *Polluted Data: Overestimating Environmental Costs*, The American Prospect, Nov./Dec. 1997, at 64.

economic welfare, even before considering health and environmental benefits. Very few general-equilibrium analyses exist that consider salutary effects on unemployed workers—which is probably the most logical way in which regulatory investments can benefit the overall economy—but that is not the only way regulatory economists can "get the sign wrong." Occasionally, market substitution can drive win/win outcomes, as apparently happened in the wake of the highly publicized withdrawal of the growth hormone Alar from the U.S. apple crop in 1989. The temporary difficulty that growers of Red Delicious and McIntosh apples had getting expected quantities to supermarket shelves the year after the withdrawal created a vacuum which other apple varieties (such as the Fuji and Gala) rapidly filled; when one looks at the entire U.S. apple market (rather than only the subset of growers who bore the costs), average price charged *and* quantity demanded both rose significantly in the several years immediately after the Alar withdrawal, indicating that both consumer and producer welfare increased.[72]

So, are costs more uncertain than risks are? Although it seems reasonable to conclude that there may tend to be greater quantitative uncertainties in risk than in cost, there may be equal or greater potential for qualitative errors in the sign of the cost estimate. With an eye toward the sources of uncertainty rather than just the magnitude, there is a fundamental asymmetry that further mitigates towards greater concern about cost uncertainty: risks are a characteristic of natural systems, whereas prices are a result of human interactions in markets. Put another way, risks are elusive, but at least they are not capable of intentionally changing their size, whereas costs can increase or decrease strategically and perhaps even in response to being studied! This extra dimension of game theory makes cost uncertainty more precarious, and therefore arguably more important to keep an eye on. In any event, it should be clear from this brief survey of the analytical landscape that both risk and cost are uncertain enough to merit serious, and roughly equivalent, efforts directed at understanding and accommodating them. No evidence to date, in my view, would support the view that cost uncertainty is so small relative to risk uncertainty that it can be treated casually or reserved for cases where more rigor "matters" (notwithstanding the illogic of asserting that one can know when uncertainty "matters," without already having estimated how much uncertainty there is).

There is another dimension to the question of relative importance, though, that tips the scales even further in favor of treating cost uncertainty with additional rigor and humility. Analysts really should be concerned not

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72.    Adam M. Finkel, *A Second Opinion on an Environmental Misdiagnosis: The Risky Prescriptions of Breaking the Vicious Circle*, 3 N.Y.U. Envtl. L. J. 295, 371 (1995).

just about which errors can affect predictions, but which errors can affect decisions. If the common decision criteria are relatively sensitive to errors of one type and robust to errors of the other, it makes no sense to concentrate on uncertainty in the latter type and downplay the former. *In regulatory arena after arena, costs turn out to matter as much or more than risks do, so our understanding of costs should at the very least match our understanding of risks.*

This statement is not meant to imply that a "dollar" in monetized risk reduction is less important, or even treated as less important, than a dollar of regulatory cost—it suggests only that, at the margin, where real decisions are constrained, "tipping points" of cost are often reached before tipping points of risk are. No regulatory arena captures this asymmetry more clearly than occupational safety and health regulation. Although the Occupational Safety and Health Administration (OSHA) is supposed to (and does) consider both costs and benefits, every health standard in its rulebook has been set at the point where marginal cost concerns reached a perceived threshold. The reason why every one of OSHA's health standards leaves behind a different level of residual risk[73] is that OSHA was unwilling to press for lowered (or common) risk levels in the face of concern that additional stringency would not be "economically feasible." For example, OSHA set the Permissible Exposure Limit (PEL) for formaldehyde at 0.75 ppm in 1992;[74] at that level, OSHA said there was considerable uncertainty about excess lifetime cancer risk.[75] Its cost analysis concluded that the most highly affected industry subsector, plywood manufacture, would face compliance costs of no more than five percent of its profits to control formaldehyde to 0.75 ppm, making that level economically feasible.[76] OSHA concluded, however, that a PEL of 0.5 ppm was not economically feasible.[77] So a potential change in the risk—one that was quite small relative to the assessed uncertainty in risk—was declared to be prohibitively costly, and yet no uncertainty analysis in cost was conducted to demonstrate how confident we should be in that rather emphatic conclusion. *If real decisions depend more*

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73.     Adam M. Finkel & P. Barry Ryan, *Risk in the Workplace: Where Analysis Began and Problems Remain Unsolved*, in Risk Assessment for Environmental Health 187, 205, tbl. 9.6 (Mark G. Robson & William A. Toscano eds., 2007).

74.     Formaldehyde, 29 C.F.R. § 1910.1048 (1992).

75.     *Id.* (OSHA's maximum likelihood estimate was $6 \times 10^{-6}$, with a 95th percentile upper bound of $2.6 \times 10^{-3}$.) *See also* Occupational Exposure to Formaldehyde, 57 Fed. Reg. 22,290, 22,291-92 (May 27, 1992).

76.     *See* Occupational Exposure to Formaldehyde, 57 Fed. Reg. 22,290, 22,302 (May 27, 1992) (projecting the total annual costs of the rule to be $660,291).

77.     *See* 29 C.F.R. § 1910.1048 (1992) (setting the PEL at 0.75 ppm, higher than 0.5 ppm).

*critically on when costs become intolerable than on when risks remain intolerable, nothing is more important analytically than being honest about the uncertainty in where that tipping point may occur.*

## VII.  Guidance:  How Are Federal Regulatory Agencies *Supposed* to Handle Cost Uncertainty?

The enthusiasm with which agencies confront uncertainty in regulatory cost, especially in contrast to how they handle uncertainty in risk, can best be gauged in two complementary ways—by examining what they say and evaluating what they do. The former is the arena of guidance, and the latter the realm of practice.

Although agency practice is conceptually simple to evaluate, there are multiple different types and sources of guidance, which I will parse into two main categories, the first one bifurcated further. The main division separates "internal" from "external" guidance, recognizing that an instruction an agency gives to itself likely reflects more knowledge of (and perhaps more deference to) institutional constraints than does advice proffered from outside the regulatory system. Tables 3a and 3b contain a chronological summary of major guidance statements about uncertainty in risk and cost produced from within the federal government: the first set of documents is produced by agencies themselves, and the second is produced by federal institutions with some responsibility to oversee agency activity (such as Congress, OIRA, the Supreme Court, and, in one special case, a blue-ribbon commission whose members were chosen by both the Clinton Administration and by both parties in Congress).[78] Table 4 then summarizes advice about regulatory risk and cost uncertainty initiated outside the federal system, generally by individual scholars or groups thereof. Because economists work on both sides of the benefit/cost firewall (valuing risk reductions as monetary benefits, and also estimating costs) (see Part I *supra*), I have added an additional column to Table 4 to capture how the environmental economics profession may tend to put a different emphasis on uncertainty in valuation versus uncertainty in cost.

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78.    PCCRAM, *supra* note 44.

Table 3a.  Guidance from Inside the Federal Agencies about Uncertainty in Risk and/or Cost

| Year | Document | Instructions about Uncertainty in Risk | Instructions about Uncertainty in Cost |
|---|---|---|---|
| 1992 | Memorandum from F. Henry Habicht, II, Deputy Administrator, U.S. EPA, to Assistant and Regional Administrators, U.S. EPA, Guidance on Risk Characterization for Risk Managers and Risk Assessors (Feb. 22, 1992). | "[T]he Agency's risk assessment guidelines call for full and open discussion of uncertainties in the body of each EPA risk assessment, including prominent display of critical uncertainties in the risk characterization." (p. 2) | None: "This memorandum does not give guidance on the use of completed risk assessments for risk management decisions, nor does it address the use of non-scientific considerations (e.g., economic or societal factors) that are considered along with the risk assessment. . . ." (p. 4) |
| 1997 | U.S. Environmental Protection Agency, EPA/630/R-97/001, Guiding Principles for Monte Carlo Analysis  (1997). | "[T]he basic goal of a Monte Carlo analysis is to characterize, quantitatively, the uncertainty and variability in estimates of exposure or risk." (p. 3)  The word "risk" is used 108 times in this document. | The word "cost(s)" is only meaningfully mentioned twice in the document, *viz.* "it may be unnecessary to perform a Monte Carlo analysis when the costs of remediation are low." (p. 5) |
| 2004 | U.S. Environmental Protection Agency, EPA/100/B-04/001, Staff Paper, An Examination of EPA Risk Assessment Principles and Practices (2004). | "EPA's policy is that risk assessments should not knowingly underestimate or grossly overestimate risks. This policy position prompts risk assessments to take a more 'protective' stance given the underlying uncertainty with the risk estimates generated." (p. 13) | Very little about cost, although section on Superfund risk assessment mentions that cost estimates for remedial alternatives "are expected to be accurate within a range of +50% to −30%." (p. 118) |
| 2005 | U.S. Environmental Protection Agency, EPA/600/R-04/195, Environmental Economics Research Strategy (2005). | | "In certain cases, expressed needs were determined to be for economic analysis and not research.  An example is cost estimates for specific rules. . ." (p. 2-1)  "Another request was for further guidance on translating private costs into social costs; . . . discussions on this topic are appropriate for the Economics Forum." (p. A2-3) |

## TABLE 3B. GUIDANCE FROM ELSEWHERE IN THE FEDERAL GOVERNMENT ABOUT UNCERTAINTY IN RISK AND/OR COST

| Year | Document | Instructions about Uncertainty in Risk | Instructions about Uncertainty in Cost |
|---|---|---|---|
| 1997 | PRESIDENTIAL/CONGRESSIONAL COMMISSION ON RISK ASSESSMENT AND MANAGEMENT (PCCRAM): RISK ASSESSMENT AND RISK MANAGEMENT IN REGULATORY DECISION-MAKING (1997). | "[M]any crucial economic policy decisions are made on the basis of point estimates of the gross domestic product, the unemployment rate, or the costs of major welfare or health care reform legislation, for example, without mathematical or even narrative descriptions of the considerable uncertainties." (p. 90) | "Cost estimates are also highly variable and imprecise, and they can vary according to the bias of the organizations affected . . . Given the assumptions and uncertainties, it is misleading to express the results of economic analyses as single numerical estimates of costs or benefits." (p. 98) |
| 1999 | Regulatory Improvement Act, S. 746, 106th Cong. (1999). | Entire §624 contains "Principles for risk assessments," including: identification of "significant assumptions" and their bases; estimating the "likelihood of such exposure scenarios"; and the presentation of "risk as one or more reasonable ranges, and, if feasible, probability distributions that reflects variabilities, uncertainties, and lack of data in the analysis." (pp. 17-21) | None—although both the risk assessment and any cost-benefit analysis must undergo peer review, and both benefit and cost estimates must include "a description of the persons or classes of persons likely to bear such costs." (p. 11) |
| 2003 | OFFICE OF MANAGEMENT AND BUDGET, CIRCULAR A-4, REGULATORY ANALYSIS (2003). | Agencies must "[d]isclose qualitatively the main uncertainties in each important input to the calculation of benefits and costs." (p. 41)<br><br>"Examples of quantitative analysis, broadly defined, would include formal estimates of the probabilities of environmental damage to soil or water, the possible loss of habitat, or risks to endangered species as well as probabilities of harm to human health and safety. There are also uncertainties associated with estimates of economic benefits and costs, such as the cost savings associated with increased energy efficiency." (pp. 39-40) | The document consistently refers in the same breath to uncertainty in both benefits and costs. However, the only road-map of what to consider is this example: "For example, in the analysis of regulations addressing air pollution, there is uncertainty about the effects of the rule on future emissions, uncertainty about how the change in emissions will affect air quality, uncertainty about how changes in air quality will affect health, and finally uncertainty about the economic and social value of the change in health outcomes." *Note that this list covers the major components of risk assessment and benefits valuation, but says nothing about regulatory cost.* (p. 41) |

TABLE 4. GUIDANCE FROM ENVIRONMENTAL ECONOMISTS ABOUT UNCERTAINTY IN RISK, VALUATION, AND/OR COST

| Year | Document | Instruction about Uncertainty in Risk | Instructions about Uncertainty in Valuation | Instructions about Uncertainty in Cost |
|---|---|---|---|---|
| 2000 | Proceedings of the Workshop on the Convergence of Risk Assessment and Socio-Economic Analysis to Better Inform Chemical Risk Management Decisions (May 1-2, 2000). | "Uncertainties in risk assessments, such as the level of confidence in a database or in a distribution, need to be stated clearly." (p. 44) | "[T]he uncertainty associated with estimates of willingness to pay should be explained to risk assessors and to policy-makers." (p. 44) | "Some participants felt that most of the uncertainty in an environmental economic assessment resides in the risk assessment and the estimates of environmental effects and consequences, not in the economic data." (p. 44) |
| 2006 | ALAN KRUPNICK ET AL., NOT A SURE THING: MAKING REGULATORY CHOICES UNDER UNCERTAINTY (2006) | "EPA should expand its institutional capacity for addressing and communicating uncertainty." (p. 226) | | "EPA should consider adding population uncertainties to its RIAs." (but not cost?) (p. 226) |
| 2004-2009 | Content analysis of the *Journal of Regulatory Economics*. | | | Of 178 total articles in this journal in this time period, only 4 discussed the effects of regulation on cost, and none of these were methods-development papers. |

This nearly thirty-year survey of resolutions and advice about uncertainty supports only one strong conclusion: long after risk uncertainty was accepted as a phenomenon that should not be swept under the rug, guidance about cost uncertainty lagged far behind, and indeed only recently began to catch up to where the rhetorical resolve to confront risk uncertainty was twenty years ago. Although the recent Institute of Medicine report "Environmental Decisions in the Face of Uncertainty" does give passing reference to cost uncertainty as one of several deficiencies to correct,[79] there is still no "Habicht Memorandum"[80] singling out cost uncertainty as a problem the EPA must confront; no subtitle in a piece of legislation dictating how agency economists should choose their models and interpret their data; and no "frontiers of environmental economics"[81] research agenda that treats uncertainty in cost as seriously as it treats controversy in estimates of the value of a longevity or an ecological benefit. In what may qualify as an "exception that proves the rule," the one prominent denunciation of single-point estimates of cost came from the 1997 Presidential/Congressional commission report.[82] However, that document is also a well-known exception in that it is, at the same time, unenthusiastic about reporting uncertainty in risk, so perhaps this doubly contradictory pair of recommendations can be attributed to the "one hand, other hand" vagaries of committee processes where sign-off is achieved by incorporating multiple viewpoints. In summary, to the extent that agencies follow their own guidance, or are eager to come into agreement with advice offered by scholars, those satisfied with point estimates of regulatory cost have had little to worry about for the past generation.

## VIII.  Practice: How are Federal Regulatory Agencies *Actually* Handling Cost Uncertainty?

In order to provide a more complete picture of the past and present practices regarding uncertainty in regulatory costs at U.S. federal agencies, I have developed a ten-level scoring system to grade the quality of such analyses, which I will apply in turn to three different time periods in the evolution of regulatory analysis. First, I will evaluate an influential EPA regulation from the 1980s and an important OSHA regulation from the 1990s, to contrast the treatment of risk and cost uncertainty at a time when

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79.    Institute of Medicine et al., Environmental Decisions in the Face of Uncertainty (2013).

80.    *Infra* note 168.

81.    *The Frontiers of Environmental Economics*, Resources for the Future (2007), http://www.rff.org/rff/Events/Frontiers-of-Environmental-Economics.cfm.

82.    PCCRAM, *supra* note 44, at 89.

these agencies were first making major efforts to improve the quality of their regulatory analyses. Next, I will report on the interesting results of scoring twenty-five EPA regulations issued in the 1990s, all of which two researchers had previously rated favorably on the desirable attribute of "presents a range of total costs."[83] Third, I will describe in detail the treatment of cost uncertainty and risk uncertainty in seven rules (and one retrospective program-evaluation study) from the EPA, OSHA, Food and Drug Administration (FDA), and National Highway Traffic Safety Administration (NHTSA), all but one of which were published within the past ten years.

## A. *Scoring System*

Table 5 presents, in ascending order of quality, ten discrete levels of analysis of uncertainty in regulatory cost. I believe this level of detail is the next step beyond most of the literature assessing the quality of regulatory analyses,[84] which have tended to score analyses via a checklist of dichotomous attributes (e.g., Does the analysis present net benefit estimates or doesn't it? Does the analysis evaluate multiple regulatory alternatives or only a single one?). My approach can be used with minor modification to grade the treatment of risk uncertainty, but it effectively isolates one attribute of quality: attention to cost uncertainty. It is therefore not suitable as a grading system for the analyses as a whole. On the other hand, it provides much more information about the quality of that one attribute than a dichotomous score possibly could. Indeed, I developed several of the specific levels in the ten-point hierarchy precisely because other researchers[85] had concluded that doing it only that well was equivalent to doing the most complete uncertainty analysis possible, at least insofar as a "Level 3" and a "Level 10" analysis would receive the same checkmark.

Perhaps the most salient feature of this hierarchy is that fully half of the gradations (Levels 1 through 5, inclusive) are not uncertainty analyses at all, but rather are various ways to present one or more point estimates, without actually considering the *imprecision* or incomplete knowledge that makes an estimate uncertain. Although there are different kinds of uncertainty, surely those that are endogenous to the regulation itself should be distinguished

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83.    *See* Robert W. Hahn & Patrick M. Dudley, *How Well Does the U.S. Government Do Benefit-Cost Analysis?*, 1 Rev. Envil. Econ. & Pol'y 199, 202 (2007).

84.    *See generally* Stuart Shapiro, *The Evolution of Cost-Benefit Analysis in U.S. Regulatory Decisionmaking*, Jerusalem Papers in Reg. & Governance (Working Paper No. 5, 2010), *available at* http://regulation.huji.ac.il/papers/jp5.pdf; Patrick A. McLaughlin & Jerry Ellig, *Does OIRA Review Improve the Quality of Regulatory Impact Analysis? Evidence from the Final Year of the Bush II Administration*, 63 Admin. L. Rev. (special edition) 179 (2011); *see infra* note 106.

85.    *Supra* note 84.

TABLE 5. HIERARCHY OF HOW A REGULATORY IMPACT ANALYSIS COULD DEAL WITH UNCERTAINTY IN REGULATORY COST

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|---|---|
| 1. | Point estimate of total cost (TC) only, with no mention of the word "uncertainty" |
| 2. | Point estimate of TC, but with narrative caveat about its uncertainty (with or without actually using the word "uncertainty"—the narrative might say, for example, that "this regulation is expected to cost $567 million annually, but the true cost might be higher or lower than that.") |
| 3. | Two or more point estimates of TC, because the RIA considers two or more *different* regulatory interventions. |
| 4. | Two or more point estimates of TC, because the RIA considers two or more mutually exclusive scenarios about how the regulated entities will comply with the regulation. (note—perhaps "level 4A" would be an RIA that has both multiple interventions and multiple scenarios, as in the EPA Regional Haze RIA) |
| 5. | A "quasi-range" for TC (it looks like a range, but in fact is composed of the multiple point estimates from level 3 or 4, connected with a hyphen to look like an actual statement about lower/upper bounds due to uncertainty). |
| 6. | A statement of uncertainty in TC derived from a rule of thumb (e.g., "the point estimate plus or minus 20 percent") (note: as in the EPA non-road diesel RIA) |
| 7. | A statement of uncertainty in TC derived by fitting different estimates to a distribution. |
| 8. | A partial Monte Carlo analysis of uncertainty in TC (in general, combining assumed uncertainties in only a couple of key input variables). |
| 9. | An elaborate Monte Carlo analysis of parameter uncertainty in TC (note: as in the Stavins et al. unpublished re-analysis of the non-road diesel RIA, *infra* note 121) |
| 10. | An elaborate Monte Carlo analysis of uncertainty in TC, *plus* multiple models for estimating costs, with or without expert elicitation of the weights that could be applied to the probability of each model being correct. |

from those that stem from our inability to discern how natural systems or external actors will behave. The latter can be reduced via research, while the former can be eliminated by simply deciding what one is actually analyzing. For example, a "Level 3" uncertainty analysis would present two or more point estimates of cost, not because of uncertainty in how expensive the regulation would be, but because the agency had not yet decided what the regulation would actually require (or was leaving it up to other actors to decide). In reality, the agency is simply presenting two (or more) point estimates within the same document—with no acknowledgment of uncertainty. However, an evaluator scoring this analysis might well notice the two disparate point estimates and applaud the agency for informing stakeholders about "uncertainty."[86] Even more unfortunately, if the agency repackages the two (or more) point estimates into what appears to be a range

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86.     *See infra* Section VIII(D)1.

(that is, reporting "[lower-higher]" in brackets rather than as two different estimates explained as the results of a yet-to-be-determined choice about regulatory scope), it is possible to confuse "range" with an actual statement about the bounds of a single quantity made imprecise by true uncertainty.

Levels 6 to 10 of the hierarchy correspond to increased levels of detail, creativity, and thoroughness in quantifying sources of uncertainty. Of course, the entire system can easily be recast with "risk" replacing "cost" in every instance, and used to grade the rigor of any risk characterization document with respect to uncertainty.

## B. *"First-Generation" Baseline of Agency Analyses of Cost and Risk Uncertainty*

In this section, I examine two influential regulations—one final rule, and one proposed rule that was not promulgated in its proposed form—both of which represent some of the first attempts by two major human health risk assessment agencies (EPA and OSHA) to conduct detailed QRAs. These examples establish a strong finding: for several decades or more, these agencies have successfully quantified uncertainty in risk using computationally and theoretically advanced methods. At the very same time, however, these agencies were generally paying no attention whatsoever to uncertainty in cost.

### 1. 1986 EPA Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions[87]

Nearly thirty years ago, the EPA was already facile with Monte Carlo analysis.[88] In order to back-calculate the concentrations of various toxic substances in leachate from hazardous waste sites that would be expected to exceed regulatory concentration limits in groundwater and surface water used for drinking, the EPA derived pdfs (some normal or lognormal, some uniform or $\log_{10}$ uniform, and some exponential) for roughly a dozen uncertain parameters of a fate-and-transport model, and proposed to base levels

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87.     Hazardous Waste Management System: Land Disposal Restrictions, 51 Fed. Reg. 1602 (Jan. 14, 1986) (codified at 40 C.F.R. pts. 260-62, 264-65, 268, 270-71).

88.     Monte Carlo simulation is a computational technique, first developed after World War II, which gauges the uncertainty in an unknown quantity by repeatedly drawing random samples from each of the variables that combine to produce the quantity. For example, the estimate of E will be uncertain when the estimates of m and c are uncertain (in the famous equation $E=mc^2$). If the analyst can specify the uncertainties in m and c, she can derive the uncertainty in E by arraying the results of many "simulations" of random values of m and $c^2$ multiplied together. *See, e.g.*, David M. Driesen, *Cost-Benefit Analysis and the Precautionary Principle: Can They Be Reconciled?*, 2013 MICH. ST. L. REV. 771, 781 (2013).

of regulatory concern on the 90th percentile of the output distribution.[89] It also proposed to allow facilities to use alternative modes of treatment other than land disposal if a comparative risk analysis, using Monte Carlo methods for assessing both treatment and disposal, showed that the cumulative distribution function (CDF) of the alternative was not significantly riskier than the disposal option. But, for its analysis of regulatory cost, the EPA presented an annualized cost estimate of $1.3 billion, with no consideration of uncertainty.[90]

### 2. 1997 OSHA Methylene Chloride (MeCl$_2$) Rule[91]

This final health standard contained an extremely detailed, wide-ranging, and transparent analysis of the uncertainty in the carcinogenic potency of MeCl$_2$.[92] OSHA performed an elaborate Bayesian Monte Carlo analysis[93] of the uncertainty in the physiologically-based pharmacokinetics of how mice metabolize MeCl$_2$, using prior pdfs for thirty-one different parameters (e.g., compartmental blood flows, tissue volumes, tissue:air partition coefficients, Michaelis-Menten metabolic parameters for the two competing enzymatic pathways) derived from a meta-analysis of available literature. It then updated these density functions using empirical Bayes estimation in light of in vivo kinetic data from chamber studies of mice exposed to various concentrations of MeCl$_2$. This procedure also accounted for all covariances among parameters, a computationally very complex refinement for 1997.[94] OSHA then derived a pdf for human pharmacokinetics, using human in vitro and in vivo data to calibrate the model.[95] OSHA

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89.    Hazardous Waste Management System: Land Disposal Restrictions, *supra* note 87, at 1623-31.

90.    EPA did present a range of from $93 to $154 million for a small offset of this cost (the savings petitioners might realize through successful applications for variances), by considering different assumptions for the cost of filing a petition and the probability that a random petition would be granted. *Id.* at 1742, 1746.

91.    Occupational Exposure to Methylene Chloride, 62 Fed. Reg. 1,494 (Jan. 10, 1997) (codified at 29 C.F.R. pts. 1910, 1915, 1926).

92.    *Id.* OSHA does not put a priority on assessing uncertainty in exposure, because its health standards set the new (enforceable) exposure limit directly as a point estimate, and under the Supreme Court *Benzene* decision, OSHA needs only to show that some exposures under prevailing conditions pose a "significant risk of material health impairment." Indus. Union Dep't, AFL-CIO v. Am. Petroleum Inst., 448 U.S. 607, 639 (1980).

93.    Adding Bayesian analysis to a Monte Carlo simulation basically means combining prior beliefs about the uncertain random variables involved with the results of experiments on some or all of those variables, so as to adjust their distributions before drawing the random values from them.

94.    *See* Frédéric Y. Bois, *Analysis of PBPK Models for Risk Characterization*, 895 ANNALS N.Y. ACAD. SCI. 317, 319 (1999).

95.    Occupational Exposure to Methylene Chloride, *supra* note 92, at 1535.

further handled model uncertainty in several different ways: (1) it presented estimates both from PBPK analysis of potency and from potency derived by allometric (body weight and surface-area) scaling, while explaining in detail why it concluded that the PBPK approach yielded more defensible estimates in this case;[96] (2) it presented separate results for two theoretical variants on the PBPK model (one in which the mouse physiologic parameters were allowed to vary across the different dose groups in the $MeCl_2$ carcinogenicity bioassay, and one in which they were assumed to be dose-independent), while explaining its preference for the former assumption;[97] and (3) it explained in great detail why it was unconvinced by a series of recent journal articles claiming that rodent tumors were irrelevant to human risk due to a purported fundamental biochemical difference between rodents and humans.[98] OSHA described the end result of all this analysis as a CDF for excess lifetime cancer risk at the new PEL for $MeCl_2$ of twenty-five ppm.[99] That CDF demarcates a factor of forty-five uncertainty separating the 95th percentile upper bound (a risk of roughly $3.6\times10^{-3}$) from the 5th percentile (roughly $8\times10^{-5}$).[100]

In contrast, the $MeCl_2$ cost analysis concluded, in its entirety, that: (1) the regulation will cost American industry exactly $101,463,037 per year;[101] (2) the most-affected industry sector—furniture stripping—would face compliance costs equal to exactly 2.04 percent of sales revenue;[102] and (3) the most heavily-affected small businesses—certain manufacturers of flexible polyurethane foam—would face costs equal to 60.3 percent of their profits, but that a price increase of 2.1 percent in this subsector would suffice to fully restore profits to pre-rule levels.[103] The word "uncertainty" does not appear anywhere in the cost section of the regulation or the accompanying analyses; the only hint of any "wiggle room" in the nine-significant-figure total cost estimate is found in one paragraph, explaining that "[i]t is important to understand that OSHA's methodology tends to overstate the economic impacts of the standard."[104]

Most importantly for the purposes of this Article, having completed all the uncertainty analysis in risk, OSHA acknowledged that "only feasibility has constrained the Agency from reducing the eight-hour time-weighted

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96.     *Id.* at 1556-59.
97.     *Id.* at 1547.
98.     *Id.* at 1520-22.
99.     *Id.* at 1555.
100.    *See id.* at 1555-56.
101.    *Id.* at 1567, tbl.VIII-4.
102.    *Id.* at 1567-68, tbl.VIII-5.
103.    *Id.* at 1570, tbl.VIII-6.
104.    *Id.* at 1568.

average (TWA) PEL in the final rule . . . because even at ten ppm, the risk remaining is significant."[105] In other words, even if the true risk was higher, or a factor of forty-five (or even more) below the level estimated in the potency analysis, OSHA would still have promulgated a twenty-five ppm PEL, because that was the lowest feasible level. The gaping unanswered question is, "how confident can or should OSHA have been that twenty-five ppm was exactly the lowest feasible level?" Only the unperformed analysis of uncertainty in cost could have shed light on this pivotal question.

In terms of the ten-level hierarchy mentioned *supra*, I would conclude that the treatment of cost uncertainty in the EPA leachate analysis merited a score of 1, or perhaps a 2 if one credits the single sentence about possible cost overestimation as a "narrative caveat about uncertainty." The OSHA cost analysis merits a score of one. In light of the Monte Carlo analysis of dose-response, plus the various elaborations on model uncertainty, the MeCl$_2$ risk analysis clearly merits a score of ten for risk uncertainty; the EPA risk analysis would receive a score of at least eight. *The contrast could not be much more stark.*

## C. *Scoring of Twenty-Four EPA Rules from the 1990s*

In order to make a much more general observation about the treatment of cost uncertainty during the recent past, I re-examined what is probably the most thorough scoring of the quality of regulatory impact analyses (RIAs) produced before 2000—the series of articles by Hahn and Dudley.[106] These researchers dissected seventy-four RIAs produced by the EPA during the Reagan, Bush Sr. and Clinton administrations, which they indicate re-present all available RIAs from EPA during that period.[107] Notably, Hahn and Dudley concluded that one-third of the rules (twenty-five of seventy-four) "provided a range estimate of total costs,"[108] which would certainly suggest that EPA was acknowledging and quantifying cost uncertainty routinely, if not across-the-board, during the late 1980s and throughout the 1990s.

A careful look at these twenty-five praiseworthy analyses, however, reveals quite a different picture. As Figure 3 shows, only a single one of the twenty-five EPA analyses scored higher than five of ten in the scale I devel-

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105.    *Id.* at 1580.

106.    Robert W. Hahn & Patrick M. Dudley, *How Well Does the U.S. Government Do Benefit-Cost Analysis?*, 1 REV. ENVTL. ECON. & POL'Y 192 (2007); Robert W. Hahn & Patrick M. Dudley, *How Well Does the U.S. Government Do Cost-Benefit Analysis?* (AEI-Brookings Joint Ctr. For Regulatory Studies, Working Paper No. 04-01, 2004).

107.    Robert W. Hahn & Patrick M. Dudley, *How Well Does the U.S. Government Do Benefit-Cost Analysis?*, 1 REV. ENVTL. ECON. & POL'Y 192, 199 (2007).

108.    *Id.*

oped *supra*.[109] Assuming reasonably that none of the forty-nine rules Hahn and Dudley scored negatively on "provided a range estimate of total costs" quantified uncertainty at all, this revised tally of one of seventy-four suggests that only roughly one or two percent of the time did EPA do more to acknowledge cost uncertainty than to present a "quasi-range." Considering all twenty-four rules, the average score on my one-to-ten scale was 3.68, and there was no improvement when comparing the eight analyses issued in the 1980s (having an average score = 3.75) to the seventeen rules issued in the 1990s (having an average score = 3.65).

FIGURE 3. COST UNCERTAINTY SCORING OF EPA REGULATIONS PRESENTED IN THIS ARTICLE



Treatment of Uncertainty in 25 Regulations that "Presented a Range of Total Costs"
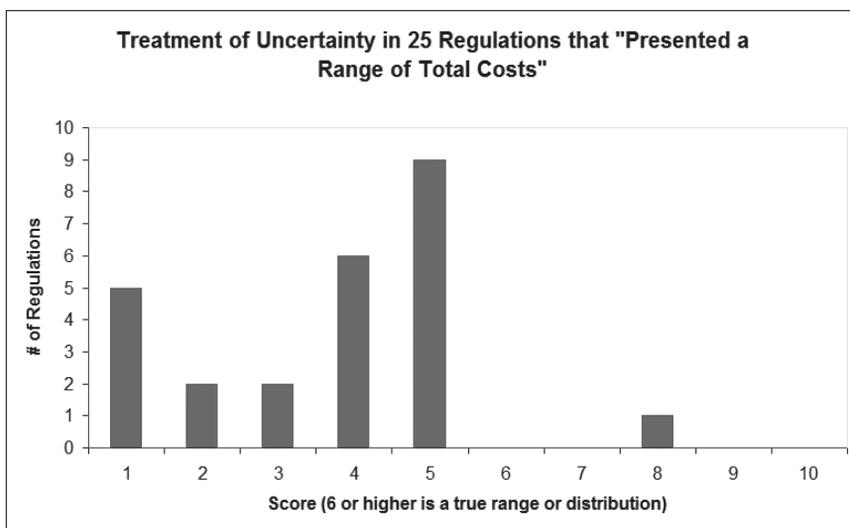
Why the discrepancy between Hahn and Dudley's dichotomous scoring and this ten-point scale, on which twenty-four of the twenty-five "positive" analyses failed to address uncertainty? In a few cases, I think Hahn and Dudley may have confused disaggregated point estimates with a "range." For example, in a 1998 rule setting emission standards for locomotives, the EPA subdivided the total cost estimate by three different categories of locomotives, despite the fact that this was clearly not an expression of uncertainty. In most cases, the issue involved mistaking multiple point

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109.     The outlier was a 1992 rule under the Safe Drinking Water Act, in which EPA conducted a simple Monte Carlo analysis in cost. By considering the uncertainty in each of several variables, EPA concluded that although the best estimate of regulatory cost was $46 million per year, the cost could reasonably be as low as $1 million/yr. or as high as $128 million/yr. Drinking Water 57 Fed. Reg. 31,776, 31,831-32 (July 17, 1992).

estimates—whether expressed as such or with the lowest and highest estimates packaged into what appears to be a range estimate—as expressions of incertitude when in fact they were expressions of *indecision*. As Section VIII(A) *supra* discusses, a statement indicating that "costs are estimated between $X and $Y" certainly can appear to be a conclusion about the imprecision of EPA's ability to forecast cost, but it can also be something else entirely. Several times in this sample, EPA produced two incompatible but infinitely precise point estimates of what it would cost for each of two alternative regulatory requirements that it or its state agencies with delegated implementation authority *had not yet chosen between*, and either presented the two estimates together or packaged them into an [$X-$Y] "quasi-range." This is akin to saying "it will take as little as six hours to drive to Disneyland, or as many as forty-six hours to drive to Disney World, depending on which destination we choose," and then having someone interpret that "range" between six and forty-six hours as an indication of how uncertain the road and traffic conditions will be. In other cases, EPA believed it could not resolve a fundamental ambiguity about how industry would choose to comply with the regulatory requirements, and presented two different cost estimates; this is in some sense a reflection of true uncertainty, but not in the sense of imprecision that more data could reduce. Even if we expand the definition of uncertainty to encompass not knowing which of two behavioral responses to regulation will predominate, surely packaging the two contingent estimates into a range conveys incorrectly the impression that all cost values between the two endpoints are possible, and perhaps even equiprobable (as a uniform distribution of uncertainty would denote).

Until very recently, therefore, while the typical treatment of risk uncertainty continued to improve and become more rigorous, the treatment of cost uncertainty had rarely improved beyond depictions that arguably were even less informative than a single point estimate would have been. At least a single cost figure expressed with eight to ten significant digits can be interpreted as "what they conclude when they don't even want to think about error."

## D. *Scoring of Selected EPA, OSHA, FDA, and Department of Transportation (DOT) Rules from 1999 and Forward*

In this section, I will review, in chronological sequence, selected environmental, health, and safety regulations issued by EPA, OSHA, FDA, and DOT in recent years, in order to gauge newer developments in the treatment of uncertainty in regulatory cost. I did not attempt an exhaustive or random sample of regulations from these four agencies (except in the case of OSHA, which only issued one relevant worker health standard between

2001-2010), but I did contact high-ranking career officials who steered me to these rules as examples of the regulatory impact analyses they were most proud of.

### 1. EPA Regional Haze Rule[110]

In 1999, EPA published an extensive CBA on a rule to reduce regional haze and provided "uncertainty in net benefits" estimates.[111] EPA offered four different "ranges" for net benefit, corresponding to two different possible enforcement regimes—either controlling sources of haze to attain an absolute improvement of one "deciview" in visibility or attaining a relative improvement of five percent over the baseline—and two different levels of stringency for each measure.[112] However, each "range" between the low-end and high-end estimates was constructed by subtracting a *point estimate* for cost from either an upper-bound or a lower-bound estimate of benefit.[113] The document states that "the expected annual control cost nationwide in 2015 . . . ranges from between $0 to a maximum of $4.4 billion,"[114] but as with so many of the EPA rules in the previous section, this is a "quasi-range," consisting of the highest and lowest value from the four mutually-exclusive scenarios, further extended by conflating uncertainty and variability. The "range" includes sub-costs for each of six U.S. regions, which explains how the lower bound can be zero—it is a point estimate under one scenario for one part of the country only.

### 2. EPA Non-Road Diesel Rule[115]

This 2004 rule (controlling emissions from diesel engines in agricultural and other off-road vehicles) is among the first, to my knowledge, where EPA actually imposed a quantitative uncertainty bound on total cost.[116] EPA presented a table of five previous regulations where it had predicted ex ante various increases in the price of gasoline or diesel fuel, and noted that ex post, the predictions were all overestimates, by a trivial

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110.     U.S. Envtl. Prot. Agency, Regulatory Impact Analysis for the Final Regional Haze Rule (1999).

111.     *Id.*

112.     *Id.* at 10-4, tbl. 10-3.

113.     *Id.*

114.     *Id.* at 6-3.

115.     U.S. Envtl. Prot. Agency, Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines (2004).

116.     The only counter-example I could find was the 1992 drinking water rule described *supra* in note 109.

amount up to a factor of 2.2.[117] EPA concluded: "given the uncertainty in estimating costs, we believe it is appropriate to consider the potential for both overestimation and underestimation,"[118] and took its point estimate of total cost and added a plus/minus twenty percent error bound to it.[119] This uncertainty is objectively smaller than previous real cases of "surprise,"[120] and I am at a loss to explain why it is symmetric—i.e., why it allows for both underestimation and overestimation, when all the previous cases considered were exclusively of the latter type—but at least it is less overconfident than a point estimate.

Interestingly, EPA contracted with Stavins et al. after the rule was published to conduct a much fuller treatment of cost uncertainty.[121] In that document, the consultants performed a fairly elaborate Monte Carlo simulation, including distributional assumptions for the cost per improved diesel engine (based on a regression equation of engine displacement on price), the historical uncertainty in the cost of the platinum catalyst needed, the "progress ratio" of technological learning in previous cases (which itself is uncertain), and other factors. They concluded with ninety-five percent confidence that the total cost would be between 1.7 times the mean estimate and (1/1.7th) of it (that is, a lognormal uncertainty), as compared to EPA's +/- 20 percent estimate.[122] In my opinion, this unpublished consultant's report still represents one of the best—and, perhaps, the single best—cost uncertainty analysis done by or for EPA.

### 3. Resources for the Future (RFF) Analysis of the EPA Clean Air Interstate Rule (CAIR)

Krupnick et al. at Resources for the Future (RFF) wrote a report in 2009 about how EPA should better quantify uncertainty.[123] The centerpiece of the report was a "mock briefing" to senior EPA management about the costs and benefits of a regulation based closely on CAIR.[124] Figure 5-3 in the RFF document presents a "probability density function for net benefit,"

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117.   CONTROL OF EMISSIONS FROM NONROAD DIESEL ENGINES, *supra* note 115, at 9-59, tbl. 9-21.

118.   *Id.* at 9-59.

119.   *Id.* at 9-60.

120.   *See* James K. Hammitt & Alexander I. Shlyakhter, *The Expected Value of Information and the Probability of Surprise*, 19 RISK ANALYSIS 135, 136 (1999).

121.   Robert N. Stavins, Judson Jaffe, Peter Hess, Edmund Crouch, Laura Green, and Shailesh Sahay, Monte Carlo Analysis: An Introduction to and Application of Formal Quantitative Assessment of Uncertainty in Regulatory Impact Analysis (2004) (unpublished manuscript) (on file with the author).

122.   *Id.* at 20.

123.   NOT A SURE THING, *supra* note 32.

124.   *Id.* at 203-17.

but the accompanying table of data makes clear that the "uncertainty" in net benefit takes no contribution from cost; *it is a pdf for benefit less a single point estimate for cost*. At least at this point in time, the nation's preeminent think-tank for environmental economics was advising EPA that, not only could it safely ignore uncertainty in cost, but it could present half an uncertainty distribution as a complete one.

### 4. OSHA Chromium-6 Regulation[125]

This RIA is essentially unchanged in its treatment of uncertainty from the methylene chloride rule made nine years before. The risk assessment is ornate, with ten different sets of confidence intervals from the epidemiology of chromium-6 and lung cancer (including two different models (relative-risk and additive-risk), two different reference populations, and two different ways of grouping exposures, plus two other models that did not depend on the reference or grouping choice).[126] Meanwhile, the cost assessment is presented as precise to nine significant figures (a total annualized cost of $282,365,793),[127] and the only nod to uncertainty in cost is the use of two mutually exclusive discount rates (3 percent and 7 percent).[128]

### 5. FDA Dietary Supplements Rule[129]

At essentially the same period that EPA and OSHA were presenting single-point estimates for regulatory cost,[130] FDA was undertaking Monte Carlo analyses on both sides of the ledger.[131] In its 2007 rule on dietary supplements, FDA presented a benefits estimate for imposing good manufacturing practices (GMPs) on makers of supplements that ranged (with a 90 percent credible interval) from $36 million per year to $54 million per year;[132] the uncertainty was primarily due to lack of knowledge about what percent of total illnesses due to contaminated supplements was actually being reported.[133] At the same time, FDA considered uncertainties in the cost per test to verify purity of the products, in the number of establishments

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125.    Occupational Exposure to Hexavalent Chromium, 71 Fed. Reg. 10,100 (Feb. 28, 2006) (codified at 29 C.F.R. pts. 1910, 1915, 1917, 1918).

126.    *Id.*

127.    *Id.* at 10,267, tbl. VIII-4.

128.    *Id.* at 10,263, 10,267, 10,308.

129.    Current Good Manufacturing Practice in Manufacturing, Packaging, Labeling or Holding Operations for Dietary Supplements, 72 Fed. Reg. 34,752 (June 25, 2007) (codified at 21 C.F.R. pt. 111).

130.    *See supra* notes 115, 125.

131.    *Id.* at 34,936.

132.    *Id.* tbl. 32.

133.    *Id.* at 34,936.

that would have to comply with GMP, and in the mean number of different batches each establishment would have to test, and came up with a range of predicted costs that extended from $109 million per year to $260 million per year.[134] Although FDA almost exclusively used two- or three-category discrete variables in this analysis, assigning equal probability to each possible realization of each input (for one variable, the uncertainty in the cost of each test, FDA used a continuous (beta) distribution),[135] it is nevertheless among the earliest probabilistic treatments of cost uncertainty from within a health and safety regulatory agency.

### 6. NHTSA Electronic Stability Control (ESC) Rule[136]

This rule from 2007 has an elaborate Monte Carlo analysis[137] of both benefits—including lives saved, traffic delays lessened, and property damage averted—and costs, and presents both 90 percent confidence intervals and "total ranges" (i.e., 100 percent confidence bounds) for each. However, the uncertainty in cost turns out to be limited to one factor—the cost of antilock brakes and ESC for the vehicles that need them (the number of such vehicles is assumed to be known precisely)[138]—and that uncertainty is simply asserted to be "+/- 10 percent." Thus, the total range for costs is simply the mean total cost of $985 million plus or minus $98 million, which yields the reported range of [$889 - $1082 million].

### 7. NHTSA Corporate Average Fuel Economy (CAFE) Standard[139]

By the next year (2008), NHTSA had made its uncertainty analysis in cost significantly more rigorous. Here, it looked at forty-one different tech-

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134.   *Id.* Although in this case the pdf for cost statistically dominated the pdf for benefit, FDA made the case that there were a large number of categories of "unquantifiable benefits" that together justified this rule despite the unfavorable sign of [B-C].

135.   *See id.* at 34,932.

136.   U.S. Dep't. Transp., FMVSS No. 126, Nat'l Highway Traffic Safety Admin.: Electronic Stability Control Systems (2007).

137.   *See id.* at section VIII.

138.   Actually, this is a deficiency in the analysis worth noting: NHTSA explains that "Although vehicle sales have gradually increased over time, they are subject to annual variation due to changes in economic conditions, which are difficult to predict. Thus, the number of vehicles ($v_i$) is treated as a constant." *Id.* at VIII-12. I think an uncertainty analyst would instead have written ". . . which are difficult to predict. Thus, the number of vehicles is treated as a uniform pdf between the lowest and highest previous values for annual sales", or something similar.

139.   U.S. Dep't. Transp., Nat'l Highway Traffic Safety Admin., Preliminary Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks (2008).

nologies to increase fuel efficiency and gathered data on the full range of published cost estimates for each.[140] NHTSA assumed that the range represented +/- three standard deviations from the mean (Gaussian distribution), and through Monte Carlo simulation derived a total cost estimate (for buyers of model year 2015 cars) of between approximately $10.940 and $19.842 billion (with a 90 percent confidence interval).[141]

## 8. FDA Shell Egg Rule[142]

This final rule from 2009 contains a Monte Carlo analysis for both costs and benefits, of roughly equal complexity. On the cost side, FDA looked at nine different contributors to the total cost of the rule, and modeled the uncertainty in each, to yield an overall cost estimate of between $57.5 million and $116.5 million per year[143]—the largest contributor to cost uncertainty being the difficulty pinning down how many egg production facilities were experiencing problems controlling rodents on-site, and hence how many would have to invest in new controls.[144]

## 9. EPA Portland Cement National Emission Standards for Hazardous Air Pollutants (NESHAP)[145]

In 2009, EPA presented an RIA for the net benefits of this major rule, and again made it appear that it had considered the major uncertainties.[146] Figure 4 shows fourteen different values for net benefit (each under two scenarios of the discount rate), but the legend reveals that the spectrum comes from fourteen different risk estimates "minus *the* cost estimate" (emphasis added).

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140.    *Id.*

141.    *Id.* at X-19.

142.    Prevention of Salmonella Enteritidis in Shell Eggs During Production, Storage, and Transportation, 74 Fed. Reg. 33030 (July 9, 2009) (to be codified at 21 C.F.R. pt. 16, 118).
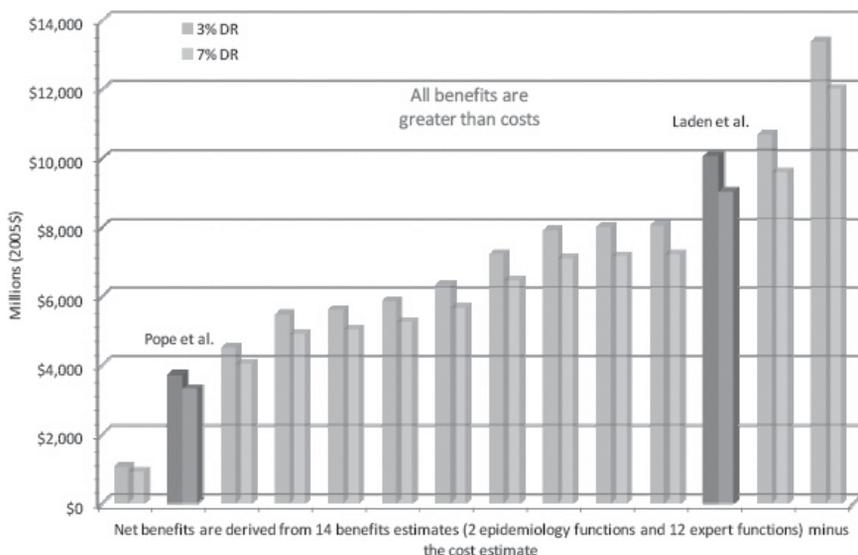
143.    *Id.* at 33,081-87.

144.    *Id.* at 33,083.

145.    RTI Int'l, Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry (2009).

146.    *Id.* at 5-12 – 5-14.

FIGURE 4.  MISLEADING DEPICTION OF UNCERTAINTY IN NET
BENEFITS (FROM THE EPA PORTLAND CEMENT
NESHAP (2009))



Net benefits are derived from 14 benefits estimates (2 epidemiology functions and 12 expert functions) minus the cost estimate

## 10.  EPA Clean Air Act CBA

One of EPA's most recent major analyses of regulatory costs and benefits—the 2011 study estimating all the health, environmental, and economic impacts of the 1990 Clean Air Act Amendments (CAAA) up to the year 2020—represents an excellent example of the disparity between the treatment of scientific uncertainty as opposed to economic uncertainty.[147] The vast difference between the width of the confidence intervals for benefit and for cost provides a strong hint that commensurate attention was not paid on each side of the benefit/cost ledger. Indeed, in the summary table of benefits and costs (on the third unnumbered page of the document), the annual monetized benefits estimated for the year 2020 range from $250 billion (a 5th percentile estimate) to $5.7 trillion (a 95th percentile estimate)—a large "uncertainty ratio" of twenty-three-fold—while the cost estimate for 2020 of $65 billion is presented with no uncertainty whatsoever. One has to turn to Chapter 3 to discover that EPA did consider four specific "tweaks" to the total cost estimate as a rudimentary sort of sensitivity analysis of cost uncertainty[148]: (1) if localities were to cap the controls they

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147.     *See* U.S. ENVTL. PROT. AGENCY, THE BENEFITS AND COSTS OF THE CLEAN AIR ACT FROM 1990 TO 2020 (2011).
148.     *Id.* at 3-11 – 3-19.

required at $10,000 per ton of ozone or fine particles removed (rather than the $15,000/ton cap EPA assumes they will apply as the base case), the costs of all local controls would drop by about $3.6 billion in 2020; (2) if volatile gasoline prices cause consumers to shift to more fuel-efficient vehicles at a higher rate than assumed in the base case, the cost of CAAA controls on motor vehicles could be about $1 billion less than assumed; (3) if EPA's base case greatly overestimated the rate at which passenger cars would fail state inspection tests, the costs of CAAA controls to upgrade vehicle emissions systems could be about $3.4 billion less than assumed; and (4) if, instead of the base case "learning rate" (10 percent per year) at which the costs of certain control technologies would decline as industry gained experience, EPA instead assumed a 20 percent learning rate, the total costs of CAAA controls in 2020 would decline by $4 billion over the base case. If, instead, EPA assumed a more pessimistic 5 percent learning rate, the total costs would increase by about $2 billion.

Table 3-3[149] in the report does not provide any information about the possible combined effects of these four alternate assumptions, but if one treats them all as independent, the minimum total cost in 2020 would be approximately $12 billion less than the base case ($3.6 + $1 + $3.4 + $4 billion in decrements), and the maximum total cost would be about $2 billion more than the base case (if the one source of cost underestimation was invoked), for a range of $53 billion to $68 billion. This represents an "uncertainty ratio" of only 1.3-fold, as compared to the twenty-three-fold ratio for benefits uncertainty.

Obviously, just being at least twenty times more confident about a cost estimate than about the corresponding risk and benefits estimate does not necessarily reflect overconfidence or carelessness about cost. Perhaps we actually can be at least ninety percent confident that in the year 2020, businesses and consumers will spend more than $53 billion, but no more than $68 billion, to effectuate all of the requirements of the CAAA. But in this case, I believe a comparison of the *effort* EPA made to consider cost uncertainty versus risk uncertainty reveals that a serious imbalance across the cost/benefit ledger continues as a hallmark of EPA practice. The four sensitivity "tweaks" that comprise the entire QUA of cost uncertainty are described in three pages, are dichotomous rather than distributional in nature, are not even combined into a single minimum-maximum range, and seem on their face to be overconfident even as descriptors of isolated parameter uncertainties. For example, EPA somewhat inexplicably uses as the *maximum* potential "technological learning rate" the 20 percent figure that it

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149.    *Id.* at 3-14, tbl. 3-3.

cites as the "central tendency presented in the peer-reviewed literature for several technologies."[150]

In comparison, EPA takes uncertainty in risk quite seriously in this report. EPA treated separately the uncertainty in how air quality may change under the CAAA (that is, uncertainty in emissions combined with uncertainty in the relationship between emissions and ambient concentration) and how changes in air quality can lead to changes in either human health outcomes or ecological outcomes. EPA quantified uncertainty in the concentration-response relationships for human health by considering both a host of parameter uncertainties (e.g., the potential for exposure misclassification caused by fixed, rather than personal, monitors, and the resulting concern about bias towards the null hypothesis) and by conducting various expert elicitations to estimate the probability that certain key alternative theories may be correct (thereby accounting for some model uncertainty).[151] EPA then conducted a Monte Carlo simulation with distributional assumptions for all input parameters,[152] and further combined these results with a distribution for the uncertainty (which is really a distribution depicting controversy) in the acceptable estimates for the value of a statistical life (and a life-year).[153]

So it is somewhat strange that the summary table that purports to be the bottom-line comparison of benefits and costs[154] carries through all of table 7-5 carries through all of the QUA for benefit uncertainty, but fails to even acknowledge or cross-reference the limited sensitivity analysis on cost uncertainty. This table provides a low, central, and high range of estimates for net benefit, *but it is fairly clear that this "quasi-range" results from subtracting a point estimate for cost from a range estimate for benefit.* As with so many of EPA's (and other federal agencies') other public statements about uncertainty in net benefit, this is a misnomer reflecting uncertainty in risk and (infinite) overconfidence in cost.

Even in the qualitative summary of uncertainty in costs and benefits, where the Agency is able to provide caveats about its degree of confidence free of any numerical straightjacket, *it is clear that EPA's default posture is to treat "risks as uncertain unless we can show they are certain," but to treat costs as "certain until proven uncertain."* Table 7-6, which lists the "potentially major sources of uncertainty for estimating the costs and benefits of the CAAA," acknowledges ten sources of risk uncertainty, three sources of uncertainty in

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150.    *Id.*
151.    *Id.* at 5-36 – 5-49.
152.    *Id*. at 7-3, n. 102.
153.    *Id.* at 7-14, tbl. 7-7.
154.    *Id.* at 7-9, tbl. 7-5.

valuation of health effects, and *zero* sources of cost uncertainty.[155] It is true that earlier in the document, EPA identified twelve different possible (but unquantifiable) sources of cost uncertainty[156] (the four "tweaks" discussed *supra*, plus others), and that EPA justifies not including any of these twelve in Table 7-6 because that table is reserved for "major" potential sources of uncertainty (that is, ones that could affect the net benefit estimate by more than five percent). But I find a great degree of circular reasoning at work here. First, since in the case of the CAAA, benefits exceed costs by about thirty-fold, we could *wipe away costs completely, or double them, without changing the net benefit estimate by more than five percent.* So, this is a strange criterion—it makes major changes in cost into minor (that is, ultimately unmentioned) changes in net benefit. In some of the cases, EPA has worked even harder to relegate cost uncertainty to the "minor" category: in the discussion of compliance cost overestimation bias, for example,[157] EPA divides the biases into roughly five different categories, and then says that "the magnitude of these biases varies substantially, but in no case would we expect the overall net impact to exceed 5 percent of overall net benefits."[158] In other words, a category that could comprise five separate "minor" effects is kept "minor" through disaggregation. Ultimately, the treatment of cost uncertainty has the flavor of an a priori determination that each effect is "minor," and then the conclusion that a whole suite of "minor" effects must be unimportant even when taken as a whole.

*In summary, FDA and NHTSA seem to have leapfrogged over EPA and OSHA in the care with which they balance the analytical treatment of uncertainty in both benefits and costs.*

## IX. Preliminary Identification of Reasons for Inattention to Cost Uncertainty

In this section, I offer some explanations, grounded in personal experience and extensive interactions with other current and former regulatory officials, risk analysts, and economists, for the basic asymmetry or disequilibrium documented in this Article. Why did risk analysts begin to acknowledge and quantify uncertainty long before regulatory economists began to, and why, to this day, is cost uncertainty more typically an afterthought (whereas risk uncertainty is more of a core attribute)? The forces leading to this asymmetry involve, and to some extent transcend, disciplinary and organizational boundaries. Regulatory analysis and action is an

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155.    *Id.* at 7-11, tbl. 7-6.
156.    *Id.* at 3-17 – 3-19, tbl. 3-4.
157.    *Id.* at 3-19, tbl. 3-4.
158.    *Id.*

arena where scholarship meets law, policy, and politics. The toxicologist or economist who comes to work at a regulatory agency has to reconcile demands from her profession, her agency colleagues and superiors, OIRA, Congress and the judiciary, and from the industry, public, and other stakeholders affected by her analysis. Each kind of actor in this arena brings preconceptions about uncertainty, and the resulting product will likely be determined by the complex interactions among them.

Accordingly, I offer four categories of reasons to help explain the relative inattention to cost uncertainty, guided in part by the landmark typology developed by political scientist Graham Allison. In his book about the Cuban Missile Crisis,[159] Allison suggested three different lenses through which one could explain the behavior of complex organizations: a classic unitary rational actor model, a bureaucratic model (wherein seeming irrationalities may be the result of an agency acting according to its standard operating procedures rather than utility maximization), and a political model (wherein the result of a clash among actors may, like the outcomes of vector algebra, have "magnitude and direction" different than that of any single expressed preference).[160] The first two categories *infra* ("practical/empirical" and "normative") correspond roughly with the first lens; the key question analysis must ask here is "how might the typical economist view uncertainty and the responsibility to explore it?" The third category ("bureaucratic") explores the classic set of organizational factors that shape and constrain group outputs, and the fourth category ("disciplinary") views regulations and RIAs as developed by compromise and struggle, where the nature and intensity of economists' influence on analysis is shaped by their training and orientation.

## A. *Practical and Empirical Explanations*

- Producers of regulatory cost analyses (i.e., economists) and consumers thereof (i.e., agency managers, leaders of oversight processes, and stakeholders) may believe that uncertainties in regulatory cost are either trivially small, or are very small and distributed symmetrically about the point estimate most easily generated. Therefore, producers do not tend to "waste time" quantifying what is unimportant, and consumers do not feel de-

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159. GRAHAM T. ALLISON, ESSENCE OF DECISION: EXPLAINING THE CUBAN MISSILE CRISIS (1971).

160. *See* JOHN D. STEINBRUNER, THE CYBERNETIC THEORY OF DECISION: NEW DIMENSIONS OF POLITICAL ANALYSIS 142 (1974).

prived by the lack of more detail.[161] RIA producers and consumers may believe that cost uncertainty is not trivial in an absolute sense, but it is so small *relative* to uncertainty in risk (or benefit), and so small relative to the "distance" between expected cost and expected benefit, that little information is lost by fixating on the latter to the exclusion of the former. In other words, if the lower confidence bound on benefit—a function of the mean benefit and its uncertainty—is much, much greater than the (overconfident) "upper confidence bound" on cost, deriving a more honest uncertainty distribution for cost would not change the fact that B >> C.[162] A more sophisticated version of this explanation would state that the uncertainty distribution for net benefit ignoring uncertainty in cost is approximately the same distribution as the one including it. Therefore, little of value to the decision is lost by using the much more easily obtained surrogate. For example, if the agency could conclude that net benefits were positive with 90 percent probability (because, perhaps, there was a 10 percent chance that the risks were greatly overestimated), and a complete uncertainty analysis in cost would change that probability to 89 percent or to 91 percent, little would be gained (other than symmetry and insulation from criticism) by conducting an analysis of cost uncertainty.

- Economists and others may believe that, although regulatory costs *are* significantly uncertain in the long run, at least two factors—the attenuation of future costs and benefits via temporal discounting, and the fact that future analysts and decisionmakers will be able to adjust the regulation as more information accrues—make these future uncertainties a low priority for present-day explanation.

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161. However, one of the other articles developed during the NSF project represents the first large psychometric survey of laypeople aimed at understanding how they perceive regulatory costs and the uncertainty therein. Johnson & Finkel, *supra* note 21. This survey revealed that laypeople generally believe that regulatory cost estimates are no less uncertain than risk estimates are.

162. Such thinking, I hasten to add, reflects a simplistic but common view that the only function of depicting uncertainty in net benefit is to gauge how confident we can be about whether the net benefit of a particular decision option is positive (or negative). But quantitative ambiguity *within* the category of positive (or negative) net benefit can be hugely important, if it could make the option chosen inferior to a different option! The question should not be "are we sure that Option A has positive net benefit?", but "are we sure that Option A has greater net benefit than any other option?"—and this latter question can be quite sensitive to perturbations in net benefit.

- Conversely, but to the same effect, economists and others may believe that cost uncertainty is indeed large, but that it is also inscrutable or intractable. The importance of acknowledging large uncertainties has to be balanced against the difficulty of doing so in a credible way, and in many realms of policy analysis we tacitly agree to ignore aspects that are both influential and daunting. On the human health risk side, we have always operated by suspending our disbelief in stochastic dose-response. It is possible that every individual health effect is literally predestined (i.e., individual risks are either zero or one, and no one actually faces a risk equal to the population average), but until we learn enough about toxicogenomics and interindividual (and intra-individual) variations in susceptibility to forecast effects rather than estimate risks, we make do with the more tractable—and perhaps correct— stance. The analogous question on the cost side is whether, in the absence of a comprehensive model of the economy, we should try to quantify the uncertainty in those costs we *can* estimate, or should instead treat cost as precise, contingent on our not being able to even start modeling the big imprecisions. Influential reports about both risk and cost uncertainty have cautioned about the problem of "uncertain uncertainty" in different ways.[163] The 1996 PCCRAM report, for example, essentially concluded that we should not strive to quantify uncertainty at all, in risk or in cost, because of the danger of providing a false sense that we know how uncertain we are.[164] Various commentators have criticized this logic, stating that the more worrisome response would be to provide a point estimate that conveys even more overconfidence.[165] By 2009, an influential climate change report[166] had a more constructive and logical response to this problem: "unlike physical parameters of the climate system, socioeconomic and technological factors need not remain constant over time . . . we should regard these uncertainty estimates of future socio-economic outcomes with less confidence than those of physical pa-

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163.    Matthew Corder & Martin Weale, *Uncertain Uncertainty*, 17 Brit. Actuarial J. 542 (2013).

164.    *Supra* note 44.

165.    M. Granger Morgan, Regulation under Uncertainty, Slide Presentation at the Workshop on Expert Judgment: Promises and Pitfalls, Resources for the Future, Washington DC (March 13, 2006) at slide 22; Adam M. Finkel, *The Joy Before Cooking: Preparing Ourselves to Write a Risk Research Recipe*, 8 Hum. & Ecological Risk Assessment 1203 (2002).

166.    U.S. Climate Change Science Program, Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision Making (2009).

rameters."[167] In other words, it is possible to express uncertainty in cost, while realizing that some uncertainty estimates are more or less firm than others. Unfortunately, the contrary view—that cost uncertainty is too precarious to quantify—may continue to dominate this more constructive reconciliation.

- A stronger form of the argument presented *supra* holds that costs are simply not a proper subject for rigorous analysis at all. I believe this to be a very powerful point, albeit a difficult one to explain. First, let's consider some aspect of the good or harm done by a regulatory intervention that we all might agree is properly outside the domain of quantification. Perhaps we could agree that no cost-benefit analysis should be attempted to gauge the wisdom of establishing a market for donor organs; even if "net benefit" could be shown to increase if such a market was permitted, the effects on the fabric of society might more properly be managed outside the domain of monetized comparisons. As strange as it may seem, I see evidence that *we tend to regard regulatory costs themselves as similarly non-quantifiable by choice.* The influential 1992 Habicht memorandum at EPA, for example, rather offhandedly explained that it sought to impel extensive uncertainty analysis in risk, but to ignore uncertainty in cost, by casting aside "the *non-scientific considerations* (*e.g.*, *economic and societal factors*) that are considered along with the risk assessment in risk management and decision-making".[168] If "economic factors" (that is, costs!) are properly dealt with in the same way sacred moral judgments are—that is, not by quantitative comparisons, but by political dialogue—then there is no point in quantifying cost with anywhere near the same rigor with which we quantify the "scientific considerations."[169] By lumping together "economic" and "societal" factors, and placing them in apposition to scientific ones, we relegate economics to the "soft" side of the firewall separating risk assessment from risk management,[170] and we send a powerful

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167.    *Id.* at 42-43.

168.    Memorandum from F. Henry Habicht, II, Deputy Administrator, U.S. EPA, to Assistant and Regional Administrators, U.S. EPA, Guidance on Risk Characterization for Risk Managers and Risk Assessors, at 4 (Feb. 26, 1992) (emphasis added).

169.    *Id.*

170.    NATIONAL RESEARCH COUNCIL, RISK ASSESSMENT IN THE FEDERAL GOVERNMENT: MANAGING THE PROCESS (1983) at 6-7. *See also* Hoffmann, *supra* note 19 at 1347. Hoffmann observes that the "conventional wisdom" places economics as part of risk management and not of risk assessment, and criticizes this as a "limited view[ ] of the role and contribution economics as a discipline can make to risk assessment."

and paradoxical message that costs are, in a sense, "too important to quantify." *But why, then, do we quantify them?* It is, of course, possible to compare non-numerical considerations impressionistically or via a referendum, but very difficult to compare numerical quantities non-numerically! If we really intend to treat costs as non-quantifiable, then we ought not to quantify them, and especially not with false precision. It is not clear whether the Habicht memorandum is saying that economics is sacred or just that it is "soft"—lumping together "economic and societal" considerations suggests that costs are akin to preferences, which are inputs to decisionmaking that are not physical quantities and that are hard to measure. Are costs really things we use impressionistically to tweak a decision with respect to the anchor point we arrive at by considering risk alone? This view is not incoherent, but neither is it consistent with political and bureaucratic reality. As stated *supra*, real decisions often balance on a narrow fulcrum of cost—a little more cost than the line can handle and the decision changes abruptly. If we insist on treating costs as "soft," then we need a decision rule that doesn't treat them as "hard!"[171]

## B.  *Normative Explanations*

• The empirical assumption that uncertainty in cost is small can be trumped by the normative assumption that uncertainty simply does not matter (whatever its breadth) because the expected value of cost tells society all it needs to know. This view is equivalent to asserting that society is (or should be) "risk-neutral" with respect to uncertainty in cost; that we are (or should be) indifferent between a certain cost of $X and a pdf for cost whose expected value is $X. This is a natural assumption—at the societal level, uncertainties about the mean should not affect decisionmaking, especially when each decision is part of a large portfolio of actions, and when large deviations from each expected value will "even out," such that the grand mean of all total-cost outcomes will have small uncertainty. Indeed, this view was first invoked with respect to uncertainty in risk in the relatively distant past.[172]

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171.    I hope it is clear that of the two coherent choices, I prefer treating costs with more rigor rather than less—that is, quantifying cost and its uncertainty in order to make systematic choices, rather than treating costs impressionistically. I make the same argument, as do many of the other chapter authors, with respect to how we (should) treat potential job losses and gains from regulation, in Does Regulation Kill Jobs?, *supra* note 21.

172.    *The Perils of Prudence*, *supra* note 35, at 13.

However, I see various problems with an assumption of neutrality in either risk or cost. First, as discussed in Part IV *supra*, it may be folly to believe one can reliably estimate the expected value without carefully considering the shape of the uncertainty distribution (at which point reporting only the mean and censoring the distributional information is a form of willful ignorance and public miscommunication). Secondly, the assumption of risk-neutrality may have some appeal when the currency is that of (average) individual risk; there is the argument that since individual risks are themselves probabilities, the expected probability contains all the same information as an uncertain lottery over that probability.[173] But when the currency involves population risk (i.e., "body counts"), it is much less clear that the entire uncertainty distribution can sensibly be reduced to its mean. A sizable literature exists[174] on both sides of the proposition that society should be indifferent between "1000 deaths for sure" and a "1 in 1000 chance of one million deaths." I find much more persuasive the arguments that these are quite different, essentially because the "damage function" is non-linear, with particular societal aversion to possible outcomes in which masses of people might suffer. Clearly, uncertainty in regulatory cost is more like a lottery over different outcomes than a way to provide useless detail about the "probabilities of probabilities." Third, and most important, the upper tail of the cost distribution has a disproportionate influence on decisionmaking—arguably more so than the tail of the risk distribution.[175] As discussed at the end of Part VI *supra*, when costs—to the overall economy, and especially to identifiable sectors or firms—exceed a preconceived threshold, they tend to dom-

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173.     For example, if your chance of death is either 2 in one million or 4 in one million with equal probability, this may be indistinguishable from reporting the chance as exactly 3 in one million. On the other hand, it seems counter-intuitive and patronizing to insist that "a probability of a probability" has no salience in all cases, especially in cases where there is a chance the risk is intolerably large. Do we regard as indistinguishable a situation where your risk of death is exactly 1 in 1000, versus a situation where 1% of the population (by virtue of some known physical difference that is not discernible at the level of any individual) faces a risk of 1 in 10? The latter situation invokes considerations of risk-aversion, as well as concerns about fairness and altruism.

174.     *See* John Broome, *The Value of Life and the Value of Population*, 9 J. Population Econ. 3 (1996); W. Kip Viscusi, *The Value of Risks to Life and Health*, 31 J. Econ. Literature 1912 (1993).

175.     Adam M. Finkel, *Protecting People in Spite of—or Thanks to—the "Veil of Ignorance,"* in Genomics and Envtl. Reg.: Sci., Ethics, & L. 290, 324 (Richard R. Sharp, Gary E. Marchant & Jamie A. Grodsky eds., 2008); Cranor & Finkel, *supra* note 18.

inate all other considerations of cost (e.g., the rest of the cost distribution) or of benefit. The extreme concern over costs that exceed some "acceptable" fraction of revenues, or that arguably might push firms or subsectors into bankruptcy, implies *by definition* that we are not expected-value decisionmakers with respect to cost.

- A weaker form of the assertion that expected values are sufficient guideposts for decisionmaking could also contribute to the asymmetry between attention to risk uncertainty and cost uncertainty. It is, of course, possible to recognize that expected net benefit might be uncertain, and yet not advocate for a thorough analysis of cost uncertainty—either because the preconception holds that cost uncertainty is small (see *supra*), *or* because the criterion for gauging net benefit under uncertainty is not expansive enough. For example, Scott Farrow listed as one of the important desiderata of economists that "we want sufficient precision to distinguish positive from negative net benefit values."[176] This could be construed as an expression of a preference for expected values, but based on discussions with Farrow, I believe he recognizes the fragility of such point-estimate comparisons. However, the phrasing "distinguish from" does suggest a one-sided focus on how probable net benefit is to be positive, rather than a full depiction of the shape and breadth of the pdf for net benefit. If, therefore, regulatory economists concentrate on generating two point estimates—a worst-case estimate (either a "reasonable" worst-case or an extreme value) and a best-case estimate of cost—they can certainly marry these to similar estimates for benefit (i.e., risk reduction) and assess whether there is "sufficient" precision to declare net benefit positive with enough confidence to recommend the corresponding decision. If the endpoint estimates of benefit come from a pdf that risk analysts have already rigorously generated, whereas those for costs come from the exercise of asking "how large (or small) could costs possibly be?," then the extra rigor on the risk side would be unused, and the conclusion that net benefit was positive might fail to be informed by the probability and magnitude of contrary scenarios.[177]

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176. Reforming Regulatory Impact Analysis, *supra* note 28, at 184.

177. *But see supra* note 162 for a cautionary mention about the myopia of caring only about distinguishing only "positive from negative," as opposed to "superior from inferior options."

• Perhaps regulatory economists are engaging in strategic behavior: their emphasis on forcing risk assessors to change from one type of point estimate to another—from an alleged "upper bound" to the expected value—has the side effect of allowing economists to hold tighter to their own point estimates. If economists believe, rightly or wrongly, that all the uncertainty analysis on the risk side is a smokescreen, and the risk assessors fixate on the upper bound, then they may construe the entire CBA enterprise as an "arms race," in which the point estimate, not the error bound, is what matters. I have written previously that the PCCRAM's enthusiasm for pdfs of exposure and warnings against pdfs of toxicologic potency might be explained not as a stark inconsistency, but as opportunistic[178]—the conventional wisdom that point estimates of exposure were "conservative" led to enthusiasm for distributions (the new distributional information would tend to move the point estimate "leftward" towards less concern), whereas the worry that point estimates of potency were underestimates led to eschewing distributional information that might move the point estimate "rightward." By the same token, economists concerned about the consistent track record of *overestimation* of regulatory cost[179] might shy away from distributions that would tend to show lower cost estimates dominating the pdf; "leftward" extension on the cost side leads to more stringent regulation, having the opposite effect of "leftward" movements in risk.

## C. *Bureaucratic Explanations*

• I believe one of the strongest factors at work here may be the influence of agency lawyers. Perhaps they are intolerant of uncertainty in cost, and force economists to be overconfident, whereas they are more accustomed to accepting that risk estimates are uncertain, like it or not. Alternatively, perhaps they feel ill-equipped to challenge the science and hence defer, but feel no such compunction with regard to economics. *This may be the "vicious paradox" of CBA: non-experts have the impression that costs are easy to pin down relative to risks, and this leads to unwarranted overconfidence in regulatory economics, and perhaps leads to pressure on regulatory economists to* appear *confident*. More importantly, perhaps, agency lawyers may also perceive that *judges are coming to*

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178.     Finkel, *The Joy Before Cooking, supra* note 165, at 1208, n.4 (2002).
179.     *See, e.g.*, OTA-ENV-635, *supra* note 69; Goodstein et. al., *supra* note 71; Finkel, *A Second Opinion on an Environmental Misdiagnosis, supra* note 72.

accept that a scientific estimate with uncertainty bounds is not a sign of
weakness or of an incomplete job, whereas a dollar figure surrounded by
uncertainty looks like a half-baked conclusion, or even a sign of laziness.*
Any appearance of having abandoned the analysis in mid-stream,
of course, is fatal to the prospects for a court to allow a regulation
to stand.

- Inputs to cost estimates often come from agency engineers, who
  tend to think in point estimates, and may not respond well to any
  after-the-fact requests from agency economists to surround those
  estimates with error bars or pdfs.[180]

- The difficulties that may be caused by the first two factors *supra*
  are exacerbated by the career-path and advancement issue: agency
  economists rarely rise to managerial positions, and therefore can't
  impel change that might comport better with the professional
  norms of the larger economics community. Richard Williams, a
  former FDA economist, surveyed agency regulatory economists,
  and noted that

  > All [those surveyed] thought it was a problem that econo-
  > mists were "*topped out*" in their agency. They thought that
  > this was a significant problem and complained about scien-
  > tists and lawyers who were at the very top of their organiza-
  > tion—but no economists ever occupied top positions. One
  > economist noted that, "*you can apply but it is not going to hap-
  > pen, only* [the physical scientists] *are going to get managerial
  > positions*."[181]

- A related problem is that, in both risk science and regulatory eco-
  nomics, it is possible that the best and most creative scholars do
  not seek out positions in public service; instead, they gravitate
  toward academia. To the extent that civil service positions are
  attractive to persons more interested in stable and long-term em-
  ployment than in attaining the highest available salaries, this
  might skew the distribution away from those who are most able
  to "land on their feet" if forced to leave a private-sector position.
  This might help explain the asymmetry described in this Article:
  risk scientists in regulatory agencies work on risk science,
  whereas economists can be assigned either to work on valuation

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180.    *See* Dale Hattis & Adam M. Finkel, Barriers to a More Even-Handed Treatment
of Uncertainties in Projected Economic Costs and Health Benefits of Environmental Regula-
tions (2014) (unpublished manuscript) (giving a more complete discussion of this factor).

181.    Richard Williams, *The Influence of Regulatory Economists in Federal Health and Safety
Agencies* 28 (Mercatus Center, George Mason University, Working Paper No. 08-15, 2008)
(emphasis added).

or on cost, further diluting the pool of the best and most creative analysts, especially to the extent that valuation is seen as far more interesting and worthy of attention than cost is (see *infra*).

- A simple matter of timing and sequencing may also mitigate against more rigor on the cost side. Because regulatory agencies tend to view the analytic process as "estimating the cost of achieving the amount of risk reduction supported by the risk analysis," the cost assessment naturally comes later in the process, when time may be at a premium and resources may be scarce.[182]

## D. *Disciplinary Explanations*

- Economists may fall prey to "physics envy,"[183] and in their desire to emulate the physicists' march towards more and more precision, they may tend to regard the open highlighting of uncertainties as evidence of being farther than desired from the goal of maximal precision (rather than evidence of reaching a different goal—that of as much precision as needed or feasible within constraints).

- Other economists have suggested that it is inappropriate that their field emulates science at all, as opposed to engineering. Colander put it this way: "Their self-classification as applied scientists leads them to contort their methodological approach to attempt to make it seem to fit a scientific method . . . not as rough and ready engineering insights that can be useful in looking at particular problems. Seeing oneself as a scientist undermines the humility the actual practice of applied economics warrants."[184]

- With regard to "deep uncertainty"[185] (i.e., the large potential errors caused by inappropriate models), more research needs to be done to probe the possible differences in training between life

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182.    I appreciate Lisa Robinson as the source of this insight. I have previously written about the constraints that this risk-focused thinking places on decision-making, and suggested a "solution-focused" alternative in which risk and cost analysis of discrete options would occur in parallel. Finkel, *Solution-Focused Risk Assessment*, *supra* note 22.

183.    Andrew W. Lo & Mark T. Mueller, *Warning: Physics Envy May be Hazardous to Your Wealth!*, (2010) (unpublished working paper), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1563882.

184.    David Colander, *Creating Humble Economists: A Code of Ethics for Economists*, 3-4 (Middlebury Economics Working Paper 11-03, 2011), *available at* http://sandcat.middlebury.edu/econ/repec/mdl/ancoec/1103.pdf.

185.    Louis A. (Tony) Cox Jr., *Confronting Deep Uncertainties in Risk Analysis*, 32 Risk Analysis 1607, 1607 (2012).

scientists and economists. I certainly recall in undergraduate courses both in biochemistry and economics that fundamental models were introduced as revealed wisdom, without much emphasis on the consequences for prediction and for policy if they were wrong. However, I think it may be much more common for scientists to explore model uncertainty quantitatively (whether through scenario analysis or formal model averaging methods), and am more hard-pressed to identify scholarly papers and agency documents in economics that present markedly different alternative predictions calling into question of the central dogmas of their field.[186] And, returning to the theme of an "arms race," perhaps economists in regulatory agencies are more wary of giving stakeholders access to "where the bodies are buried" in terms of the assumptions that might be incorrect.

- A more recent trend may exacerbate the pre-existing differences between risk scientists and economists. The rise of "Freakonomics"[187] as a ticket to fame may put a premium on spending time finding clever relationships, rather than doing the "grunt work" of careful analysis of something as seemingly dull as "what it costs." This is anecdotal, but I am struck by the fact that RFF held a competition several years ago for papers to be presented in a conference on "the frontiers of environmental economics,"[188] and none of the papers chosen had anything to do with the estimation of regulatory cost. Is it possible that some problems will never be solved, because doing so would require admitting that generations past were in error for having *regarded* them as solved?

- To the extent that highlighting uncertainty is a hallmark of analytic humility, it is possible that refusing to do so reflects hubris within the profession involved. I discern, perhaps unfairly, a tendency among some economists to profess that their training gives them abilities superior to those trained in the very fields they have recently begun to comment on. For example, Landsburg

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186. *See, e.g.*, Brian Mannix, *Employment and Human Welfare: Why Does Benefit-Cost Analysis Seem Blind to Job Impacts?*, in Does Regulation Kill Jobs?, *supra* note 21 (pointing out in detail that construing regulatory cost as the cost of compliance to affected businesses is itself a gross oversimplification—social cost consists of changes in producer and consumer surplus across the economy—but rare is the regulatory impact analysis that models general-equilibrium regulatory cost).

187. Steven D. Levitt and Stephen J. Dubner, Freakonomics: A Rogue Economist Explores the Hidden Side of Everything (2009).

188. *The Frontiers of Environmental Economics*, Resources for the Future, *available at* http://www.rff.org/rff/Events/Frontiers-of-Environmental-Economics.cfm.

commented in the New York Times on a review of his book *The Armchair Economist* that "to suggest [in a review of my book] that economists 'are not spending much time with epidemiologists' and other experts in the fields where we've offered unsolicited contributions . . . overlooks [that] it's economists, not epidemiologists or anyone else, who are experts in trading off costs against benefits."[189] Economist Emily Oster took this even a step further recently, claiming "I realized that training as a health economist was in many ways better than training in public health or medicine for this [discerning which observational studies of health effects are meritorious and which are not.]"[190] If being an economist confers special insight into "true" correlations and causal effects in fields where specialized training can be dismissed as unnecessary or even unhelpful, then perhaps it seems deflating to announce those "findings" with error bars or admitted imprecision.

- There may be a correlation between political ideology and tolerance of uncertainty, and, at the same time, a correlation between ideology and the "side" of CBA one works on (i.e., risk or cost). New neuroscience research suggests that politically conservative people may tend to see uncertainty as a weakness[191]—perhaps because they are more fundamentalist in their spiritual beliefs, and fundamentalism tends to be at odds with doubt. If economists in the agencies tend to be more politically conservative than risk scientists therein, this might explain why they strive to get "the answer" to the question they are asked, rather than a snapshot of how uncertain that answer might currently be.

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189.    Steven Landsburg, Letter to the Editor, *The Bedside Economist*, N.Y. Times, Aug. 29, 2007. Landsburg also wrote that "The principle of comparative advantage explains why some people become medical doctors, while other, different, people go into fields such as economics that require at least a minimal ability to reason logically." Steven Landsburg, More Sex Is Safer Sex: The Unconventional Wisdom of Economics 19 (2007). I am not aware of analogous pronouncements by epidemiologists or toxicologists, for example, professing abilities comparable to or superior to those of economists in estimating supply and demand functions, or gauging regulatory costs, but perhaps they exist and I have failed to find them.

190.    Emily Oster, Expecting Better: How to Fight the Pregnancy Establishment with Facts 38 (2013).

191.    John T. Jost, Jack Glaser, Arie W. Kruglanski, & Frank J. Sulloway, *Political Conservatism as Motivated Social Cognition*, 129 Psychol. Bull. 339 (2003).

## X.  Recommendations for Improving the Analysis of Cost Uncertainty

Regulatory economists could readily adapt long-standing methods to quantify uncertainty in regulatory cost. In a companion paper,[192] we observe that there exist two complementary approaches: (1) "bottom-up" analyses, wherein each input to a cost estimate is given a statistical distribution and the uncertainties are propagated; and (2) "top-down" analyses, wherein prior experience with respect to cost or an important aspect thereof is used as raw material to calibrate the work in progress. We note especially that, in many cases, the pdfs for parameter uncertainty already exist and need only be transported into a Monte Carlo or similar analysis. For example, when the cost of an intervention arises from the changes in consumer and producer surplus that are in turn caused by an increase in compliance costs for those producing a good, those estimates of consumer and producer surplus depend crucially on the estimate of the own-price demand elasticity of the good. The regression equations that approximate elasticity naturally provide an estimate of its standard error—an ideal input to a propagation-of-error model.

In another companion piece,[193] we discuss methods that can simultaneously help correct for bias (i.e., misestimation), as well as for over- or under-confidence in the presentation of uncertainty.

## Conclusions

Our cost-benefit edifice—in which billions of dollars and tens of thousands of lives hang in the balance—is not "equi-sturdy,"[194] and this may be a huge problem—both an intellectual concern and a welfare concern. This Article and the others under the umbrella of our NSF project attempt to shed light on the disparities between risk science and regulatory economics as analytic pursuits, and to probe the genesis of these disparities. Precisely because "what it costs" may seem mundane, we need to be sure we get this half of the problem right, or at least as right as we get the other half. But getting the costs—along with their uncertainties, their interindividual distribution, and the effects on real welfare that they impel—right is interesting and hard work.

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192.    Dale Hattis & Adam M. Finkel, Barriers to a More Even-Handed Treatment of Uncertainties in Projected Economic Costs and Health Benefits of Environmental Regulations (2013) (unpublished manuscript).

193.    Jack Siegrist, Scott Ferson & Adam M. Finkel, Advanced Bias Correction: Factoring out Bias and Overconfidence (2013) (unpublished manuscript).

194.    Siegrist et al., Ravnoprochnost, *supra* note 19.

As a comment on the respective roles of risk scientists and regulatory economists in the federal and state regulatory systems, as well as the interactions among these professionals, this Article takes the view that regulatory economists have helped impel needed improvements in risk assessment methods,[195] while also largely being responsible for inventing and popularizing the myth that risk assessment routinely yields very "conservative" estimates. Rather than hoping that scientists turn the tables and spend time hectoring economists to improve their analytic performance, I suggest that change should come from within, led by those economists who are unsatisfied with the sort of cost-benefit analyses in which cost appears to be the poor stepchild.

Ultimately, and notwithstanding all the discussion in this Article about estimation, honesty, and transparency, quantifying the uncertainties in regulatory costs is most important because it can help break the vicious circle of mediocre decisions driven by mediocre analysis.[196] It may be true that a point estimate of cost is all that is needed to show that the benefits of taking one particular action exceed its costs. (If so, one hastens to ask whether all the ornate work to characterize uncertainty in benefit is needed, too, but that is a depressing response to the asymmetry.) What, though, do we really learn from a confident statement that "doing X is better or worse than doing nothing?" It would be far better, I contend, to ask probing questions comparing X to Y, to Z, and to other options, any of which may be more welfare-maximizing than "X or not X."[197] To fix traditional cost-benefit analysis, we need better *cost* analysis, which currently suffers from too little rigor (as compared to risk analysis). We also need improved cost analysis to finally allow us to answer questions about how to identify, implement, and evaluate sustainable solutions to our litany of unresolved environmental, health, and safety problems.

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195.    In this regard, I agree with Sandra Hoffmann that "if economists view their role as limited to the evaluation of costs and benefits or analysis of economic impacts of policy, they may not pause to think about how their field could improve risk modeling." *Supra* note 19, at 1352. I simply urge them to think as well, and perhaps more often, about how their field could improve *economic* modeling.

196.    *See* Finkel, *I Thought You'd Never Ask*, *supra* note 10.

197.    *See* Finkel, *Solution-Focused Risk Assessment*, *supra* note 22.