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Macro-Risks: The Challenge for Rational Risk Regulation

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I. INTRODUCTION

In his book about the financial crisis that led to the so-called "Great Recession," Michael Lewis tells the story of Michael Burry, a short-seller who realized that many subprime mortgage bonds were worthless if the inevitable happened—if home prices leveled off.[1] Home prices did not need to actually *fall* for the financial meltdown to occur; they simply needed to level off. Models that valued subprime home loan-based derivatives did not reveal the extent of the risk because the models could not account for stable or falling home prices. Burry assumed that once this information became widespread, the market for these risky derivatives would collapse.[2] To his surprise, even when the insight was widely shared, the party continued for years. By then, many individuals and institutions were too heavily invested in not seeing that the emperor had no clothes to change course before the meltdown began.[3]

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1. *See* MICHAEL LEWIS, THE BIG SHORT 47–48 (2010) (discussing efforts of Mike Burry to create a derivative to bet against the subprime mortgage bond market).

2. *Id.* at 47 (noting Burry's concern that "[i]t's going to blow up before I can get this trade on"). *See also* Michael J. Burry, *I Saw the Crisis Coming. Why Didn't the Fed?*, N.Y. TIMES, Apr. 3, 2010, http://www.nytimes.com/2010/04/04/opinion/04burry.html.

3. *See, e.g.*, Michiyo Nakamoto & David Wighton, *Citigroup Head Stays Bullish on Buy-Outs*, FIN. TIMES, July 9, 2007, http://www.ft.com/intl/cms/s/0/80e2987a-2e50-11dc-821c-0000779fd2ac.html#axzz1VsCLE220 (quoting Citigroup chief executive officer Charles Prince

We had a reaction similar to Burry's the first time we read one of Harvard economist Martin Weitzman's articles on the failure to include fat tailed risks in the leading integrated assessment models (IAMs) of climate change costs and benefits.[4] The aspect of climate change most worthy of substantial attention by anyone interested in rational risk regulation is the existence of catastrophic, irreversible outcomes.[5] Small shifts in rainfall or temperature may or may not be worthy of regulatory expenditures, but they do not pose core, long-term threats. Peer-reviewed publications by paleoclimatologists and climate scientists suggest, however, that there are disturbingly high likelihoods of temperature increases and sea level rises that could cause the kinds of systemic failures that almost brought down the financial system in 2008.[6]

Weitzman pointed out as early as 2007 that the state-of-the-art IAMs did not account for fat-tailed catastrophes. He later formalized his analysis in his Dismal Theorem, which proved that unlike normal,

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for the proposition that "as long as the music is playing, you've got to get up and dance. We're still dancing.").

4. *See* Martin L. Weitzman, *A Review of* The Stern Review on the Economics of Climate Change, 45 J. ECON. LITERATURE 703, 720 (2007); Martin L. Weitzman, *On Modeling and Interpreting the Economics of Catastrophic Climate Change*, 91 REV. ECON. & STAT. 1, 2 (2009). For an early reaction, see Michael P. Vandenbergh, Brooke Ackerly & Fred Forster, *Micro-Offsets and Macro-Transformation: An Inconvenient View of Climate Change Justice*, 33 HARV. ENVTL. L. REV. 303, 317–19 (2009).

5. *See, e.g.*, RICHARD POSNER, CATASTROPHE: RISK AND RESPONSE 43–58 (2007) (discussing the possibility of abrupt climate change and noting the existence of "a number of ominous feedback possibilities"); Robert H. Socolow, *High-Consequence Outcomes and Internal Disagreements: Tell Us More, Please*, CLIMATIC CHANGE (forthcoming 2011) (manuscript at 1–2), *available at* http://www.springerlink.com/content/00318p08511j9164/ (stating that "I assume that Objective Number One for anyone in the policy-making community is to form an independent judgment of how urgent the climate problem is. Does the world need to drop everything else and assign climate change the highest priority, or is climate change one of several important problems?"). The notion that some environmental problems require distinct responses because they are irreversible is not new to the economics literature. *See, e.g.*, Kenneth J. Arrow & Anthony C. Fisher, *Environmental Preservation, Uncertainty, and Irreversibility*, 88 Q.J. ECON. 312, 318 (1974).

6. *See, e.g.*, Richard A. Betts et al., *When Could Global Warming Reach 4°C?*, 369 PHIL. TRANSACTIONS ROYAL SOC'Y A, 67, 67 (2011) (predicting a temperature rise of 7°F relative to preindustrial times by 2060 to 2070); INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS 795, 1704 (Susan Solomon et al. eds., 2007) [hereinafter IPCC PHYSICAL SCIENCE] (concluding that global warming will be irreversible for thousands of years and carries significant risks of sustained droughts as bad or worse than the 1930s dust bowl and covering much of the world); Steven C. Sherwood & Matthew Huber, *An Adaptability Limit to Climate Change Due to Heat Stress*, 107 PROC. NAT'L. ACAD. SCI. 9552, 9552 (2010) (predicting that amounts of warming predicted by several model simulations could well cause sporadic heat waves affecting large fractions of the populated areas of the planet that would kill anyone without access to air conditioning).

thin-tailed risks, the fat tails of uncertainty about the consequences of climate change cause the expected damages to be dominated by low-probability catastrophes: "The economics of fat-tailed catastrophes raises difficult conceptual issues that cause the analysis to appear less scientifically conclusive and more contentiously subjective than what comes out of an empirical CBA [cost-benefit analysis] of more thin-tailed situations. But if this is the way things are with fat tails, then this is the way things are. . . . . Perhaps in the end the climate-change economist can help most by *not* presenting a cost-benefit estimate . . . as if it is accurate and objective."[7] In the last several years, legal scholars have begun to examine the implications of Weitzman's concerns for climate change laws and policies.[8]

In addition, it has become increasingly apparent that tipping points may well exist, points beyond which catastrophic outcomes will be difficult if not impossible to prevent. For example, a recent expert elicitation study suggests that there is a greater than fifty percent probability that the earth's climate system will cross an irreversible tipping point by the year 2100 if we continue on a business-as-usual trajectory.[9] The tipping points discussed in these studies do not refer

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7. Weitzman, *On Modeling and Interpreting*, *supra* note 4, at 18. *See also* Jonathan S. Masur & Eric A. Posner, *Climate Regulation and the Limits of Cost-Benefit Analysis* 32–33 (John M. Olin Law & Econ. Working Paper No. 525, 2010), *available at* http://www.law.uchicago.edu/files/file/525-315-jm-eap-climate.pdf (noting that quantitative cost-benefit analysis is of little if any use in managing climate change risks because of both the enormous scientific uncertainties and the inseparability of scientific questions from normative or political ones).

8. *See, e.g.*, Jody Freeman & Andrew Guzman, *Climate Change and U.S. Interests*, 109 COLUM. L. REV. 1521, 1554 (2009) (discussing treatment of fat-tailed risks in IAMs); Vandenbergh, Ackerly & Forster, *supra* note 4, at 317–19 (examining implications of fat-tailed risks for climate policy); Masur & Posner, *supra* note 7, at 19 (noting that IAMs may be "underestimating the probability of catastrophic events by significant margins"); Daniel A. Farber, *Uncertainty*, 99 GEO. L.J. 901, 923–27 (2011) (discussing fat-tailed distributions and catastrophic outcomes). *See also* Jody Freeman & Andrew Guzman, *A Reply*, 41 ENVTL. L. REP. 10,726, 10,728 (2011) (noting that IAMs "systematically understate the economic effects of climate change" because of their omission of several categories of harm, including catastrophic events).

9. Kirsten Zickfeld et al., *Expert Judgments about Transient Climate Response to Alternative Future Trajectories of Radiative Forcing*, 107 PROC. NAT'L. ACAD. SCI. 12,451, 12,452–53 (2010) (reporting that thirteen of fourteen experts assigned a probability greater than 0.5 to the climate system undergoing or becoming irrevocably committed to "a fundamental state change" by 2100 under a high-emissions scenario similar to the historically observed trajectory, with nine of the fourteen assigning a probability greater than ninety percent; eight of the fourteen assigned a probability greater than fifty percent even for a "medium" trajectory, in which drastic emissions curtailment would stabilize atmospheric CO_2 at 550 parts per million by 2100). *See also* Elmar Kriegler et al., *Imprecise Probability Assessment of Tipping Points in the Climate System*, 106 PROC. NAT'L. ACAD. SCI. 5041, 5041 (2009) (reporting "conservative lower

specifically to catastrophes large enough to end civilization, but they do represent significant, abrupt, and irreversible changes in the climate system that would have dramatic global impacts. In addition, greenhouse gas emissions over the next several decades may make it impossible to avoid some tipping points, even if emissions are dramatically curtailed in subsequent years.[10] Although most tipping points discussed in the literature may not lead to catastrophic harms, there is no method to rigorously determine CO_2 concentrations corresponding to tipping points, and classes of tipping points may exist that have not yet been identified in the scientific literature. The problem is not one of known thresholds for catastrophic harm, but one of uncertainty and ignorance surrounding a real but indeterminate possibility for irreversible global catastrophe.

We believe that reducing the likelihood of truly catastrophic outcomes should be a central goal of any system designed to achieve rational risk management. That may appear to be an obvious proposition, but as we will discuss, the risk-assessment and risk-management communities are not functioning as if that is the central goal. We also believe that the existence of unknown but plausible tipping points supports a sense of urgency regarding risk assessment and risk management.

We might have expected a rational risk-management system to respond to the Weitzman analysis with an effort to find better ways to treat fat-tailed uncertainty about catastrophic risks and to introduce those new assessments into regulatory analysis and policy debates about climate change. The growing concern about tipping points might have induced the risk-management system to move quickly to incorporate these fat-tailed risks into the analysis. The response could have involved modifying traditional cost–benefit techniques to account for these outcomes. It could have involved supplementing or replacing cost–benefit analysis of climate change with other

bounds for the probability of triggering at least 1 [tipping point event] of . . . 0.56 for high global mean temperature change (above 4 °C) relative to year 2000 levels").

10. Johan Rockstrom et al., *A Safe Operating Space for Humanity,* 461 NATURE 472, 473 (2009) (noting that a number of tipping points probably lie within the range of 350 to 550 parts per million of CO_2; the current concentration of CO_2 is roughly 390 parts per million); INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS 222 fig.3.12 (John T. Houghton et al. eds., 2001), and supplementary online data at http://www.ipcc-data.org/ancilliary/tar-bern.txt and http://www.ipcc-data.org/ancilliary/tar-isam.txt (showing that three of the six major emissions scenarios produce CO_2 concentrations of 550 ppm or more by 2060). *See also* Timothy M. Lenton et al., *Tipping Points in the Earth's Climate System,* 105 PROC. NAT'L ACAD. SCI. 1786, 1788 (2008) (providing detailed tipping point assessment).

techniques that account for these outcomes and are likely to carry appropriate weight in regulatory and policy decision-making. Or, at a minimum, it could have included prominent, full disclosure of the limitations of the analysis in ways likely to affect the policy debate.

Unfortunately, that did not happen. The response to Weitzman's analysis bears an uncanny resemblance to the response of financial institutions to unwanted information about the risks of mortgage-backed securities. Some criticized the points made by Weitzman and other critics of climate cost–benefit analysis as just a rehash of previous arguments over precautionary versus cost–benefit approaches to environmental policy.[11] Others faulted Weitzman for placing too high a value on preventing the permanent destruction of civilization.[12] Others acknowledged the limited treatment of tail risks but only conducted limited additional sensitivity analyses or argued that the catastrophic tail of the climate risk distribution was not nearly as fat as Weitzman had presumed.[13]

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11. *See, e.g.*, Gary W. Yohe & Richard S.J. Tol, *Precaution and the Dismal Theorem: Implications for Climate Policy and Climate Research* (Working Paper FNU-145, Sustainability & Global Change Research Unit, Hamburg Univ., 2007), *available at* http://econpapers.repec.org/paper/sgcwpaper/145.htm (arguing that if the Dismal Theorem implies an extremely precautionary policy response to fat-tailed risks, then there is no way to set priorities among multiple fat-tailed risks, but also sharing this Article's conclusion that the Dismal Theorem does imply an urgent need to develop better ways of understanding and rationally treating fat-tailed macro risks).

12. *See, e.g.*, Robert S. Pindyck, *Fat Tails, Thin Tails, and Climate Change Policy* 4 (Nat'l Bureau of Econ. Research, Working Paper No. 16353, 2010) (arguing that if the extinction of the human race, including "the end for future generations" is valued at a large but finite multiple of the value of statistical life, "the dismal theorem no longer holds"); William D. Nordhaus, *An Analysis of the Dismal Theorem* 6–7, 12–14 (Cowles Found. Discussion Paper No. 1686, 2009) (analyzing other examples of potential catastrophes and concluding that "societies do not behave as if catastrophic outcomes have unbounded negative disutility"). *But see* Martin Weitzman, *Reactions to the Nordhaus Critique* 8–14 (Harvard Envtl. Econ. Program Discussion Paper No. 09-11, 2009) (arguing that replacing the infinite value of the value of civilization or the human race with "an uncomfortably large, but finite number" does not remove the Dismal Theorem's conclusion that for fat-tailed risks, rational willingness to pay will be dominated by low-probability catastrophes even when "the most catastrophic extremes are unlikely ever to materialize").

13. *See, e.g.*, Nordhaus, *supra* note 12, at 8–12 (criticizing Weitzman's method of calculating tail risk). *But see* Weitzman, *supra* note 12, at 5 (noting that "[c]ontrary to what Nordhaus states, my article relied on three recent peer-reviewed scientific studies to estimate roughly the PDF [probability density function] of S_2"). *See also* Christopher J. Costello et al., *Bounded Uncertainty and Climate Change Economics,* 107 PROC. NAT'L. ACAD. SCI 8108, 8109 (2010) (noting that if the damage from a given temperature rise is close to the range reported by IPCC, then truncating the fat tails of the risk distribution resolves many of the problems Weitzman's Dismal Theorem introduces for cost-benefit analysis, but with the caveat that "if the consumption loss caused by warming increases much more rapidly with temperature, this result could be overturned").

When responding to critics of cost–benefit analysis more generally, some have pointed out that cost–benefit analysis is just one tool to inform policymakers.[14] They are certainly correct on that point, but it is important to account for the impact on the policy debate of having one dominant tool that is used for major federal rulemaking and that generates a hard, quantitative outcome.[15] When weighed against the results of any non-mandatory, qualitative approach, the effects on the policy development and the surrounding debate are predictable.

Perhaps the best example of the impacts of IAMs on policy development is the focus on identifying a range of social costs of carbon.[16] This leads to policies based on IAMs that largely neglect fat-tailed risks,[17] and the result is a range of social costs of carbon ranging in 2010 from roughly five to thirty-five dollars per ton of carbon dioxide, with a central point estimate of twenty-one dollars per ton. Federal agencies are to use social costs of carbon within this range in regulatory decision-making. This range is entirely on-target so long as we ignore the principal aspect of climate change that should concern us the most: low probability, irreversible, catastrophic outcomes. The unsurprising result of an analysis that ignores fat-tailed risks is that a low relative priority is given to reducing catastrophic climate risks as compared to other societal risks.[18] Thus the numbers generated by this very precise assessment fail a basic plausibility assessment: they are derived from IAMs that largely ignore the precise types of

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14. *See, e.g.*, CASS R. SUNSTEIN, RISK AND REASON: SAFETY, LAW, AND THE ENVIRONMENT 111 (2002) (stating that "[t]he quantitative description should supplement rather than displace a qualitative description of relevant effects. . . . Agencies should be permitted to make adjustments . . . on the basis of the various 'qualitative' factors").

15. Sheila Jasanoff, *Acceptable Evidence in a Pluralistic Society*, *in* ACCEPTABLE EVIDENCE: SCIENCE AND VALUES IN RISK MANAGEMENT 29, 44 (Deborah G. Mayo & Rachelle D. Hollander eds., 1991) (noting that "[r]educing scientific uncertainty to mathematical terms offers decision makers a means of rationalizing actions that might otherwise seem insupportably arbitrary and subjective. . . . Numerical assessments possess a kind of symbolic neutrality that is rarely attained by qualitative formulations").

16. *See* Energy Conservation Program: Energy Conservation Standards for Small Electric Motors, 75 Fed. Reg. 10,874, 10,909–12 (Mar. 9, 2010); U.S. DEP'T OF ENERGY, FINAL RULE TECHNICAL SUPPORT DOCUMENT (TSD): ENERGY EFFICIENCY PROGRAM FOR COMMERCIAL AND INDUSTRIAL EQUIPMENT, at app. 15A (2010) (including "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866"), *available at* http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html.

17. *See* Masur & Posner, *supra* note 7, at 4.

18. *See* Freeman & Guzman, *supra* note 8, at 1594. *See also* Ryan Lizza, *As the World Burns*, NEW YORKER, Oct. 11, 2010, http://www.newyorker.com/reporting/2010/10/11/101011fa_fact_lizza.

outcomes that should be first on the agenda of a rational risk regulator.[19]

The assessment of climate change risks also raises a broader issue that is fundamental to understanding EPA at forty and to improving environmental regulatory activity over the next forty years. In this Essay, we argue that, if environmental policymaking is to succeed in its second forty years, present concerns about climate risk assessment suggest a broader need to improve assessment and decision-making regarding what we call macro-risks. Our analysis suggests not only a need to focus more on macro-risks, but also a need for the macro-risk assessment process to be driven more by the nature of the risk and less by the capabilities of traditional risk assessment techniques—which were honed on micro-risk analysis but face serious shortcomings when applied to macro-risks. We suggest that a new focus is necessary if rational risk regulation is to occur regarding macro-risks, and if cost–benefit analysis is to maintain its hold on environmental policymaking across administrations and partisan lines as the climate problem becomes more evident.

We begin by distinguishing macro- and micro-risks and by describing why catastrophic climate change represents a largely unaccounted-for macro-risk. We believe that climate concerns will dominate the risk issues addressed by environmental policymaking over the next forty years, and we focus on climate change here, but we believe the analysis is relevant to resource allocation across a wide range of social risks—including global pandemics, nuclear war, and asteroid impacts. We then suggest shifts in methodology and institutional arrangements to improve the prospects for rational risk regulation regarding macro-risks. No easy remedies exist, but we suggest several viable steps to enhance the prospects for rational macro-risk regulation.

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19. *See* Jasanoff, *supra* note 15, at 44–45 (stating that "quantitative risk assessment is far less an independent decision technique than a surrogate for deeper political divergences that choose . . . to express themselves as disputes about evidence. . . . The ultimate decision maker will still be confronted with the problem of cutting the knot of uncertainty, and it is by no means clear that better quantitative characterizations of the range of political choice will enhance the legitimacy of the final decision").

II. MACRO-RISKS V. MICRO-RISKS

A. *Micro-Risk Regulation*

Since the founding of EPA, the risk regulation movement has made substantial progress regarding rational regulation of micro-risks. By micro-risks, we mean the type of subject matter that is typically addressed by any one rulemaking, even a major rulemaking with $100 million or greater economic impact. Rulemakings and other policy initiatives addressing micro-risks often address very important issues—the health effects of hazardous air pollutants in industrial air emissions, maximum contaminant levels in drinking water, effluent limitations for pollutant discharges to navigable waters—but failure to optimally manage these risks, even failure to address them at all, will not result in threats to the social fabric or long-term sustainability of the nation or globe. In addition, although uncertainties about costs and benefits often exist for micro-risks, micro-risk decisions are not dominated by uncertainties about extremely unlikely events.

In the last three decades, the legal authorities supporting White House oversight of the cost–benefit analysis process have become increasingly clear.[20] In addition, the techniques have become increasingly sophisticated for analysis of the costs and benefits of regulations addressing micro-risks.[21] Although important debates still exist about discount rates, the valuation of non-market amenities, the role of the Office of Information and Regulatory Affairs, and other issues,[22] micro-risk analysis has survived and expanded. Over the last several decades, cost–benefit analysis has garnered the support of many centrist social welfarists,[23] and the result has been the continuation of its use in White House review of regulations in both Republican and Democratic administrations.[24]

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20. *See, e.g.*, MATTHEW D. ADLER & ERIC A. POSNER, NEW FOUNDATIONS OF COST-BENEFIT ANALYSIS (2006).

21. *Id.*

22. *See, e.g.*, *id.*; Daniel A. Farber, *Rethinking the Role of Cost-benefit Analysis*, 76 U. CHI. L. REV. 1355, 1379–96 (2009).

23. *See, e.g.*, RICHARD L. REVESZ & MICHAEL A. LIVERMORE, RETAKING RATIONALITY: HOW COST-BENEFIT ANALYSIS CAN BETTER PROTECT THE ENVIRONMENT AND OUR HEALTH (2008); SUNSTEIN, *supra* note 14; W. KIP VISCUSI, FATAL TRADEOFFS: PUBLIC AND PRIVATE RESPONSIBILITIES FOR RISK 153–59 (1992) (noting that risk information risk increases regulations' effectiveness); John D. Graham & Jonathan Baert Wiener, *Resolving Risk Tradeoffs*, *in* RISK VERSUS RISK 226 (John D. Graham & Jonathan Baert Wiener eds., 1995).

24. *Compare* Exec. Order No. 12,291, 46 Fed. Reg. 13,193 (1981) *with* Exec. Order No. 12,866, 58 Fed. Reg. 51,735. 51,742 § 6(a)(C)(iii) (1993) (requiring that agencies "assess both the costs and the benefits of the intended regulation"). For a review of EPA officials' perspectives

Since quantitative White House analysis of the costs and benefits of environmental regulations began in the late 1970s, however, environmentalists have cast a wary eye on the process. Is it being used to improve net social welfare by directing regulatory resources toward the most important environmental problems? Or is it simply being used to reduce the burden on regulatory targets, even if that means a net loss in welfare?[25] This is more than a theoretical question. Over the long term, the answer will determine whether the large number of policymakers and scholars who care about the environment but are not environmental advocates support the use of cost–benefit analysis. If it is a tool to provide more rational risk regulation, it is likely to continue to gather widespread support, and kinks or inadequacies can be worked out along the way. If it is simply a tool for reducing the costs imposed on regulated industries, then its support narrows to a smaller, more ideologically-driven base, and its function is much more difficult for non-aligned social welfarists to defend.

B. *Macro-Risk Regulation*

We suggest that macro-risks pose a challenge to the continued viability of cost-benefit analysis as a central component of rational risk regulation. By macro-risks, we mean those risks that have the potential to dramatically disrupt the character of markets and economies on a global scale and for very long times. Climate change is the leading example. Other macro-risks that pose similar problems for policymakers include global pandemics, nuclear war, and asteroid impacts, and we believe these problems can benefit from the kinds of macro-risk analysis that we outline here for climate change.[26] Our concept of macro-risks is comparable to the term "mega-catastrophe," which Kousky and her colleagues characterize as having severe impacts covering a large fraction of the planet, irreversibility in practical terms on timescales relevant to policymaking, and significant

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on White House oversight of EPA regulatory development across administrations, see Lisa Schultz Bressman & Michael P. Vandenbergh, *Inside the Administrative State: A Critical Look at the Practice of Presidential Control*, 105 MICH. L. REV. 47 (2006).

25. *See, e.g.*, Press Statement, Office of the President, Statement of the President on the Ozone National Ambient Air Quality Standards (Sept. 2, 2011), *available at* http://www.whitehouse.gov/the-press-office/2011/09/02/statement-president-ozone-national-ambient-air-quality-standards (requesting EPA Administrator Lisa Jackson to withdraw a Clean Air Act ozone standard and noting "the importance of reducing regulatory burdens and regulatory uncertainty" without discussing the net effects of the proposed ozone standard).

26. *See, e.g.*, POSNER, *supra* note 5 (examining potential catastrophic risks).

uncertainty not only in the sense of probabilities associated with specific hazards, but also in the sense of ignorance of the full list of hazards to assess. Because these mega-catastrophes violate the conditions for insurance markets to function and because they take place on scales of time and space that exceed even governments' ability to spread risk, Kousky and her colleagues conclude that "[t]raditional responses to the risk of extreme events are of limited value in mitigating risks."[27] Thus, a rational-choice framework for managing these risks requires a new approach.[28]

Unfortunately, much less progress has been made regarding assessment of macro-risks compared to assessment of micro-risks, even though the former are inarguably more important than the latter. Cost–benefit analysis for risk management generally assumes, either implicitly or explicitly, that markets continue to function and to equilibrate, so welfare theorems are satisfied.[29] Micro-risks can indeed be treated as small perturbations to an equilibrium economy: markets adjust to the perturbations, a new equilibrium is established, and the social welfare at the new perturbed equilibrium can be compared to the welfare at the previous unperturbed equilibrium. The disruption may increase or decrease the total welfare and may alter its distribution, but this leaves the overall economy sufficiently similar to its previous state that comparisons are useful and meaningful. Moreover, when the second welfare theorem applies, these perturbations are reversible: after removing the perturbation—and perhaps enacting a one-time transfer of assets—the market can return things to the *status quo ante*.

Macro-risks are entirely different, and conventional cost–benefit analysis breaks down when it attempts to treat them in this manner because they may leave the economy so unlike its previous state that quantitative comparisons of utility cease to be good descriptors of the change. A distinctive characteristic of macro-risks is that the expected value of regulation becomes extremely sensitive to which mathematical treatment is chosen to represent scientific uncertainty

27. Carolyn Kousky et al., *Responding to Threats of Climate Change Mega-Catastrophes* 2–3 (Harvard Kennedy School Faculty Research Working Paper No. RWP10-008, 2010), *available at* http://ssrn.com/abstract=1507992.

28. *See* Weitzman, *supra* note 12, at 8–14 (noting the limits of traditional cost-benefit analysis).

29. FRANK ACKERMAN, CAN WE AFFORD THE FUTURE? 8–12 (2009).

about extremely unlikely global catastrophes.[30] When this uncertainty is bounded or modeled with thin tails, the expected utility is dominated by reasonably foreseeable micro-risks. Conversely, when the uncertainty has fat tails, expected utility is dominated by unlikely events that are poorly understood and difficult or impossible to treat rigorously. Global climate change is the paradigmatic macro-risk: its tail risks threaten not just to perturb markets but to disrupt them entirely. The effects of climate change are expected to be irreversible for thousands of years; because the magnitude of the damages in the tail of the risk distribution are large on the scale of the entire global economy and threaten death tolls that are large on the scale of the world population, they cannot be treated as small perturbations to a system in equilibrium. These large changes violate several assumptions of cost–benefit models based on marginal analysis of quasi-equilibrium conditions: Costs and benefits may be discontinuous and path dependent, so marginal costs and benefits may not, in fact, be well-defined but may become infinite and may take on multiple values depending on the history that led to them.[31] Rather, since they threaten to disrupt the markets themselves and to dramatically change the conditions and constraints of people's lives around the world, we need a very different way to think about them.[32] Moreover, even a very small risk that there are tipping points, especially ones that could set off uncontrollable runaway warming, poses a great challenge to policies of waiting for greater certainty before undertaking expensive precautionary measures. In the words of an early and influential assessment of uncertainties about climate change, "[a] wait-and-see policy may mean waiting until it is too late."[33]

30. *See* Weitzman, *On Modeling and Interpreting*, *supra* note 4. *But see* Costello et al., *supra* note 13.

31. Terry Barker, *The Economics of Avoiding Dangerous Climate Change,* 89 CLIMATIC CHANGE 173, 182–84, 188–89 (2008).

32. IPCC PHYSICAL SCIENCE, *supra* note 6, at 775–77, 822–31 (noting irreversible aspects of climate change); Sherwood & Huber, *supra* note 6, at 9554 (discussing death tolls); Weitzman, *Stern Review*, *supra* note 4 (noting the scale of economic costs); Weitzman, *supra* note 12, at 2 (noting that standard cost-benefit analysis is not very useful in guiding policy under these circumstances). In illustrating the shortcomings of traditional cost-benefit analysis at assessing macro-risks, Jaeger et al. point out that the horrors of World War I and World War II are not apparent in graphs of gross world product. Carlo Jaeger et al., *Stern's Review and Adam's Fallacy*, 89 CLIMATIC CHANGE 207, 208–209 (2008).

33. JULE G. CHARNEY ET AL., CARBON DIOXIDE AND CLIMATE: A SCIENTIFIC ASSESSMENT, at viii (1979), *available at* http://www.nap.edu/openbook.php?record_id=12181.

Even strong proponents of cost-benefit analysis acknowledge the difficulty of applying it to this sort of macro-risk. Richard Posner writes that "global warming seems like the poster child for the limitations of cost-benefit analysis."[34] William Nordhaus writes that, "[i]f global warming is the mother of all public goods, it may also be the father of decision-making under uncertainty," and in his integrated assessment model, "every equation . . . contains major unresolved questions."[35] Richard Tol points out that if catastrophic climate change produces negative economic growth, this leads to mathematical absurdities—infinite variance in the social cost of carbon—that can render a cost-benefit analysis meaningless.[36]

Nordhaus writes that his integrated assessment model "analyz[es] the economics of global warming under the assumption of perfect foresight or certainty" while acknowledging that "studies by [him] and others provide inconsistent results about the impacts of uncertainty." Yet he concludes that "the certainty-equivalent policy is very close to the policy [accounting for] a full range of uncertainty."[37] This is true for uncertainties in the central part of a normal probability distribution, but for extreme risks and fat tails, things may break down, and different (and arguably more realistic) choices for some of Nordhaus's parameters lead to very different results, with optimal emissions mitigation trajectories that entail rapid emissions reduction over a few decades.[38] This contrasts with Nordhaus's results,

34. POSNER, *supra* note 5, at 155.

35. WILLIAM NORDHAUS, A QUESTION OF BALANCE 62 (2008).

36. *See* Richard S.J. Tol, *Is the Uncertainty About Climate Change Too Large for Expected Cost-Benefit Analysis?,* 56 CLIMATIC CHANGE 265, 277–80 (2003) (noting that if economic growth becomes negative, even in some regions of the planet, the IAM results produce infinite uncertainty in the social cost of carbon, even for finite damages). *See also* Richard S.J. Tol & Gary W. Yohe, *Infinite Uncertainty, Forgotten Feedbacks, and Cost-Benefit Analysis of Climate Policy*, 83 CLIMATIC CHANGE 429, 440–41 (2007) (noting that adding a second policy lever, international development aid, can remedy the infinite uncertainty, but that this lever is not robust).

37. NORDHAUS, *supra* note 35, at 63.

38. *See* Frank Ackerman et al., *Fat Tails, Exponents, Extreme Uncertainty: Simulating Catastrophe in DICE*, 69 ECOLOGICAL ECON. 1657, 1660, 1664 (2010) (noting that Nordhaus provides "no clear explanation for the crucial assumption that" damages from global warming are proportional to the square of the temperature rise, and that if damages are proportional to the fourth or fifth power of temperature rise, an optimal policy would lead to complete abatement of carbon emissions in 30 to 100 years). *See also* Elizabeth A. Stanton et al., *Inside the Integrated Assessment Models: Four Issues in Climate Economics*, 1 CLIMATE & DEVELOPMENT 166, 172 (2009) ("DICE, like a number of other models, assumes that . . . damages are a quadratic function of the temperature change. . . . Our review of the literature uncovered no rationale, whether empirical or theoretical, for adopting a quadratic form for the damage function. . . . Sensitivity analyses of the Stern Review . . . show that fixing the exponent

in which optimum trajectories gradually reduce emissions over the course of two centuries.[39]

Nordhaus acknowledges Weitzman's and Tol's fears about tail risks disrupting the entire economy, but he dismisses these concerns because his own model does not produce these catastrophic outcomes.[40] This dismissal is surprising given that Nordhaus acknowledges the limits of such models: "We emphasize . . . that models such as the present one have limited utility in looking at the potential for catastrophic events."[41] Nordhaus goes on to defend the use of IAMs despite these shortcomings, writing that "fears about low-probability outcomes in the distant future should not impede . . . steps to deal with the high probability dangers that are on us today. We should start with the clear and present dangers, after which we can turn to the unclear and distant threats."[42]

For many micro-risks, this may be a sound approach. However, IAMs that do not account fully for the combination of catastrophic outcomes and tipping points may affect the sense of urgency and priority among the public and policymakers regarding climate mitigation. If the IAMs contribute to a go-slow approach, and if our inaction over the next several decades allows atmospheric carbon concentrations to cross any of several tipping points, the go-slow approach may commit us to a trajectory that could lead to catastrophe. Certainly if we exclude the possibility of truly catastrophic outcomes and tipping points, a go-slow approach is the most rational. But, as we note at the outset, climate scientists have identified a number of potential tipping points in the climate system that could be crossed while the slow policy ramp is implemented, and the risk assessment process has not induced the public or policymakers to grasp the implicit risks of the go-slow approach or the magnitude of the consequences for guessing incorrectly about tail risks. The climate science suggests that the possibility of catastrophe is quite real, and, to the extent the likelihood can be quantified, it exists at levels that none of us would accept for getting on an airplane

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at 3—assuming that the damages are a cubic function of the temperature—increases average annual damages across the 200 year forecast horizon . . . by a remarkable 23% of world output. Thus the equally arbitrary assumption that damages are a cubic, rather than quadratic, function of temperature would have a large effect on IAM results, and consequently on their policy implications" (citations omitted)).

39. *See* NORDHAUS, *supra* note 35, 146–47.

40. *Id.* at 146–47.

41. *Id.* at 147.

42. *Id.*

or driving a car, much less managing the ability of the planet to sustain billions of people for hundreds or thousands of years.[43]

Furthermore, concerns about severe climate harms are not just the pipe dreams of catastrophists.[44] We discuss here just three of the numerous examples of plausible catastrophic outcomes that do not appear to be accounted for in the leading IAMs. Additional examples can be found in a number of the most highly regarded, peer-reviewed scientific journals and books.[45]

Extreme Heat Waves. Our first example was identified in a recent paper published in the *Proceedings of the National Academy of Sciences* by Sherwood and Huber. The paper examines the effects of climate change 300 years from now, asking what regions on earth would be too hot and humid for humans to survive outdoors even under optimal conditions— that is, naked, soaking wet, and with high winds to cool them.[46] The implications of the paper are stark and are hard to square with an analysis whose high-end damages are roughly ten percent of gross domestic product (GDP). For seven degrees Celsius of average warming, some currently inhabited regions of the planet would experience sporadic heat waves that would kill anyone caught outside or without access to air conditioning within hours. For eleven to twelve degrees Celsius average warming, these kill zones would expand to include most places currently inhabited by people. These heat waves would not come every year, but when they did, life would be possible in those places only by remaining indoors with air conditioning at all times.

What is the probability that the planet will heat up eleven degrees or more? If we continue along the higher end of plausible business-as-usual emissions paths, atmospheric CO_2 could reach four times its preindustrial level over the next century or so. Several recent

43. *See, e.g.*, Nicholas Stern, *The Economics of Climate Change*, 98 AM. ECON. REV. 2, 5 tbl.1 (2008) (providing table with likelihoods of temperature increases over two degrees C above pre-industrial levels).

44. For a discussion of how the likelihood of a climate catastrophe has affected a leading climate scientist, see Elizabeth Kolbert, *The Catastrophist*, NEW YORKER, June 29, 2009, at 39.

45. *See, e.g.*, AVOIDING DANGEROUS CLIMATE CHANGE (Hans J. Schellnhuber et al. eds., 2006); V. Ramanathan, *On Avoiding Dangerous Anthropogenic Interference with the Climate System: Formidable Challenges Ahead*, 105 PROC. NAT'L ACAD. SCI. 14245 (2008); Joel B. Smith et al., *Assessing Dangerous Climate Change Through an Update of the Intergovernmental Panel on Climate Change (IPCC) "Reasons for Concern,"* 106 PROC. NAT'L ACAD. SCI. 4133 (2009).

46. Sherwood & Huber, *supra* note 6, at 9552 (concluding that "recent estimates of the costs of unmitigated climate change are too low unless the range of possible warming can somehow be narrowed").

analyses estimate that there is at least a five percent probability that the climate sensitivity is greater than six degrees Celsius.[47] If that is correct, quadrupling CO_2 could raise temperatures by more than twelve degrees Celsius. Even if we take these model results with a grain of salt, supposing that there's a ninety-five percent chance they are grossly wrong about the probability of a six degree climate sensitivity or the consequences of eleven degree warming, that leaves more than a one-in-four-hundred probability—five percent chance that the papers are right times a five percent chance that the sensitivity is greater than 6 degrees—that most currently inhabited areas will experience occasional heat waves deadlier than anything in recorded history. If these heat waves occur on average once every ten years in any region, the average annual death toll among the world's poor would be hundreds of millions.[48]

Global Food Shortages. Another macro-risk associated with climate change is the breakdown of the world's food supply. If drought, extreme heat, or severe weather causes a catastrophic loss of a single nation's agricultural output for a year or two, global trade can respond to supply food to the stricken nation. Moreover, in a world of plenty where surpluses are taken for granted, food is cheap and agriculture is a small part of the GDP of developed nations, so the potential impacts of climate change on food production seem very small using today's marginal elasticities. If climate change produces a chain of crop failures across many nations, however, the disruptions—whether we measure them in dollars or lives lost—could well be far

47. Malte Meinshausen et al., *Greenhouse-Gas Emission Targets for Limiting Global Warming to 2°C,* 458 NATURE 1158, 1158 (2009) (estimating a 5% probability of a sensitivity greater than 7°C); N.G. Andronova & M.E. Schlessinger, *Objective Estimation of the Probability Density Function for Climate Sensitivity,* 106 J. GEOPHYS. RES. ATMOSPHERES 22,605, 22,605 (2001); Reto Knutti et al., *Constraints on Radiative Forcing and Future Climate Change from Observations and Climate Model Ensembles,* 416 NATURE 719, 719 (2002); J.M. Gregory et al., *An Observationally Based Estimate of the Climate Sensitivity,* 15 J. CLIMATE 3117, 3117 (2002); G.H. Roe & M.B. Baker, *Why is Climate so Unpredictable,* 318 SCIENCE 629, 630 fig.2 (2007). *But see* J.D. Annan & J.C. Hargreaves, *Using Multiple Observationally-Based Constraints to Estimate Climate Sensitivity,* 33 GEOPHYS. RES. LETT. L06704, L06704 (2006) (assigning a 5% probability that climate sensitivity exceeds 4.5°C, with negligible probability that it exceeds 6°C).

48. In the absence of the development and global deployment of some remarkable new energy technology, attempting to remedy this by providing air conditioning to everyone on earth would create a deadly race as a burgeoning coal-powered electrical generation infrastructure hastens the arrival of the heat waves against which it is intended to protect.

greater than would be predicted by multiplying crop losses by current market prices.[49]

Quantitatively assessing the probability and magnitude of widespread crop failures around the planet is not possible with any degree of certainty. Rising temperatures have both beneficial and harmful effects on crop yields. Carbon dioxide fertilization may or may not offset a large part of the anticipated heat and water stress. Farmers can adapt to changing climate, both by changing planting times and crop choices and also by adopting more expensive technology in the fields. The interactions of all these factors produces great uncertainty and estimates of the impact of climate change on global food production reported in one recent review range from a one percent gain to a twenty percent loss.[50] These estimates understate the fat tail on the high-risk side of the distribution, however, because they do not account for higher-than-expected climate sensitivity; extreme weather events, including heat waves, heavy precipitation, severe storms, and so on; indirect effects of climate change on air quality, pests, and disease; sea-level rise, which would particularly affect rice production; and reductions in grain quality.

To understand the potential vulnerability in the agricultural sector, consider the so-called Medieval Warm Period, between about 900 and 1400 C.E. Temperatures in what is now the contiguous United States were slightly warmer than today, and the region suffered a sequence of mega-droughts of much greater severity than the Dust Bowl drought of the 1930s, which lasted between 40 and 240 years.[51] Solomon and her colleagues report good agreement among different climate models that recurring droughts of similar or greater severity—up to three times as severe as the Dust Bowl—are expected in many parts of the world if greenhouse gas emissions are not sharply curtailed, and these patterns of recurring droughts would be irreversible for thousands of years.[52] Even with all the improvements to agriculture that modern technology has provided, such droughts

49. Kousky et al., *supra* note 27, at 6–7 (describing the way multiple local disasters could cascade to rapidly create a global mega-catastrophe).

50. David B. Lobell, *Global Crop Production and Food Security*, *in* CLIMATE CHANGE SCIENCE AND POLICY 113, 115 (Stephen H. Schneider et al. eds., 2010).

51. *See* Edward Cook et al., *Megadroughts in North America: Placing IPCC Projections of Hydroclimatic Change in a Long-Term Paleoclimate Context*, 25 J. QUATERNARY SCI. 48, 55, 57–59 (2010).

52. Susan Solomon et al., *Irreversible Climate Change Due to Carbon Dioxide Emissions*, 106 PROC. NAT'L. ACAD. SCI. 1704, 1706–07 (2009).

would be devastating, and recent research comparing past climates to model calculations adds strength to the predictions that global warming could very well produce similar droughts.[53] In many countries, including the U.S., India, and China, major aquifers are being rapidly depleted, so coping with drought by irrigating with groundwater will become increasingly difficult.[54]

As population growth stresses the ability of many Asian nations, such as India, China, and Bangladesh, to feed their people, trade is accelerating with African nations for food and other agricultural products, such as biofuels and raw materials for industry.[55] Several strategically important oil states are also looking to sub-Saharan Africa as major food suppliers. Acquisitions of farmland by outsiders can exacerbate political instability.[56] As complex interactions between agriculture, economic development, trade, shifting alliances, and the internal political dynamics of vulnerable nations respond to stresses from climate change, the repercussions are unpredictable and potentially global. Robert D. Kaplan has argued that climatic stress has the potential to act as a tipping point in countries, such as Bangladesh, that are currently peaceful, but could both tip into internal violence and spark broader regional or global conflict.[57]

Ocean Acidification. A third type of macro-risk is ocean acidification. Quite separately from its climatic effects as a

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53. Cook et al., *supra* note 51, at 58–59; Peter J. Fawcett et al., *Extended Megadroughts in the Southwestern United States During Pleistocene Interglacials,* 470 NATURE 518, 520 (2011). It is not possible to predict mega-droughts with confidence, but recent research confirms that such mega-droughts did take place during the warmest parts of the interglacial periods of the last half-million years, as computer model calculations had indicated. This agreement between theory and observation adds credibility to those same models' predictions that such droughts are a likely consequence of anthropogenic global warming.

54. SANDRA POSTEL, PILLAR OF SAND: CAN THE IRRIGATION MIRACLE LAST 6 (1999).

55. *See, e.g.,* Scott Baldauf, *Hunger and Food Security: Is Africa Selling the Farm?,* CHRISTIAN SCI. MONITOR, Feb. 6, 2011, http://www.csmonitor.com/World/Global-Issues/2011/0206/Hunger-and-food-security-Is-Africa-selling-the-farm.

56. *Id.* Crop failures in Africa could intensify local conflicts between exporting food and consuming it domestically and also create international conflicts as importing nations treat failure to honor export agreements as threats to their national security. *See* Kousky et al., *supra* note 27, at 7. *See also* David D. Zhang et al., *Global Climate Change, War, and Population Decline in Recent Human History,* 104 PROC. NAT'L. ACAD. SCI. 19214 (2007) (describing connections between natural climatic change, crop failures, civic disruption, and war during the Little Ice Age of the 15th to 19th centuries).

57. ROBERT D. KAPLAN, MONSOON, at xiv, 134–53 (2010) (concluding that "[t]he monsoon is nature writ large, a spectacle of turbulence that suggests the effect of the environment on humankind living in increasingly crowded and fragile conditions . . . . America's ability to grasp what . . . the monsoon represents . . . will help determine America's own destiny and that of the West as a whole").

greenhouse gas, carbon dioxide also has a significant effect on the acidity of the worlds' oceans. Roughly one third of the carbon dioxide emitted into the atmosphere dissolves into the oceans, where it reacts with water to form carbonic acid.[58] Whereas the details of climatic change are so complicated that they challenge even the most powerful computers, ocean acidification results from very simple and straightforward chemistry—although the biological response of ecosystems is still rather uncertain.[59] This acidification is likely to reduce the natural alkalinity of sea water to the point where the carbonate shells and exoskeletons of corals, shellfish, plankton, urchins, and so on start to dissolve.[60] Disrupting the lowest trophic levels of ocean ecosystems, such as corals and plankton, can have dramatic and catastrophic effects on economically valuable populations of ocean life: the fossil record shows mass extinctions of sea life that coincide with ocean acidification, but there are too many complicating factors to make clear causal connections.[61] It is clear that corals and other calcifying species can gradually evolve to survive in conditions at least as acidic as anthropogenic carbon emissions are likely to produce, but this evolution takes millions of years and rapid changes in ocean acidity can drive calcifying organisms to extinction. Finally, the interactions between ocean acidification and other anthropogenic stresses are poorly understood and may dramatically amplify the risks.[62]

Although we cannot make certain predictions of the ecological impacts of CO_2 emissions due to ocean acidification, there is a real prospect of mass extinctions that could cascade through the marine food web and devastate fisheries, which provide as much as twenty

58. Ocean water is technically slightly alkaline. The acidification due to CO_2 emissions is not expected to turn the water acidic, but because it reduces the alkalinity and brings the water closer to an acidic state, it is called acidification. *See, e.g.*, Scott C. Doney et al., *Ocean Acidification: The Other CO_2 Problem*, 1 ANN. REV. MARINE SCI. 169, 170 (2009).

59. *See, e.g.*, Quirin Schiermeier, *Earth's Acid Test*, 471 NATURE 154 (2011).

60. Doney et al., *supra* note 58, at 174–78; J.A. KLEYPAS ET AL., IMPACTS OF OCEAN ACIDIFICATION ON CORAL REEFS AND OTHER MARINE CALCIFIERS: A GUIDE FOR FUTURE RESEARCH (2006), *available at* http://www.isse.ucar.edu/florida/report/Ocean_acidification_res_guide_compressed.pdf.

61. Doney et al., *supra* note 58, at 183–84; Ken Caldeira, *What Corals Are Dying to Tell Us About CO_2 and Ocean Acidification*, OCEANOGRAPHY, June 2007, at 188, 188–89; J.E.N. Veron, *Mass Extinctions and Ocean Acidification: Biological Constraints on Geological Dilemmas*, 27 CORAL REEFS 459, 469 (2008).

62. *See generally* Philip W. Boyd, *Beyond Ocean Acidification*, 4 NATURE GEOSCI. 273 (2011).

percent of the protein consumed by people worldwide.[63] Beyond their contribution to food supplies, fisheries provide jobs and economic activity that are crucial to poor nations, so losing fisheries would add to economic and political stress arising from climate change. If combined with a collapse of cereal production, as described above, this loss of fisheries could produce a globally catastrophic famine.[64]

III. A NEW FOCUS ON MACRO-RISKS

How can the risk regulation system be adapted to account for macro-risks? Rational regulation of macro-risks requires identifying, assessing, comparing, and communicating information about macro-risks in ways that enable the public and policymakers to engage in informed, unbiased decision-making about the preferred level and timing of social investment in risk reduction. Although the same could be said for micro-risks, the differences between micro- and macro-risks suggest that different approaches often will be necessary. We do not offer comprehensive reforms, but we suggest several steps to improve risk assessment and risk management for climate macro-risks.

A. Macro-Risk Assessment

From our perspective, two options are preferable to risk assessment approaches that essentially exclude low probability but catastrophic outcomes: (1) development of modified models that account for uncertainties about these catastrophic outcomes; or (2) an expert elicitation to generate subjective judgments that account for these outcomes. Regardless of the approach taken, we suggest subjecting the assumptions and outputs of the selected approach to plausibility assessments by experts in the relevant underlying disciplines and communicating the outputs of the process in ways that account for the likely impacts of information on the policy debate.

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63. Doney et al., *supra* note 58, at 179–80, 184; Sarah R. Cooley & Scott C. Doney, *Anticipating Ocean Acidification's Economic Consequences for Commercial Fisheries*, 4 ENVTL. RES. LETTERS 024007, at 6–7 (2009); R.I. Perry, *Potential Impacts of Climate Change on Marine Wild Capture Fisheries: An Update*, 149 J. AGRIC. SCI. 63, 69–70 (2011).

64. Summarizing the prospects for global fisheries, Jeremy Jackson writes, "In light of everything we know about upheavals in the geological past, another great mass extinction appears inevitable," adding that "the question is not whether these trends will happen, but how fast they will happen, and what will be the consequences for the oceans and humanity." Jeremy B.C. Jackson, *The Future of Oceans Past*, 365 PHIL. TRANSACTIONS ROYAL SOC'Y B 3765, 3772 (2010).

Models that Account for Tail Risks. In developing risk assessment methods that are appropriate for macro-risks, risk analysts should avoid the tendency to assume that every problem examined by cost–benefit analysis is a traditional market failure best addressed by tweaks to the market system.[65] As we discuss above, classical economics typically deals with externalities as a perturbation on a fundamentally stable and efficient free market. The public intervention to address these externalities typically involves making small corrections to a largely *laissez faire* system, either by assigning property rights, pricing the externality, or directly regulating behavior. With climate change, the externalities become as large as the market system, and this calls for a different paradigm.[66] This heuristic inference receives rigorous quantitative support from Weitzman's Dismal Theorem.[67] Although it may be difficult to modify traditional cost–benefit methods to account for fat tails, a new generation of research is exploring the consequences of adding explicit treatment of extreme risks in the tails of the distribution.[68]

One response to the concern about the limitations of IAMs is that cost–benefit analysis is only one of many ways to provide input into the decision-making process, and if this one does not account for

65. We should not expect rational risk assessment necessarily to translate to low-cost, moderate-cost, or high-cost risk regulation. If the risk assessment analysis suggests that no regulation is necessary, then that outcome needs to be reported and given serious weight. Similarly, if it suggests that major regulatory activity is necessary, even if costly or unpopular, then that outcome, too, requires airing and serious consideration. *See* Kousky et al., *supra* note 27, at 25–27 (commenting on the need for "better understanding of the behavioral and institutional constraints that must lie behind our failure to pursue seemingly obvious self-interested actions"). If, instead, it simply suggests that a moderate approach be taken regardless of the issue, it is not necessarily rational. *See* Masur & Posner, *supra* note 7, at 25 (noting that the OMB Interagency Working Group on the Social Cost of Carbon did just this, when it "adopted 'political' solutions, designed to appease all sides, where more difficult technical decisions were called for"). It is just moderate, which will in some cases be rational and in others not.

66. *See, e.g.*, Jaeger et al., *supra* note 32; ACKERMAN, *supra* note 29, at 160; ULRICH BECK, RISK SOCIETY: TOWARD A NEW MODERNITY 19–20 (1992) (noting that the economic paradigm in which conflict arises dominantly over distribution of scarce goods, which can largely be treated as economic internalities, is being joined if not replaced by a new paradigm that focuses on conflict over distributing abundant bads, which are largely externalities).

67. *See* Weitzman, *On Modeling and Interpreting*, *supra* note 4, at 18.

68. *See, e.g.*, Ackerman et al., *supra* note 38; Michael D. Gerst et al., *Accounting for the Risk of Extreme Outcomes in an Integrated Assessment of Climate Change*, 38 ENERGY POL'Y 4540 (2010); Derek M. Lemoine & Christian Traeger, *Tipping Points and Ambiguity in the Integrated Assessment of Climate Change* (Univ. Cal. Berkeley Dep't Agric. & Resource Econ. & Policy CUDARE Working Paper No. 1111, 2010), *available at* http://escholarship.org/uc/item/9nd591ww.

plausible catastrophic outcomes, the answer is to simply add other analyses to the policy mix. But the current policymaking process does not work this way. Cost-benefit analysis, not any other form of analysis, is required under the relevant executive orders. In theory, non-quantified, "soft" assessments can be considered alongside the quantitative outcomes of cost-benefit analysis,[69] but quantitative outcomes can be expected to dominate non-quantitative outcomes in policy debates.[70]

Expert Elicitation. The use of expert elicitation is a substantial departure from the dominant approach to micro-risks, but it may generate a more rational regulatory response for climate change than a more traditional quantitative approach that does not account for fat-tailed uncertainty.[71] As the debate between Weitzman and his critics over the proper interpretation of the Dismal Theorem underscores, a quantitative analysis of fat-tailed climate risks and policies to address them depends crucially on the value society places on its continued existence and on the mathematical representation of the extreme uncertainty regarding threats to its continued existence. Is the correct net present value for preventing a permanent collapse simply a multiple of the value of a statistical life, or is the value of civilization vastly greater than the sum of its parts? Given the scope both of the risks and of the remedies—mitigation, adaptation, and geoengineering—that are proposed, it is essential to address squarely the question of what value to place on the future of civilization. Such discussion need not focus specifically on the end of civilization, for the Dismal Theorem implies generally that for any improbable catastrophe that threatens to significantly disrupt society, fat tailed uncertainty can cause it to dominate a cost-benefit calculation, depending on the relationship between the cost of the disruption and the shape of the tails in the probability distribution. In the face of

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69. *See* Exec. Order No. 12,866, 58 Fed. Reg. 51,735, 51,735 § 1(a); SUNSTEIN, *supra* note 14, at 111.

70. *See, e.g.*, Editorial, *National Mission,* N.Y. TIMES, June 20, 2010, http://www.nytimes.com/2010/06/21/opinion/21mon1.html (noting $150 per year cost to American households of proposed climate legislation but expressing benefits in qualitative terms).

71. Michael Oppenheimer et al., *The Limits of Consensus*, 317 SCIENCE 1505, 1505 (2007) (suggesting that "alternatives to model-based approaches, such as . . . expert elicitation, . . . certainly would have been useful to policy-makers"). On the use of expert elicitation in environmental rulemaking, see, for example, SHEILA JASANOFF, THE FIFTH BRANCH 116–18 (1990) (describing controversies over the EPA's use of expert elicitation in its 1986 revision of ambient ozone standards), and Sheila Jasanoff, *supra* note 15, at 36–37 (extending this discussion to lead and sulfur emissions).

these types of concerns, a qualitative expert elicitation may lead to a more rational regulatory response than a quantitative analysis that is opaque to most policymakers and the public.

The complexity of cost-benefit analysis also can mask other important value judgments that are particularly important for macro-risks but are embedded in choices about discount rates and other issues that are largely inaccessible to the public. Even economists cannot provide a completely coherent or consistent account of inter-temporal discounting for macro-risks. In the debate between Stern and Nordhaus over the ethical foundations of discount rates, each is able to demonstrate significant inconsistencies in the other's treatment of the marginal elasticity of consumption, with the result that each economist's choice of discount rate reflects tacit ethical preferences, and data from actual markets are sufficiently inconsistent that the dispute cannot be resolved empirically.[72] When the issue being analyzed is a micro-risk problem, this lack of accessibility is probably a cost worth bearing, given the analytical rigor added to the regulatory process. When the issue being analyzed is a macro-risk such as catastrophic climate change, the choice may affect massive allocations of resources within the current generation and among the current generation and tens or hundreds of future generations. This level of opacity may be acceptable for micro-risks, but it is unlikely to yield rational regulatory responses to macro-risks.[73]

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72. William Nordhaus, *Critical Assumptions in the Stern Review on Climate Change*, 317 SCIENCE 201, 202 (2007); Nicholas Stern & Chris Taylor, *Climate Change: Risk, Ethics, and the Stern Review*, 317 SCIENCE 203 (2007). Nordhaus points out that Stern's choice for the elasticity of the marginal utility of consumption implies taking from the poor in this generation to give to the rich in future generations while Stern points out that Nordhaus's preferred value would imply support for a policy that heavily taxed the rich today, transferred 1 percent of the proceeds to the poor, and lost or destroyed the other 99 percent. Since both of these hypothetical programs are *prima facie* absurd, it is clear that the Ramsey approach to discounting breaks down for the large time spans involved in macro risks. *See also* John Quiggin, *Stern and His Critics on Discounting and Climate Change: An Editorial Essay*, 89 CLIMATIC CHANGE 195, 198–202 (2008) (demonstrating the connection between disagreements between Stern and his critics and the widely recognized "equity premium puzzle" of economics and also observing that actual market pricing of low-risk bonds imply low intertemporal discounting rates consistent with Stern's values for pure time preference and elasticity of the marginal utility of consumption).

73. For a review of concerns about the application of standard cost-benefit analysis techniques to climate change, see Masur & Posner, *supra* note 7. Ackerman and DeCanio have observed that mainstream integrated assessment models make assumptions about probability distributions and economic efficiency that do not reflect the best scientific and empirical knowledge of the climate system or the state of the economy, and that these assumptions tacitly bias the models against taking strong action to mitigate climate change. STEPHEN J. DECANIO, ECONOMIC MODELS OF CLIMATE CHANGE: A CRITIQUE 157 (2003); Ackerman et al., *supra*

Interdisciplinary Plausibility Assessment. Regardless of the method chosen, it is important to subject climate and other macro-risk assessments to plausibility assessments by experts in the fields underlying the economic analysis.[74] For example, climate scientists are better situated than economists to understand the state of the physical world if temperatures are four degrees Celsius higher. They should be asked to judge the plausibility of economic models' assessments of the economic impacts that will occur at those temperatures. Is it possible that GDP will only be reduced by one to five percent in a world marked by a four degree Celsius rise, as the Intergovernmental Panel on Climate Change (IPCC) and the DICE model suggest?[75] It is, but recent analyses of what conditions will prevail under a four degree Celsius temperature regime suggest that the economic costs of adaptation to or enduring such climate change are much more uncertain and depend much more critically on social and psychological factors than adaptation to or enduring two degree Celsius warming.[76] Thus, there is a distinct possibility that the IPCC and the DICE model far underestimate the damage from or cost of adapting to four degree Celsius warming, and this discrepancy could grow quickly for warming beyond four degrees Celsius. An interdisciplinary plausibility analysis would be expensive and time-consuming, and it is not necessary for run-of-the-mill cost–benefit

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note 38, at 1657. DeCanio comments that integrated economic–environmental models have very poor accuracy at predicting energy demand even a decade or two in the future, in part because the models incorrectly assume that firms operate at maximum efficiency and also because the dynamics of technological innovation are too poorly understood to be modeled effectively. These flaws lead the vast majority of models to grossly overestimate the growth of energy demand and thus to overstate the cost of reducing greenhouse gas emissions. Despite these known weaknesses, quantitative models tend to dominate policy discussions in part because their results generate simple, quantitative outcomes that can be widely applied across many regulatory settings, whereas qualitative analyses are difficult to express and to apply widely.

74. Kousky et al., *supra* note 27, at 23–27 (calling for a balanced portfolio of geoengineering, adaptation, and aggressive mitigation; and making decisions based on a structured consideration of the entire range of expert judgment).

75. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: IMPACTS, ADAPTATIONS, AND VULNERABILITY 17 (Martin L. Parry et al. eds., 2007), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf; NORDHAUS, *supra* note 35, at 51.

76. *See* Mark New et al., *Four Degrees and Beyond: The Potential for a Global Temperature Increase of Four Degrees and Its Implications*, 369 PHIL. TRANSACTIONS ROYAL SOC'Y A 6 (2011); Mark S. Smith et al., *Rethinking Adaptation to a 4°C World*, 369 PHIL. TRANSACTIONS ROYAL SOC'Y A 196 (2011). For a discussion of the implications of a four degree C warming, *see* New, *supra*, and the articles that follow, all of which are available at http://rsta.royalsocietypublishing.org/content/369/1934.toc (dedicated issue addressing implications of global average temperature increase of four degrees C and higher).

analyses of micro-risk issues, but it is necessary when the assessment concerns the type of macro-risk issues that have been insufficiently addressed by the risk regulation process to date.

Communication of Macro-Risk Assessment Information. Regardless of the risk assessment methods used, risk assessment results for macro-risks should be communicated in ways that reflect how information influences policymakers and the public. Unlike micro-risks, where the issues will often not rise to the level of non-expert concern, macro-risks by their very nature will more often be the subject of active public debate and deliberation by policymakers at the highest levels. Few in the general public likely understand that the social costs of carbon—or more generally experts' comfort with go-slow approaches—are based on models that exclude tail risks and tipping points, and include discount rates that value continued human existence in several hundred years at next to nothing. Perhaps knowing this information would not change near-term risk response preferences, but not knowing this information certainly can be expected to make an aggressive response less likely.

The limited treatment of catastrophic harms in IAMs is not the only example of climate risk assessment and risk communication that is unlikely to yield rational risk regulation. One response to the challenges posed by calculating costs and benefits of climate change is to avoid the need for a cost–benefit analysis by simply selecting a climate change goal and performing a cost effectiveness analysis.[77] This would simplify the analysis and would avoid the fat tail problem. The shortcoming of this approach, however, is that it does not provide guidance on what the climate change goal should be, and it focuses the public debate on quantitative estimates of the costs of climate mitigation without comparable estimates of the benefits of reducing climate harms. A recent example of this phenomenon is the request by Congress for EPA to prepare a cost-effectiveness analysis of the Waxman-Markey climate change bill in the House of Representatives.[78] The cost effectiveness analysis provided fodder for critics of the near-term pecuniary costs of the bill without providing

77. *See, e.g.*, Richard D. Morgenstern, *Critiquing the Critique of the Climate Change Winner Argument*, 41 ENVTL. L. REP. 10,720, 10,720–22 (2011) (arguing that a cost-effectiveness analysis, not a cost-benefit analysis, is appropriate for evaluating climate change policy).

78. U.S. ENVTL. PROT. AGENCY, EPA ANALYSIS OF THE AMERICAN CLEAN ENERGY AND SECURITY ACT OF 2009, H.R. 2454 IN THE 111TH CONGRESS 1 (2009), *available at* http://www.epa.gov/climatechange/economics/pdfs/HR2454_Analysis.pdf.

comparable information about the benefits,[79] and much of the debate revolved around the near-term costs, not the underlying reasons for bearing those costs.[80]

Another example of the importance of accounting for public debates in the communication of climate risk assessment issues is the treatment of sea level increases in the IPCC 2007 report to policymakers. The quantitative result in the report for the decade between 2090 and 2099 was thirty-five centimeters, or about fourteen inches, as the central estimate, with fifty-nine centimeters, roughly two feet, in the worst case. The text noted, albeit rather cryptically for non-experts, that this figure excluded contributions from break-up of the Antarctic and Greenland ice sheets since ice sheet break-up could not be modeled reliably.[81]

This approach may have been true to the best risk assessment methodology, but it was a risk management mistake.[82] A full understanding of the likely 2100 sea level increase required reading not only the quantitative figures on page thirteen, but also the qualitative warning on pages fourteen and seventeen. Skeptics used the fifty-nine centimeter figure to discredit policy advocates who had been warning about sea level increases of a meter or more. The skeptics argued that those policy advocates were alarmists, and that the IPCC estimate for sea level increases went down, not up, from the 2001 IPCC report—known as AR3—to the 2007 IPCC report—known as FAR. This left non-skeptics scrambling to note the qualifying language and unable to attach a quantitative figure to it.

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79. The EPA analysis covers costs due to higher energy prices, price changes for other goods and services, impacts on wages and returns on capital. *Id.* at 4. It does not account for the benefits of avoiding the effects of climate change. *Id.*

80. *See, e.g.*, DAVID KREUTZER, HERITAGE FOUND., HERITAGE ANALYSIS OF WAXMAN-MARKEY HITS WHERE OTHERS MISS (2009), *available at* http://www.heritage.org/research/reports/2009/08/heritage-analysis-of-waxman-markey-hits-where-others-miss (faulting EPA for underestimating the costs by making unrealistic assumptions); LAURIER T. JOHNSON, NATURAL RES. DEF. COUNCIL, THE HERITAGE FOUNDATION'S WAXMAN-MARKEY ANALYSIS, *available at* http://docs.nrdc.org/globalwarming/files/glo_10042201a.pdf (criticizing the Heritage Foundation's cost analysis for making unrealistic assumptions).

81. *See* IPCC PHYSICAL SCIENCE, *supra* note 6, at 13–17.

82. Oppenheimer, *supra* note 71, at 1505 (noting that "[t]he emphasis on consensus in IPCC reports . . . has put the spotlight on expected outcomes. . . . [I]t is now equally important that policy-makers understand the more extreme possibilities that consensus may exclude or downplay"). For a discussion of how potential catastrophic events should be discussed in the next IPCC report, see Socolow, *supra* note 5, at 3 (noting that the next report of the IPCC should communicate fully about the state of scientific understanding regarding catastrophic outcomes).

Although the IPCC report to policymakers may have taken the appropriate risk assessment approach, the report, as its name suggests, is designed to enhance rational risk management by informing policymakers and the public. It is entirely predictable that placing a low quantitative estimate in one place and very important qualifying information elsewhere, in a document explicitly written for policymakers and in a policy environment in which skeptics are more than willing to cherry-pick the results, will not generate a complete policy debate. More recently, Rahmstorf summarized semi-empirical studies of sea-level rise, which demonstrate the shortcomings of the IPCC approach: "Since the beginning of satellite measurements, sea level has risen 80 percent faster . . . than the average IPCC model projection."[83] Rahmstorf concludes that the most probable value for sea-level rise by 2095 would be 114 centimeters: seventy-nine centimeters greater than the IPCC's central estimate and almost twice the IPCC's worst-case value.[84] The worst-case reported by Rahmstorf was close to 200 centimeters, and Rahmstorf emphasized that even this was likely an underestimate because the semi-empirical models neglected the possibility of nonlinear acceleration of ice-flow.[85]

B. Macro-Risk Management Institutional Arrangements

As difficult as macro-risk assessment may be, macro-risk management is even more difficult. For catastrophic climate change, the uncertainty about outcomes and tipping points, the mismatch between near-term costs and long-term benefits, and the uneven distribution of costs and benefits among countries and economic sectors all complicate risk management. We do not offer a complete solution, but we suggest two measures that will enhance the prospects that the right people have the necessary information to act.

Identify and Inform the True Gatekeepers. Even the most accurate and complete macro-risk assessment methods will not lead to rational risk regulation if they do not affect the actual decision-makers. To be successful, rational risk regulation for macro-risks must affect the top decision-makers who not only have the authority to make decisions at this level, but also to influence public opinion. We have prepared this Essay for a conference about EPA, and EPA

83. Stefan Rahmstorf, *A New View on Sea-Level Rise*, 4 NATURE REP. CLIMATE CHANGE 44, 44 (2010).

84. *Id.* at 45.

85. *Id.* at 44–45.

and the other federal environmental agencies—Interior, NOAA, Agriculture, and Energy, for example—tend to get the blame when policy fails to match expert perceptions of risk, but, in the final analysis, macro-risk decisions are not made by EPA or the other agencies. The EPA administrator and other agency heads have an effect on macro-risk decisions, but the scale of the resource allocations, the tremendous political costs of informing the public about risks that it does not want to hear about, and the cost of building public support for rational responses to those risks occurs at the White House and at the highest levels of Congress, if it occurs at all. Pounding on EPA to do a better job of matching expert and public perceptions of risk, given the regulatory and resource controls imposed on the Agency by the Office of Management and Budget (OMB), other White House offices, and Congress, reflects a misperception of the locus of decision-making on climate and other macro-risks.

Instead, decisions regarding macro-risk are ultimately made by the president and top congressional leaders with the advice of a very close circle of advisors.[86] Decision-making often does not occur even among the usual suspects at the White House—the environmental experts, whether at the Council on Environmental Quality, OIRA, or other offices established by presidents to address these issues—but rather by the very top political and economic advisors.[87] Given the near-term costs and long-term benefits of carbon mitigation, it is not surprising that generalist advisors in Republican and Democratic administrations have given policy preference to other more immediate and more politically salient, but ultimately less important, issues than climate change. A similar phenomenon has occurred at the very top levels of Congress.[88]

From our perspective, rational regulation of macro-risks will only occur when the generalist advisors closest to the President and the top leaders of Congress understand the nature of the leading environmental risks and are induced to recommend adequate allocations of political capital to address them. That is a tall task, but we believe it is a mistake to frame the challenge in any other way. An important starting point is for scholars and policy analysts to focus on

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86. *See* Lizza, *supra* note 18.

87. *Id.*

88. Although the U.S. House of Representatives passed a cap-and-trade bill in 2009, the Senate never brought a bill to the floor. *See id.*

how these generalist advisors can be induced to confront information about macro-risks, even if these risks pose a political challenge.[89]

Generate Periodic Macro-Risk Reports. New institutional mechanisms can be adopted to increase the likelihood that the core group of influential policymakers confront the hard choices presented by macro-risks. In the late 1980s and early 1990s, movement in this direction seemed imminent. Two EPA reports attempted to assess risks and to induce the White House and Congress to re-allocate resources to the highest risks.[90]

In the *Unfinished Business* report, prepared at the request of EPA Administrator Lee Thomas during the second Reagan Administration, senior EPA staff sought to identify and rank risks in four categories: cancer, non-cancer health, ecological, and welfare risks.[91] The report noted that EPA's resources better matched public perceptions of risk than the perceptions of EPA experts. The conclusions in the report have withstood the test of time surprisingly well. For example, the two most substantial ecological and welfare risks identified in the report were stratospheric ozone depletion and global warming.[92] Global warming also was ranked fifth and stratospheric ozone depletion sixth on the list of 31 welfare risks evaluated.[93] The 1990 Regulating Risk report by the EPA Science Advisory Board (SAB) reviewed the *Unfinished Business* report and largely supported its conclusions.[94] As to climate, EPA and outside environmental experts thus identified the issue as a high priority concern as early as the mid- to late-1980s.

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89. Kousky et al. recommend also explicitly researching institutional and behavioral obstacles that have prevented meaningful action thus far. *See* Kousky et al., *supra* note 27, at 26.

90. The publication of an annual regulatory plan and semiannual regulatory agenda play this role for many rulemakings and policy initiatives directed at micro-risks, but they are not designed to stimulate a broader identification and prioritization of efforts to address macro-risks. *See, e.g.*, U.S. ENVTL. PROT. AGENCY, REGULATORY PLAN AND SEMIANNUAL REGULATORY AGENDA (2010), *available at* http://www.epa.gov/lawsregs/documents/regagendabook-fall10.pdf. The Government Performance and Results Act (GPRA) also requires EPA and other government agencies to link goals more closely with activities and expenditures, but it does not address prioritization of regulatory resources at the macro-risk level. *See* Government Performance and Results Act of 1993, Pub. L. No. 103-62, 107 Stat. 285 (1993) (codified as amended in scattered sections of 5. U.S.C., 31 U.S.C., and 39 U.S.C.).

91. U.S. ENVTL. PROT. AGENCY, UNFINISHED BUSINESS: A COMPARATIVE ASSESSMENT OF ENVIRONMENTAL PROBLEMS (1987).

92. *Id.* at 48.

93. *Id.* at 55.

94. SCI. ADVISORY BD., U.S. ENVTL. PROT. AGENCY, SAB-EC-90-021, REDUCING RISK: SETTING PRIORITIES AND STRATEGIES FOR ENVIRONMENTAL PROTECTION 4 (1990).

The subsequent climate science has only increased the relative priority warranted for carbon mitigation, but the preparation of reports identifying and prioritizing environmental risks has not continued. Perhaps most important, ground was lost in the response to the deregulatory momentum of the mid-1990s. For example, the National Environmental Policy Act of 1969 (NEPA) required the White House CEQ to prepare annual state of the environment reports to Congress and the President.[95] These reports provided a starting point for evaluating the allocation of environmental risk-reduction resources. Congress enacted the Federal Reports Elimination and Sunset Act (the Reports Elimination Act) in 1996, however, and it removed the NEPA report and many other reports from the dozens that agencies were required to submit to Congress.[96] Rather than viewing the NEPA presidential report requirement as an independent, viable requirement even after the Reports Elimination Act, CEQ ceased producing the report altogether.[97] The NEPA report was a vehicle for matching risks to risk reduction resources that was lost. Ironically, by reducing policymakers' focus on risk resource allocation, the loss of the NEPA report ultimately may have decreased the efficiency and increased the size of regulatory agencies.

To increase the prospects for rational macro-risk management, the CEQ could revisit its interpretation of NEPA and the Reports Elimination Act, and could begin again to generate an annual state of the environment report for the president, even if Congress would rather not receive the report. Rather than just a summary of the state of the environment, the report each year could include an explicit identification and ranking of those risks that pose genuine societal-level threats. Congress could mandate preparation of such a report, but, even if it does not, there is a good argument that CEQ still has

95. 42 U.S.C. § 4341 (1994) (repealed 2000) (requiring President to transmit to Congress annually an Environmental Quality Report which shall set forth "(1) the status and condition of the major natural, manmade, or altered environmental classes of the Nation, including, but not limited to, the air, the aquatic . . . and the terrestrial environment . . . ; (2) current and foreseeable trends in the quality, management and utilization of such environments"). For a discussion of this issue, see Michael P. Vandenbergh, *The Private Life of Public Law*, 105 COLUM. L. REV. 2029, 2085 (2005).

96. *See* Federal Reports Elimination and Sunset Act of 1995, Pub. L. No. 104-66, § 3003(a), 109 Stat. 707, 734. *See also* 42 U.S.C. § 4341 (2006) (noting termination of section 4341 requirement of annual Environmental Quality Report to Congress).

97. Arguably, a separate provision of NEPA still requires a report to the President. *See* 42 U.S.C. § 4344(7) (requiring Council "to report at least once each year to the President on the state and condition of the environment").

the authority under NEPA despite the provisions of the Reports Elimination Act.[98]

On a similar note, new legislation or executive branch policy could require preparation of a "Regulating Risk" report by government and non-government experts by the end of the first year of each new presidential term.[99] To provide transparency on the differences between government and non-government experts' assessment of risks and experts' versus politicians' views, the new approach could require that a version be prepared and made publicly available by the EPA SAB prior to OMB comment. The report could then be modified after receipt of comments by the public, OMB, CEQ, and other White House offices. Making the comments of all of these entities publicly available would help clarify the varying perceptions of risks by policymakers who are closer to direct electoral politics. Both perspectives are valuable, but an unflinching assessment of risks by experts who are insulated from politics may be necessary for the democratic process ultimately to yield rational risk management. If the implications of a risk assessment prevent it from being made and communicated to the public in an unbiased way at the outset, the opportunity for democratic debate and decision-making may be lost.

IV. CONCLUSION

No one can know whether the financial meltdown of 2008 and 2009 could have been prevented, but it is reasonable to have expected the top managers and directors of the major corporations that went bankrupt or survived only because of federal bailouts to have asked the hard questions when their employees were betting the company on perpetual growth in housing prices. Top government policymakers should have asked similar questions. At the very highest levels of

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98. Reports that identify important risks are already a part of defense policy debates, and the Department of Defense discussed climate change in the most recent national security report. See U.S. DEP'T OF DEF., QUADRENNIAL DEFENSE REVIEW REPORT, at iv (2010), *available at* http://www.defense.gov/qdr/QDR%20as%20of%2029JAN10%201600.pdf (noting that the "[r]ising demand for resources, rapid urbanization of littoral regions, the effects of climate change, the emergence of new strains of disease, and profound cultural and demographic tensions in several regions are just some of the trends whose complex interplay may spark or exacerbate future conflicts").

99. For example, although GPRA has pushed agencies in the direction of measuring performance and aligning performance with congressional directives and micro-risks to some extent, GPRA has not induced agencies or the political process to better align resource allocations with macro-risks.

business and government, someone should have been asking: What will be the impact of these derivatives if housing prices level off or decline? Is a leveling off of housing prices impossible or simply an event that has not occurred in the time horizon included in the risk assessment models? How much will we lose? If the losses have been hedged, who are the hedging parties and why do we think they will be solvent if the economy is in the tank?

We now know that on occasion some individuals raised these issues. Yet the party continued despite whatever concerns they may have raised. Perhaps the rewards of ignoring the risk discouraged many from asking tough questions and enabled those who profited in the near term to marginalize those who asked tough questions, whether in board rooms or in government.

The top White House and congressional leaders play a similar role as to climate change. A rational macro-risk regulation system should induce these key gatekeepers to ask and to act upon the answers to questions such as the following: What is the likelihood of catastrophic climate outcomes? Are there tipping points that might be passed beyond which emissions reductions will be largely ineffective? When might they occur? To what extent does the output of an IAM or the social cost of carbon reflect plausible catastrophic outcomes? What is the effect on model outputs if climate change causes negative economic growth? What are the implications of a range of discount rates for valuing all economic activity in 2100? 2200? 2300? It is reasonable for the public to expect that key policymakers are asking these types of questions.

Even if the hard questions are asked, it is not possible for the risk management process to ensure that top policymakers will make rational and unbiased decisions. But it is essential for the risk assessment process to provide the information necessary for rational decision-making to occur. Perhaps one indicator of a society that responds rationally to risk is that it is able to learn from its mistakes. To date, the jury is out on whether the next forty years of environmental policymaking will demonstrate the level of rational risk regulation concerning macro-risks that we have seen regarding micro-risks, or whether the climate meltdown will simply mature more slowly than the financial meltdown.