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Policy Analysis for Natural Hazards: Some Cautionary Lessons from Environmental Policy Analysis

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POLICY ANALYSIS FOR NATURAL HAZARDS: SOME CAUTIONARY LESSONS FROM ENVIRONMENTAL POLICY ANALYSIS

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ABSTRACT

How should agencies and legislatures evaluate possible policies to mitigate the impacts of earthquakes, floods, hurricanes and other natural hazards? In particular, should governmental bodies adopt the sorts of policy-analytic and risk assessment techniques that are widely used in the area of environmental hazards (chemical toxins and radiation)? Environmental hazards policy analysis regularly employs proxy tests, in particular tests of technological "feasibility," rather than focusing on a policy's impact on well-being. When human welfare does enter the analysis, particular aspects of well-being, such as health and safety, are often given priority over others. "Individual risk" tests and other features of environmental policy analysis sometimes make policy choice fairly insensitive to the size of the exposed population. Seemingly arbitrary numerical cutoffs, such as the one-in-one million incremental risk level, help structure policy evaluation. Risk assessment techniques are often deterministic rather

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than probabilistic, and in estimating point values often rely on "conservative" rather than central-tendency estimates.

The Article argues that these sorts of features of environmental policy analysis may be justifiable, but only on institutional grounds—if they sufficiently reduce decision costs or bureaucratic error or shirking—and should not be reflexively adopted by natural hazards policymakers. Absent persuasive institutional justification, natural hazards policy analysis should be welfare-focused, multidimensional, and sensitive to population size, and natural hazards risk assessment techniques should provide information suitable for policy-analytic techniques of this sort.

INTRODUCTION

How should policy analysis for natural hazards be structured? Academics have given relatively little systematic attention to this question, by contrast with the question of structuring policy analysis for so-called "environmental" hazards (that is, chemical toxins and radiation).[1] To be sure, scholarly literatures focusing on risk assessment and management of certain specific natural hazards are well-developed—consider the literatures on flood, hurricane, and seismic risks.[2] But there is no general paradigm for natural hazards risk assessment comparable to the overarching framework for environmental risk assessment that the seminal *Red Book* (1983)[3] put in place. Since the publication of the *Red Book*, numerous governmental commission reports and academic reports on

1. The term "environmental risk assessment," by contrast with "ecological risk assessment," is often used to mean the assessment of health and safety risks posed by toxins and radiation. Although this terminology is confusing, it is common in the risk assessment literature. *See* Peter Calow, *Environmental Risk Assessment and Management: The Whats, Whys and Hows?*, *in* HANDBOOK OF ENVIRONMENTAL RISK ASSESSMENT AND MANAGEMENT 1–2 (Peter Calow ed., 1998). I therefore use "environmental" in this Article as pertaining to toxins and radiation, and count FDA, OSHA, and NRC as well as EPA as "environmental" agencies.

2. *See, e.g.*, FLOODS AND LANDSLIDES: INTEGRATED RISK ASSESSMENT (Riccardo Casale & Claudio Margottini eds., 1999); H. JOHN HEINZ III CTR. FOR SCI., ECON. AND THE ENV'T, THE HIDDEN COSTS OF COASTAL HAZARDS: IMPLICATIONS FOR RISK ASSESSMENT AND MITIGATION (2000) [hereinafter HIDDEN COSTS]; NAT'L INST. OF BLDG. SCIS., ASSESSMENT OF THE STATE OF THE ART EARTHQUAKE LOSS ESTIMATION METHODOLOGIES (1993). For a good summary of risk assessment models in these different areas, see Arleen A. Hill & Susan L. Cutter, *Methods for Determining Disaster Proneness*, *in* AMERICAN HAZARDSCAPES: THE REGIONALIZATION OF HAZARDS AND DISASTERS 13 (Susan L. Cutter ed., 2001) [hereinafter AMERICAN HAZARDSCAPES].

3. NAT'L RESEARCH COUNCIL, RISK ASSESSMENT IN THE FEDERAL GOVERNMENT: MANAGING THE PROCESS (1983).

environmental risk assessment or management have appeared;[4] the counterpart literature, which treats *natural* hazards as a general problem for policy analysis, is much smaller.[5]

Turning from academic work to governmental practice, there certainly *are* agencies that have well-developed policy-analytic protocols for addressing natural hazards—consider the guidance documents for evaluating flood reduction measures that the U.S. Army Corps of Engineers (ACE) has developed over the years.[6] But expertise in policy analysis varies widely among natural hazards agencies. Compare ACE with the Federal Emergency Management Agency (FEMA), which has only fairly recently begun to develop risk assessment models.[7] By contrast, all the leading federal agencies that focus on chemical toxins and radiation—the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA), and the Nuclear Regulatory Commission (NRC)—have adopted risk assessment as a key component of their decisionmaking.[8]

It is interesting to speculate about the reasons for the differential development of policy analysis in the environmental and natural hazards bureaucracies. The reasons may be in part historical (the happenstance of the *Red Book*'s publication), cultural (the culture of science at EPA, and of toxicology at FDA, both of which were receptive to risk assessment), or structural (the fact that natural hazards policymaking is more highly devolved to the states than environmental policymaking; for example, FEMA's main tool for

4. Much of this literature is summarized and cited in HUMAN AND ECOLOGICAL RISK ASSESSMENT: THEORY AND PRACTICE (Dennis J. Paustenbach ed., 2002).

5. An important exception is DENNIS S. MILETI, DISASTERS BY DESIGN: A REASSESSMENT OF NATURAL HAZARDS IN THE UNITED STATES (1999).

6. *See generally* NAT'L ACAD. OF SCIS., ANALYTICAL METHODS AND APPROACHES FOR WATER RESOURCES PROJECT PLANNING (2004) (describing ACE practices); NAT'L RESEARCH COUNCIL, NEW DIRECTIONS IN WATER RESOURCES PLANNING FOR THE U.S. ARMY CORPS OF ENGINEERS (1999) [hereinafter WATER RESOURCES PLANNING] (same); NAT'L RESEARCH COUNCIL, RISK ANALYSIS AND UNCERTAINTY IN FLOOD DAMAGE REDUCTION STUDIES (2000) [hereinafter FLOOD DAMAGE REDUCTION STUDIES] (same).

7. *See* Robert V. Whitman et al., *Development of a National Earthquake Loss Estimation Methodology*, 13 EARTHQUAKE SPECTRA 643 (1997); HAZUS: FEMA's Software Program for Estimating Potential Losses from Disasters, http://www.fema.gov/plan/prevent/hazus/index.shtm (last visited Aug. 24, 2006).

8. *See* Matthew D. Adler, *Against "Individual Risk": A Sympathetic Critique of Risk Assessment*, 153 U. PA. L. REV. 1121, 1148 n.91 (2005).

hazards mitigation is the funding of state mitigation plans and measures[9]).

In any event, academics and policymakers need to engage in more sustained discussion about how to evaluate the threats that natural hazards pose to human life, health, property, and other human interests, and the desirability of governmental policies for reducing those threats. Hurricane Katrina, with an estimated $100 billion in property damage and 1,330 fatalities, underscores the importance of the discussion[10]—as does Katrina's seismic counterpart, the 1995 Kobe earthquake, with an estimated $115 billion in property damage and 6,500 deaths.[11] But the roughly $10 billion in annual property and crop damage (to say nothing of indirect economic effects) and hundreds of annual fatalities caused by seismic and weather events in the U.S. in the years before Katrina should have been sufficient indication of its importance.[12]

This Article aims to contribute to that discussion. The particular strategy I adopt will be to draw from the U.S. experience with environmental hazards policy analysis in suggesting cautionary lessons for natural hazards policy analysis.

It is important to distinguish, at the outset, between *policy analysis* and *policy tools*. Natural hazards *policy tools* are the various kinds of interventions by which governmental bodies, federal or state, can reduce the harms caused by earthquakes, floods, hurricanes, tornadoes, and other natural hazards. These include steps such as the following:

- Constructing levees, floodwalls, and dams
- Incorporating provisions in building codes, for new buildings, that reduce the risk of building collapse or other damage in the event of earthquakes or hurricanes, or that require structures in the floodplain to be sufficiently elevated

9. *See* DAVID R. GODSCHALK ET AL., NATURAL HAZARD MITIGATION: RECASTING DISASTER POLICY AND PLANNING 11–16 (1999).

10. WHITE HOUSE, THE FEDERAL RESPONSE TO HURRICANE KATRINA: LESSONS LEARNED 7–8 (2006).

11. *See* George Horwich, *Economic Lessons of the Kobe Earthquake*, 48 ECON. DEV. & CULTURAL CHANGE 521 (2000).

12. *See* Jerry T. Mitchell & Deborah S.K. Thomas, *Trends in Disaster Losses*, *in* AMERICAN HAZARDSCAPES, *supra* note 2, at 77, 79–81.

- Reinforcing existing buildings to resist wind and ground movement
- Relocating homes, commercial property, or infrastructure away from floodplains and hurricane-prone coastal areas
- Limiting future construction in these areas through zoning
- Requiring individuals in high-risk areas to purchase insurance, which may help induce them to take individual mitigation measures
- Disseminating information about natural hazard risks and countermeasures
- Temporarily evacuating individuals in advance of a specific flood or hurricane
- Providing emergency food, medical care, shelter, and social services to an area hit by an earthquake, flood, hurricane, tornado, or other natural hazard.[13]

By contrast, *policy analysis* means the application of some decisionmaking technique for choosing among policy tools. Cost-benefit analysis is one policy-analytic technique. A different technique is to choose the policy that involves the lowest risk of premature death for some individual (for example, the average individual) from some particular risk source (for example, a particular toxin or natural hazard). A third technique is to consider only policies that are technologically "feasible" or "practicable," and within this set consider the policy that involves the lowest risk of premature death for some individual from some particular risk source. This is an illustrative, not exhaustive, list.

The chief policy tools for reducing the harms caused by chemical toxins and radiation—for example, reducing industrial emissions of air and water pollutants, requiring workers to wear protective gear, cleaning up waste dumps, limiting the use of pesticides, or regulating food additives—are, clearly, quite different from the policy tools for reducing the harms caused by natural hazards. By contrast, policy-analytic techniques are (at least to some substantial extent) translatable from the environmental to the natural hazards domain.

It is therefore natural to ask: what lessons can be drawn for the (less developed) field of natural hazards policy analysis from the (more developed) field of environmental policy analysis? This Article addresses that question, focusing on major cautionary lessons. What

13. *See* MILETI, *supra* note 5, at 155–240.

are the recurrent features of existing environmental policy analysis that are (or may well be) problematic, and that natural hazards agencies should hesitate to incorporate into their choice procedures?[14] My focus on large and cautionary lessons is a heuristic device, designed to structure the learning exercise. There are many nonproblematic features of environmental policy analysis that natural hazards agencies should duplicate, and many small mistakes that can be avoided; but a list of all the lessons, positive and negative, large and small, that can be gleaned from the history of policy analysis at EPA, FDA, OSHA, and NRC would be overwhelming. I therefore train my attention on the major cautionary lessons.

Some commentators are opposed to the very enterprise of rigorous policy analysis.[15] *That* is not my view. Environmental agencies are to be applauded for developing a large and integrated set of protocols for making a range of difficult policy decisions in the teeth of great uncertainty. This is a genuine accomplishment in good governance, which should be emulated by federal agencies such as FEMA and ACE and by state agencies in California,[16] Florida, and elsewhere that address natural hazards. My heuristic focus on the imperfections of the environmental agencies' protocols is certainly not meant to suggest that environmental policy analysis has generally been a failure, or that natural hazards agencies should eschew the use of systematic choice procedures.

Nontrivial normative advice about policy matters is invariably somewhat controversial. I do not pretend that my recommendations for policy analysis are robust across all plausible moral views. Searching for a true "overlapping consensus," here, is a quixotic enterprise. On the other hand, giving useful advice does not entail adopting some fully specified and therefore highly controversial moral view. My general moral framework for this Article, one that I

14. I frame the question in terms of features of environmental policy analysis that "may be" problematic, and that natural hazards agencies should hesitate to incorporate, because (as shall emerge from the discussion below), the central lesson that emerges from a review of environmental policy-analytic practice is a qualified one. Proxy criteria, criteria that give especial weight to some aspect of well-being, and simplified techniques for risk assessment *may* be justified, but only on institutional grounds. In particular, see *infra* text accompanying notes 36–39.

15. *See* Adler, *supra* note 8, at 1132 n.39 (citing sources).

16. *See* GOVERNOR'S OFFICE OF EMERGENCY SERVS., STATE OF CALIFORNIA MULTI HAZARD MITIGATION PLAN (2004), *available at* http://www.oes.ca.gov (follow "Hazard Mitigation" hyperlink; then follow "State Multi-Hazard Mitigation Plan" hyperlink).

have adopted in other work, is "weak welfarism."[17] Weak welfarism is a pluralistic framework that recognizes overall well-being as a morally relevant consideration, but also allows for distributive considerations and moral rights.

More precisely, weak welfarism says that the morally justifiable choice in any governmental choice situation is a function of a possible plurality of moral factors $\{W, F_1, F_2 \ldots\ldots F_M\}$, where W is overall well-being, and $M \geq 0$. Utilitarianism is a limiting case of weak welfarism. Utilitarians insist that $M = 0$. But equity-regarding views also fall under the rubric of weak welfarism. An equity-regarding view has the structure $\{W, E, \ldots\}$, where W is overall well-being and E attends to the distribution of well-being, or of important preconditions for well-being, such as income. Finally, "deontological" views can be subsumed within this framework. These views posit various moral rights—such as the right not to be killed, or perhaps the right not to be put at risk of death—that constrain government's pursuit of overall well-being or the equalization of well-being.[18]

The framework of weak welfarism will generate prescriptions for policy analysis that are *relatively* uncontroversial—prescriptions which should be accepted by anyone holding a more specific moral view subsumable within this framework.

The existing scholarship on environmental policymaking often draws a sharp distinction between "risk management" (a somewhat confusing term for what I am calling policy analysis) and "risk assessment."[19] A policy-analytic technique structures governmental officials' deliberations. Risk assessment is not itself a policy-analytic technique. Rather, it is a characterization of the effect of environmental or natural hazards on human life or health, or other

17. *See* MATTHEW D. ADLER & ERIC A. POSNER, NEW FOUNDATIONS OF COST-BENEFIT ANALYSIS 25–61 (2006).

18. Weak welfarism also subsumes intrinsicalist environmental views, which see environmental degradation as morally problematic independent of any effect on the well-being of humans or other individual entities (such as certain animals) that possess a well-being. For simplicity, I ignore intrinsicalist environmental views. Those views posit an environmental factor F^* that (by definition) is not sensitive to well-being. F^* alone would not support the general theme pressed in this Article: that policy analysis should, at some level, be welfare-focused, attend to the plurality of welfare dimensions (multidimensionality), and be sensitive to population size. Still, it is implausible that F^* would be the *sole* morally relevant factor. A plausible specification of weak welfarism would surely include overall well-being, equity, or rights along with F^*; and those constructs *do* support the general theme, as fleshed out below.

19. *See, e.g.*, Dennis J. Paustenbach, *Primer on Human and Environmental Risk Assessment*, *in* HUMAN AND ECOLOGICAL RISK ASSESSMENT, *supra* note 4, at 5–7.

human interests, which functions as an input to *certain* policy-analytic techniques. Cost-benefit analysis is a policy-analytic technique that requires a risk assessment. By contrast, the procedure of reducing toxins to the lowest level technologically feasible does not require a risk assessment. This procedure necessitates a quantification of the toxin levels associated with different policy choices, and a determination of the feasibility of those levels, but it does not need to quantify the deaths or death risks associated with the different choices.

The structure of my analysis will track the standard distinction between "risk management" and "risk assessment." Part I of the Article discusses policy analysis proper. Part II discusses risk assessment. First, what are the major cautionary lessons for natural hazards policy analysis that can be gleaned from the environmental policy analogue? Second, what are the major cautionary lessons for the practice of risk assessment?

I. Policy Analysis

Section 112 of the Clean Air Act,[20] which governs certain air pollutants, illustrates some of the major features of environmental policy analysis as currently practiced in the U.S. EPA is required to set an initial emissions level for covered pollutants by considering technological feasibility as well as the cost of reducing emissions. At a minimum, for new sources in a given source category, the emissions level cannot be higher than "the emission control that is achieved in practice by the best controlled similar source"; a minimum reduction for existing sources is similarly set by reference to current pollution control practices.[21] Then, within a set period of time after the establishment of this initial level, EPA is required to consider establishing a lower level if the incremental lifetime cancer risk to the maximally exposed individual exceeds one in one million (the "trigger provision").[22]

Note how this structure for EPA decisionmaking prioritizes safety over other human interests: it is a one in one million fatality risk, not property damage or other nonsafety effects of pollution, that

20. Clean Air Act § 112, 42 U.S.C. § 7412 (2000).

21. § 7412(d)(3). These are the requirements for "major" sources, as opposed to "area" sources. *See* § 7412(d)(5).

22. For a more detailed discussion of section 112 of the Clean Air Act, see Adler, *supra* note 8, at 1150–52, and the sources cited at 1150 n.96.

is supposed to prompt EPA to consider revising the initial emissions level.[23] Note, too, how the structure incorporates a proxy test. EPA is not told to set the emissions level by maximizing safety, or by balancing all aspects of human well-being as per cost-benefit analysis; instead, the test of technological feasibility (meaning, in this case, both physical achievability and existing practices[24]) is an important ingredient in determining how stringently the pollutant should be regulated. Further, observe that the trigger provision in section 112 uses a non-zero numerical cutoff. Why a one in one million risk to the maximally exposed individual? Why not a one in one hundred thousand risk? Or a zero risk? Observe, finally, that section 112's trigger provision does not depend on the size of the population exposed to the pollutant. The provision is defined in terms of the risk to the maximally exposed individual, not the number of expected deaths from the pollutant. Doubling or quadrupling the exposed population will not affect whether the trigger provision comes into play.[25]

Each of these aspects of section 112—the prioritization of safety, the use of technology-based proxies, insensitivity to population size, and the use of non-zero risk cutoffs—is widespread in environmental policy. And each grounds a cautionary lesson for natural hazards policymakers.

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23. Technically, the trigger provision is embedded in a broader provision, § 7412(f)(2)(A), that instructs EPA to revise the technology-based standards under § 7412(d) if necessary *either* to "provide an ample margin of safety to protect public health" *or* "to prevent, taking into consideration costs, energy, safety, and other relevant factors, an adverse environmental effect." However, this general provision is supplemented by the trigger provision, which provides a more specific condition under which EPA is required to consider lowering the technology-based limits and is defined solely in terms of safety—the risk to the maximally exposed individual. § 7412(f)(2)(A).

24. On the different meanings of technological feasibility, see ADLER & POSNER, *supra* note 17, at 75, 91; *see also infra* text accompanying notes 50–52.

25. The trigger provision is not a substantive provision. If triggered, it requires EPA to consider lowering the emission level; but section 112 does not clearly specify what substantive test EPA should use at that point. EPA, in fact, employs a population-size-sensitive test. *See* Adler, *supra* note 8, at 1151–52 & n.102; *see also* National Emission Standards for Hazardous Air Pollutants for Organic Hazardous Air Pollutants from the Synthetic Organic Chemical Manufacturing Industry, 71 Fed. Reg. 34,422, 34,428 (June 14, 2006). So section 112, as interpreted by the EPA, has some elements that *are* population-size sensitive. But the trigger provision itself is not.

A. Do Not Give Priority to Safety or Any Particular Aspect of Well-Being (AGIR)[26]

Environmental policy analysis often prioritizes safety (longevity and health) over other aspects of human well-being. The simplest example is when the agency employs some kind of safety-maximization criterion, seeking to minimize the health and longevity impacts of a particular toxin. Paradigm cases are the Delaney Clause, which requires FDA to refrain from licensing carcinogenic food additives, notwithstanding the nutritive or hedonic benefits of those additives or, for that matter, their benefits in preventing diseases; the general provision for additives, which demands that they be "safe";[27] and section 109 of the Clean Air Act, which requires EPA to issue standards for certain major air pollutants at a level that "protect[s] the public health" with an "adequate margin of safety," notwithstanding economic costs.[28]

A different kind of prioritization occurs when the policy-analytic technique hybridizes safety considerations with other considerations, but does so in a way that gives especial weight to safety. For example, the Occupational Safety and Health Act instructs OSHA to set a standard for workplace toxins at a level which "most adequately assures, to the extent feasible, . . . that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard . . . for the period of his working life."[29] A standard way to read this provision is that OSHA should maximize safety within the constraints of technical feasibility and economic feasibility (in other words, not bankrupting firms).[30] Economic costs are not totally ignored by the test, but they come into play only when large enough to trigger bankruptcy; safety is not the sole consideration, since it is hedged by technical and economic feasibility, but it is more important than economic costs.

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26. "AGIR" stands for "absent good institutional reason."

27. *See* Adler, *supra* note 8, at 1164–67 (describing FDA regulation of food and color additives, including the Delaney Clause).

28. *See* Clean Air Act § 109, 42 U.S.C. § 7409(b) (2000); Whitman v. Am. Trucking Ass'ns, 531 U.S. 457, 465 (2001).

29. 29 U.S.C. § 655(b)(5) (2000).

30. *See* David M. Driesen, *Distributing the Costs of Environmental, Health, and Safety Protection: The Feasibility Principle, Cost-Benefit Analysis, and Regulatory Reform*, 32 B.C. ENVTL. AFF. L. REV. 1 (2005); Occupational Exposure to 1,3-Butadiene, 61 Fed. Reg. 56,746, 56,791 (Nov. 4, 1996).

The fact that environmental policymakers regularly give priority to safety over other human interests (either as a matter of statutory requirement, as in the above examples, or as a matter of administrative discretion) has been the focus of much scholarly criticism—and indeed *is* worrying from the perspective of weak welfarism. Human well-being is multidimensional. Martha Nussbaum has defended a plausible list of intrinsic human interests, the basic constituents of human welfare, which runs as follows:

- life
- bodily health
- bodily integrity
- senses, imagination and thought
- emotions
- practical reason
- affiliation
- other species
- play
- control over one's environment[31]

Of course, one might quarrel with the details of Professor Nussbaum's list, and indeed there are various competitor lists in the philosophical literature;[32] but no plausible list counts longevity and health as the sole human interests, or as interests that have a categorical ("lexical") priority over others.

The multidimensionality of human well-being means, first, that policy-analytic techniques designed to identify policies which maximize overall well-being should not (bracketing institutional considerations) give special priority to safety. And, indeed, cost-benefit analysis—the standard such technique—incorporates no such priority.

This point is not surprising. More surprising, perhaps, is the claim that distributive considerations, too, are multidimensional. Egalitarian moral theory remains quite controversial. There are continuing disagreements about (1) the "currency" for equity (should government aim to equalize welfare, or rather to equalize individuals' "holdings" of certain resources that are preconditions for welfare, such as income); (2) the structure of the equity measure, namely

31. *See* MARTHA C. NUSSBAUM, WOMEN AND HUMAN DEVELOPMENT: THE CAPABILITIES APPROACH 78–80 (2000).

32. *See* ADLER & POSNER, *supra* note 17, at 31–32.

whether it focuses on raising individuals above some low level of well-being or resources, or instead is concerned about the overall pattern of well-being or resources throughout the population; and (3) the application of equity measures under conditions of uncertainty, namely whether government should seek to equalize actual resources or well-being, or instead to equalize individuals' expectations of resources or well-being.[33] But all of the plausible possibilities are sensitive to the multiplicity of human interests represented on a list such as Professor Nussbaum's. No plausible permutation would suggest that equality merely demands the equalization of safety or safety risks.

Finally, policymakers who attend to moral rights also ought to engage in a kind of multidimensional analysis (bracketing institutional considerations).[34] Preliminarily—a point that will be repeated below—it should be stressed that government does not violate moral rights merely by failing to mitigate a natural hazard that causes serious welfare setbacks. If I am a competent adult who listened to and understood the weather forecast and chose to remain in the path of a hurricane, suffering grave injury as a result, then government's failure to force or induce me to evacuate did not violate my moral rights. However, there may well be some governmental choices regarding natural hazards that deontologists would see as rights-violating—for example, setting up a poorly constructed or inadequate levee, which is described to residents as protective but fails or is overtopped and harms some of them.

The point I wish to make here is that the subset of harmful governmental choices that are rights-violating will not be limited to a particular aspect of welfare. One sometimes gets the sense from the environmental literature that the only genuine moral rights are rights to bodily integrity. Sophisticated deontologists would reject that view. I violate your rights by punching you *or* by stealing your car.

33. *See* Matthew D. Adler, *Equity Analysis and Natural Hazards Policy*, *in* ON RISK AND DISASTER: LESSONS FROM HURRICANE KATRINA 129 (Ronald J. Daniels et al. eds., 2006); Matthew D. Adler & Chris William Sanchirico, *Inequality and Uncertainty: Theory and Legal Applications*, 155 U. PA. L. REV. (forthcoming Dec. 2006).

34. It is plausible to think that there is a tight linkage between moral rights and "deontological" constraints or duties—namely, that *P*'s moral right is correlative to a deontological duty that *Q* owes to *P*, such as a duty not to kill *P* or impose a risk on *P*—and for purposes of this Article I use the notions of moral rights and deontological constraints interchangeably. For a discussion of deontological constraints on killing and risking, and citations to the literature on moral rights and deontological constraints, see Adler, *supra* note 8 at 1223–32.

Similarly, government's construction of a bad levee that ends up killing individuals and destroying many homes violates both moral rights to life and moral rights to property.

It has been suggested to me that safety is not really a single dimension of well-being—in the way that, say, play or recreation is—because being alive is a precondition for realizing any dimension of well-being.[35] Consider Professor Nussbaum's list. One can have friends (the good of affiliation), have a vibrant emotional life (emotions), develop and realize goals (practical reason), and so on, without engaging in play; but one cannot do any of these things without being alive. But this way of looking at things makes giving priority to safety seem yet more arbitrary. Imagine that the dimensions of well-being are $\{V_1 \ldots\ldots V_N\}$ and longevity is seen, not as a separate dimension, but as a general precondition for realizing any of the V_i. Consider, now, a policy-analytic test that tells the policymaker to maximize longevity rather than engage in cost-benefit analysis. In effect, this tells the policymaker to consider changes to each V_i that occur in a certain way (through a change in an individual's longevity), but not changes that occur in other ways (by changing enjoyment, recreation, friendship, consumption and so on without changing longevity). The longevity-maximization test therefore draws a (seemingly) arbitrary distinction between the different modalities by which an individual's attainment of the various V_i can change.

So is there any way to justify safety-prioritizing policy-analytic tests such as those put in place by the Delaney Clause, the food additive licensing provisions, section 109 of the Clean Air Act, or the OSHA toxins provision? Given the multidimensionality of welfare, and therewith the moral constructs that figure in weak welfarism—overall well-being, equity, moral rights—is there any way to justify the widespread use by environmental decisionmakers of decision procedures that give special priority to safety? The answer is yes. Institutional considerations may perhaps warrant safety-prioritizing procedures. Bureaucrats are not cognitively perfect or perfectly law-abiding; they cannot be expected to implement the policy-analytic criteria assigned to them with zero decision costs (direct and delay costs) and zero error rate.[36]

35. Thanks to David Driesen for pressing me to consider this point.

36. On the importance of institutional considerations in structuring administrative decision procedures, see ADLER & POSNER, *supra* note 17, at 62–123.

Consider the construct of overall well-being. It is *possible* that a provision which instructs an environmental agency to set pollution levels using a safety-maximization criterion is a better way to implement the criterion of overall well-being than a provision instructing the agency to set pollution levels using cost-benefit analysis. Why? The safety-maximization criterion has some (albeit quite imperfect) correlation with the construct of overall well-being.[37] Safety-maximizing projects are likelier to increase overall well-being than projects identified through a coin flip. Further, although the cost-benefit criterion is better correlated with overall well-being, cost-benefit analysis may have higher decision costs, and/or be associated with a higher rate of bureaucratic error, than safety maximization. Cost-benefit analysis may be more expensive in terms of direct costs (meaning analysts' wages, contractors' fees, computer time, and the cost of securing information for the analysis). It may tend to take longer than safety-maximization, and therefore delay the implementation of beneficial policies more than safety maximization does. It could have a higher error rate[38] than safety maximization—because well-intentioned bureaucrats are more likely to make mistakes in their application of cost-benefit analysis than in their application of the safety-maximization criterion; or because the application of cost-benefit analysis by the agency is more difficult for the agency's political overseers to monitor, making it easier for bureaucrats to advance their own (non-welfare-maximizing) preferences under the pretense of performing cost-benefit analysis. Considering both the correlation of the cost-benefit criterion and the safety-maximization criterion with overall well-being, and the decision costs and error rates associated with the two criteria, it *could* be the case that instructing some environmental agency to employ safety-maximization is actually better, in terms of overall well-being, than instructing the agency to employ cost-benefit analysis.

For short, I will call this kind of argument for a policy-analytic criterion an "institutional" argument (because it attends to the actual results of directing governmental officials to follow some policy-analytic criterion, given how governmental institutions actually work).

37. *See id.* at 91–95.

38. By error rate, I mean the rate at which the criterion assigned to bureaucrats (in this example, the cost-benefit criterion or the safety maximization criterion) is incorrectly applied. A criterion with zero error rate may, of course, still be inadvisable, if it is too poorly correlated with the underlying moral considerations such as overall well-being.

In point of fact, I very much doubt that institutional considerations *do* make safety-prioritizing procedures a better mechanism for advancing overall well-being than cost-benefit analysis.[39] But this is an empirical question, having to do with the capacities and motivations of agency staff and overseers.

Whatever the answer to that question, one can draw the following cautionary lesson from environmental policy analysis: namely, natural hazards agencies should not *arbitrarily* give high priority to certain aspects of well-being over others. A policy-analytic technique that gives especial priority to safety, or some other human interest, is unjustified *unless* alternative, multidimensional procedures are actually a poorer way to implement weak welfarism, given the high decision costs and/or rate of bureaucratic error associated with these multidimensional techniques. Notably, the literature on environmental policymaking fails to provide this sort of institutional defense of prioritizing safety.

A second point: the institutional grounds for administrative procedures that give special priority to some aspect of well-being simply shift the locus of multidimensional policy analysis. A multidimensional analysis should still occur at some point in the governmental process. Perhaps high-level agency officials issue a directive instructing lower-level staff to employ unidimensional (e.g., safety-focused) analytic criteria in making some class of decisions. But then, presumably, the high-level officials should engage in some sort of multidimensional analysis to determine whether the unidimensional procedure tracks overall well-being, equity, or moral rights—all multidimensional constructs—sufficiently well. Or perhaps we are to imagine Congress instructing agency officials, at all levels, to employ the unidimensional criterion. But then Congress should

39. *See* ADLER & POSNER, *supra* note 17, at 62–123. The reader might wonder how the view generally adopted in this Article, which entertains the possibility of institutional justifications for policy-analytic criteria that give priority to a particular aspect of well-being (such as safety), or that are proxy criteria rather than focusing on well-being, is consistent with the defense of cost-benefit analysis that Eric Posner and I present in NEW FOUNDATIONS OF COST-BENEFIT ANALYSIS, *supra* note 17, and other work. The answer is twofold. First, and most importantly, our defense of cost-benefit analysis rests in part on empirical claims, about how cost-benefit actually works in institutions; in this Article I mean to bracket those empirical issues, and provide recommendations for natural hazards policy that can be accepted even by those who dispute our empirical claims. Second, NEW FOUNDATIONS OF COST-BENEFIT ANALYSIS recommends that cost-benefit analysis be used for large policy choices, and leaves open the question whether other criteria (with lower decision costs) would be appropriate for smaller decisions. *See id.* at 83, 186.

itself undertake a multidimensional analysis, or at least consult an expert commission about how to structure the agency's decisionmaking. Before the commission can properly advise Congress to require the agency to focus on safety (for example), it ought to consider *both* the safety and non-safety components of overall well-being, equity, and moral rights and determine that, given decision costs and bureaucratic error, a safety-focused procedure is the best way to implement these multidimensional moral constructs.

How relevant are these observations about multidimensionality to natural hazards policy analysis? To begin, it is quite obviously true as an empirical matter that natural hazards not only kill or injure humans, but produce a variety of other sorts of welfare setbacks. They cause property damage, business interruptions, and resultant losses of wealth. Beyond that, they produce temporary or even protracted homelessness, psychological trauma, unemployment (often coupled with distress, anxiety, or anger), the disruption of families and communities, the interruption of schooling, and the destruction of cultural heritage.[40] Further, even if the causal impact of some particular type of natural hazard were somehow confined to welfare dimension V^*—even if, somehow, the hazard simply caused physical injury, or psychological trauma—the effect of a policy intervention to mitigate the hazard would involve governmental or private expenditures, which would ramify along dimensions other than V^*.

Natural hazards decisionmakers, like their environmental counterparts, do sometimes employ choice criteria that give special priority to certain aspects of well-being. The clearest example is ACE's procedures for determining whether and how to build flood control structures, such as levees and floodwalls. ACE has for many years relied on cost-benefit analysis as its central criterion for making these decisions.[41] However, this is a truncated kind of cost-benefit analysis. ACE has traditionally included economic costs and benefits

40. *See* HIDDEN COSTS, *supra* note 2, at 45–104; NAT'L RESEARCH COUNCIL, THE IMPACTS OF NATURAL DISASTERS: A FRAMEWORK FOR LOSS ESTIMATION (1999); Charles W. Howe & Harold C. Cochrane, *Guidelines for the Uniform Definition, Identification, and Measurement of Economic Damages from Natural Hazard Events*, *in* ECONOMICS AND THE WIND 159 (Bradley T. Ewing et al. eds., 2005).

41. On ACE's decisionmaking procedures, see generally sources cited *supra* note 6. I say "as its central criterion" because ACE's ultimate decisions are a mix of cost-benefit analysis and other factors—for example, building beyond the height identified by cost-benefit analysis, up to the one hundred-year flood, for levee certification purposes. *See infra* text accompanying notes 53–55, 81.

in the analysis—the cost of building the structure, the benefit of the structure in reducing property damage to buildings and contents caused by inundation—but not safety or most ecological effects.[42]

This is not to say that noneconomic factors are completely ignored. For example, ecological effects have traditionally been considered by ACE as a constraint on the maximization of economic benefits.[43] But the agency's practice has been to refrain from monetizing safety and most ecological effects and incorporating these impacts in its cost-benefit analyses of flood reduction measures. So there is an inversion from the environmental case, in which regulators often give priority to safety over economic costs.

It is hard to see what the institutional justification for ACE's truncated cost-benefit analysis would be. Consider safety benefits. The marginal decision costs of predicting both the safety and economic benefits of flood control structures, rather than simply the economic benefits, would seem to be low. Further, given that there are now well-accepted techniques for pricing safety, employed by environmental agencies in those instances when they do engage in cost-benefit analysis,[44] it is not clear why adding safety to the list of monetized impacts would substantially increase bureaucratic shirking or error by ACE staff. To be sure, decisions about how to build flood control structures may typically have a small effect on the sheer number of flood fatalities and injuries, because the government can warn and evacuate in advance of a flood.[45] However, the warn-and-evacuate strategy is not perfect at preventing fatalities and injuries (as Katrina evidences) and the overall welfare value of saving even a single life is large. Thus information about safety impacts, which can be incorporated in ACE's cost-benefit analysis at low marginal decision costs, would seem to be worth incorporating.

What about the valuation of ecological effects? Here, ACE is on slightly firmer ground. Many applied economists believe that "non-

42. *See* NAT'L ACAD. OF SCIS., *supra* note 6, at 53–55, 60; NAT'L RESEARCH COUNCIL, RIVER BASINS AND COASTAL SYSTEMS PLANNING WITHIN THE U.S. ARMY CORPS OF ENGINEERS 95–98 (2004). I say that ACE has refrained from monetizing "most" ecological effects because it does monetize recreational values. *See* WATER RESOURCES PLANNING, *supra* note 6, at 67–70.

43. *See* NAT'L ACAD. OF SCIS., *supra* note 6, at 61.

44. *See* Adler, *supra* note 8, at 1197–98.

45. Thanks to Jason Johnston for this important observation—one that has also been made, independently, by Lester Lave and Tunde Balvanyos. *See* Lester B. Lave & Tunde Balvanyos, *Risk Analysis and Management of Dam Safety*, 18 RISK ANALYSIS 455, 458 (1998).

use" values should be incorporated in cost-benefit analysis, but I have argued elsewhere that this position is incorrect.[46] I will not repeat the analysis here. Suffice it to say that cost-benefit analysis is a procedure for determining which policies increase overall well-being, and that willingness-to-pay amounts that are grounded in disinterested rather than self-interested preferences should therefore be screened out by the cost-benefit analyst. In the area of ecological valuation, this means screening out non-use values. On the other hand, it is hard to see why ACE would be justified in excluding *use* values from its cost-benefit analyses—namely, changes to the well-being of those who physically interact with ("use") some ecological resource, including recreational values such as hunting, fishing, boating, hiking, and camping; the benefits of clean, potable water and good visibility; scenic values; and so on. There is now a large literature in ecological economics on monetizing use values,[47] and so the decision and manipulability costs of incorporating these in ACE's cost-benefit procedure would seem to be lower than the benefit (in more accurately identifying welfare-maximizing flood control projects).

Ultimately, whether ACE should monetize safety effects or ecological use values along with economic costs and benefits implicates empirical questions—about how different variants of cost-benefit analysis would actually operate at ACE—that I can hardly resolve in this Article. The critical point, for my purposes here, is a more general one: well-being is multidimensional; the moral constructs of overall well-being, equity, and rights are also multidimensional; therefore, an administrative decision procedure which gives priority to one aspect of well-being or a proper subset of its aspects is suspect. Such a procedure should be critically scrutinized by agency overseers and academics, and should be rejected absent a persuasive institutional justification for the procedure—one that compares the procedure to alternative, multidimensional procedures in terms of decision costs, bureaucratic error rates, and correlation with underlying moral constructs.

46. *See* ADLER & POSNER, *supra* note 17, at 133–36; Matthew D. Adler, *Welfare Polls: A Synthesis*, 81 N.Y.U. L. REV. (forthcoming Dec. 2006).

47. For reviews of ecological cost-benefit analysis, including use values, see A. MYRICK FREEMAN III, THE MEASUREMENT OF ENVIRONMENTAL AND RESOURCE VALUES: THEORY AND METHODS (2d ed. 2003); A PRIMER ON NONMARKET VALUATION (Patricia A. Champ et al. eds., 2003); Maureen L. Cropper, *Has Economic Research Answered the Needs of Environmental Policy?*, 39 J. ENVTL. ECON. & MGMT. 328 (2000).

B. Do Not Use Proxy Tests (AGIR)

Technology-based policy analysis is widely used in environmental law. A preliminary word of clarification: sometimes, environmental regulations are divided into "command and control" regulations, which require firms to use specified technologies, and "performance" regulations, which demand a certain level of emissions reduction without specifying how to achieve that reduction. This distinction is *not* the one I mean to draw here. My interest, again, is in characterizing governmental choice procedures, *not* in differentiating the various kinds of primary obligations that government might impose on private individuals.

Technology-based *policy analysis* uses technological criteria as part of the recipe for governmental choice. In the case of environmental policy, technology-based policy analysis tends to focus on "feasible" or "available" technology.[48] Sometimes, technological considerations displace safety considerations as the main policymaking criterion. The provision in Clean Air Act section 112 governing initial emissions limits has this form; EPA, in setting these limits, is instructed to consider technical feasibility as well as cost, but not safety.[49] Sometimes, technological criteria are hybridized with safety or other considerations, as in the case of OSHA's toxins provision, where technological feasibility functions as a constraint on the maximization of safety benefits.

Technological availability or feasibility might be a matter of what is physically possible, given current science and engineering, or rather a matter of norms and practices among some group of actors.[50] It is hard to imagine the first sort of approach having much role in natural hazards policy analysis. Consider levee design: the largest physically possible levee would be hundreds of feet high and massively thick and strong. Surely ACE should (always!) stop well short of this point in building its levees. "Physical possibility" as a goal in levee design would be absurd, and as a putative constraint would be no constraint at all. Parallel points could be made about the construction of hazard-

48. *See* Driesen, *supra* note 30.

49. "These emission standards are to be based not on an assessment of the risks posed by [hazardous air pollutants], but instead on the maximum achievable control technology . . . for sources in each category." Sierra Club v. EPA, 353 F.3d 976, 980 (D.C. Cir. 2004). As explained above, after EPA sets these initial limits, it must eventually consider setting lower limits, and at that stage does consider safety. *See supra* text accompanying notes 20–25.

50. *See* ADLER & POSNER, *supra* note 17, at 75, 91.

resistant buildings and structures—both ordinary residential and commercial property and more critical infrastructure. The strongest physically possible building would be absurdly expensive. Technology also comes into play in warnings and evacuations. It is technologically possible to evacuate everyone from Florida and the Gulf Coast for all of hurricane season, or to send a government representative to warn every household in person.[51] But these are not serious policy proposals.

Technological availability in the second, norms and practices sense, is more thinkable. For example, seismic codes could be specified with reference to current building practices. New construction could be required to be as protective as some percentile of existing construction.[52]

A different sort of technology-based approach to policy analysis, exemplified by ACE practices, employs specific technological rules of thumb. Until the 1990s, ACE traditionally "added 3 feet of freeboard to the design height of its levees, a principle that became a staple of Corps flood damage reduction studies and projects."[53] This three-feet-of-freeboard rule was, in particular, used when ACE built levees to withstand a one hundred-year flood, rather than to maximize net benefits—which occurred when local communities were willing to subsidize the additional levee construction costs needed to reach the one hundred-year mark, so that the area protected by the levee would not be counted as part of the one hundred-year floodplain for purposes of the National Flood Insurance Program.[54] Adding three feet was "a measure to prevent overtopping caused by higher water . . . than was forecast for the design flood, as some uncertainties may not have been explicitly considered."[55]

Closely related to technology-based policy analysis, and an important tool in current natural hazards decisionmaking, is reliability-based analysis.[56] An excellent example is the approach used

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51. *See, e.g.*, Roger Pielke, Jr. & R.E. Carbone, *Weather Impacts, Forecasts, and Policy: An Integrated Perspective*, BULL. AM. METEOROLOGICAL SOC'Y, Mar. 2002, at 393 (discussing costs of overwarning about hurricanes and other adverse weather impacts).

52. *See* Bruce R. Ellingwood, *Earthquake Risk Assessment of Building Structures*, 74 RELIABILITY ENGINEERING & SYS. SAFETY 251, 256 (2001).

53. FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 13. *See generally id.* at 139–58.

54. *See infra* note 81.

55. FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 13.

56. In general, reliability-based tests for structures might be framed as: "Use all feasible technology to ensure that the structure performs function *F* except in extreme event *E*," where

by governmental or quasi-governmental bodies in drafting seismic building codes.[57] These bodies typically aim to write codes that will avoid building collapse in the event of any nonextreme earthquake (for example, any earthquake smaller than the 475-year earthquake).[58] The decisional criterion employed by the code drafters is "prevent building collapse in nonextreme earthquakes" rather than "maximize net benefits, including both economic and safety impacts" or "maximize safety benefits." A similar approach has been traditionally used in designing dams, specifically in deciding how low the risk of dam failure (collapse or overtopping) should be. The goal has traditionally been to design the dam so that it will not fail except in an extreme precipitation event.[59] The criterion, here, is "construct the dam so that it will not fail during nonextreme rainfalls" rather than "maximize net benefits," defined inclusively or narrowly.

To sum up: a variety of proxy tests are currently used, or might conceivably be used, by environmental and natural hazards decisionmakers. These are proxy tests insofar as they focus the decisionmaker's attention on some feature of available choices *other than* their impact on well-being or some of its dimensions. Proxy tests might be technology-based tests (of various kinds), or, a close cousin, reliability tests. Or they might take some other form.

All this is descriptive. But are proxy tests an appropriate policy-analytic tool for environmental or natural hazard regulators? The answer should have a familiar ring: proxy tests are justifiable, if at all, on institutional grounds. And even if proxy tests *are* justified, their use by administrative agencies simply shifts the locus of welfare-focused, (non-proxy-based) decisionmaking within the governmental process.

F might be not collapsing (in the case of a building), remaining passable (in the case of a bridge or roadway), generating electricity (in the case of a power plant), and so on.

57. On seismic codes, see OFFICE OF TECHNOLOGY ASSESSMENT, REDUCING EARTHQUAKE LOSSES (1995) [hereinafter REDUCING EARTHQUAKE LOSSES]; Ellingwood, *supra* note 52.

58. *See* REDUCING EARTHQUAKE LOSSES, *supra* note 57, at 78–79, 103–09; Julian J. Bommer, *Deterministic Vs. Probabilistic Seismic Hazard Assessment: An Exaggerated and Obstructive Dichotomy*, 6 J. EARTHQUAKE ENGINEERING 43, 60–61 (2002); Ellingwood, *supra* note 52.

59. *See* NAT'L RESEARCH COUNCIL, SAFETY OF DAMS: FLOOD AND EARTHQUAKE CRITERIA 8–60 (1985); Lave & Balvanyos, *supra* note 45; David A. Moser, *Risk-Based Analysis in Flood Damage Reduction Studies*, *in* U.S. ARMY CORPS OF ENG'RS, HYDROLOGY & HYDRAULICS WORKSHOP ON RISK-BASED ANALYSIS FOR FLOOD DAMAGE REDUCTION STUDIES 1, 2–4 (1997).

To begin, it is clear that proxy tests will, at some rate, select suboptimal policies—policies that are worse than alternatives with respect to overall welfare, equity, and rights. The critical literature on technology-based tests in environmental law makes this point, showing how a requirement that firms employ "feasible" pollution-reducing measures can lead to inefficient overregulation (if, for example, small firms are required to employ high-fixed-cost technologies) or underregulation (if it would be most efficient to reduce pollution beyond the point that is technologically feasible given continued production of the good, for example by shutting down production entirely).[60]

Similar observations can be made about proxy-based criteria for natural hazards policymaking. Consider ACE's three-feet-of-freeboard rule. The rule is meant to provide an extra margin of protection for communities at risk of flooding. But the protection provided by the rule varies from community to community. A recent study by the National Research Council found that the annual probability of flooding in communities protected by levees built to the one hundred-year flood plus three feet of freeboard varied widely, from one in ten thousand to one in one hundred.[61] "[T]his fixed-freeboard approach provided inconsistent degrees of flood protection to different communities and provided substantially different levels of protection in different regions."[62]

A similar point can be made about the *incremental* protection provided by the three-feet-of-freeboard rule. Absent freeboard, the community will have an annual probability p of flooding; after freeboard, the community will have an annual probability q of flooding. The difference between p and q depends on local hydrology (the shape of the so-called flood-frequency curve) and local hydraulics (the features of the channel in which the flood waters flow). Finally, the variable incremental protection provided by the three-feet-of-freeboard rule has no systematic connection to the benefits of incremental protection—to the amount of property and number of lives at risk.

Or consider the proxy test used to write seismic building codes: ensure that buildings do not collapse except in extreme earthquakes.

60. *See, e.g.*, Bruce A. Ackerman & Richard B. Stewart, *Reforming Environmental Law*, 37 STAN. L. REV. 1333, 1334–40 (1985).

61. FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 144–45, 149–58.

62. *Id.* at 13.

This maps, roughly, onto a safety-focused test, which says to construct buildings to avoid fatalities except in extreme earthquakes—since fatalities caused by building shaking in earthquakes mainly occur when buildings collapse.[63] But the mapping is not perfect, because some damage to buildings short of collapse may cause fatalities (for example, when ceilings or lights fall on occupants).[64] Further, much economic loss can occur when buildings are shaken without collapsing: direct economic loss by virtue of damaged building components, systems, or contents (which are expensive to replace), indirect economic loss by virtue of business interruption, and other indirect effects.

> Recent experience . . . has shown that structural collapses, although spectacular and newsworthy, are by no means the only source of earthquake-related losses. Economic losses also stem from business interruptions; loss of records and computer databases in the service economy; . . . and widespread, noncatastrophic damage to residential and commercial structures throughout the earthquake region. . . . [One] estimate implies that catastrophic building failure, which is what codes and retrofits are designed to prevent, will be responsible for less than one-tenth of California's future bill for direct earthquake losses.[65]

In short, "a code-complying building can 'survive' an earthquake (i.e., not collapse and kill people) and still end up a shambles inside and out."[66] Weak welfarism surely does not require that all buildings be reinforced to the point of suffering no damage at all in nonextreme earthquakes. But presumably there is some such strengthening beyond the point identified by the no-collapse proxy that would be warranted—in particular, that would have welfare benefits exceeding the costs of the additional strengthening.

Even though proxy-based tests pick out suboptimal policies at some nonzero rate, instructing agencies to employ proxy tests can be optimal if they are sufficiently accurate in tracking overall well-being,

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63. *See* REDUCING EARTHQUAKE LOSSES, *supra* note 57, at 72–73.

64. *See* CAL. SEISMIC SAFETY COMM'N, EARTHQUAKE RISK MANAGEMENT: MITIGATION SUCCESS STORIES 17–20 (1999) (discussing program to reinforce ceiling lighting systems in Los Angeles School District buildings, given the risk of injuries or fatalities if systems fell during an earthquake).

65. REDUCING EARTHQUAKE LOSSES, *supra* note 57, at 110.

66. *Id.* at 106. For a similar point about the losses in Hurricane Andrew from building damage short of collapse, see MILETI, *supra* note 5, at 129.

equity, and moral rights, and if the decision costs and rate of bureaucratic error under alternative tests is sufficiently high. But is this possibility in fact realized? In the domain of environmental policy, the answer is difficult and contested, and may well depend on context. Technology-based proxies may not require a risk assessment,[67] whereas a cost-benefit or safety-maximization procedure will. So technology-based proxies may have lower decision costs. But, given advances in computational speed, software, and data availability, which facilitate risk assessment,[68] the decision-cost gap, here, is shrinking. Technology-based proxies may also be clearer in their requirements, hence less manipulable by bureaucrats (or interest groups). The shift from a safety-maximization approach to a technology-based approach *does* seem to have revived the regulation of air pollutants under section 112 of the Clean Air Act.[69] On the other hand, FDA has long regulated food additives using risk assessment, under the general requirement that food additives be "safe." It clearly has managed to evaluate numerous additives, specifically by using a test that ensures that the "individual risk" to a high-end (90th percentile) food consumer is below a "no observed adverse effect level" (NOAEL) based threshold (for noncarcinogenic toxins) or the threshold of a one-in-one million lifetime fatality risk (for carcinogen-containing additives exempt from the Delaney Clause).[70] Although FDA *has* tried to evade the Delaney Clause, finding various statutory loopholes to subject carcinogens to the one-in-one million de minimis threshold instead,[71] I am not aware of evidence that the FDA has regularly subverted this safety threshold or the parallel threshold for noncarcinogens to serve nonsafety goals.

67. By risk assessment, again, I mean a characterization of the impact of the natural hazard on one or more aspects of well-being. A policy-analytic test that is framed purely in terms of technology will not require a risk assessment, but a hybrid test that references *both* technology *and* safety (or other aspect(s) of well-being) will.

68. *See* F. Bendimerad, *Loss Estimation: A Powerful Tool for Risk Assessment and Mitigation*, 21 SOIL DYNAMICS & EARTHQUAKE ENGINEERING 467 (2001); Michael E. Hodgson & Susan L. Cutter, *Mapping and the Spatial Analysis of Hazardscapes*, *in* AMERICAN HAZARDSCAPES, *supra* note 2, at 50–60; Jason K. Levy et al., *Advances in Decision Support Systems for Flood Disaster Management: Challenges and Opportunities*, 21 WATER RESOURCES DEV. 593 (2005).

69. *See, e.g.*, David P. Novello, *The Air Toxics Program at the Crossroads: From MACT to Residual Risk*, 18 NAT. RESOURCES & ENV'T 57 (2004).

70. *See* Adler, *supra* note 8, at 1164–67.

71. *See id.* at 1165–67; Richard A. Merrill, *FDA's Implementation of the Delaney Clause: Repudiation of Congressional Choice or Reasoned Adaptation to Scientific Progress?*, 5 YALE J. ON REG. 1 (1988).

Scholars need to think about proxy-based natural hazards tests in similar terms—by looking to the decision costs and bureaucratic error rates associated with these tests, as compared to alternative policy-analytic tests. In some cases, it will pretty clearly emerge that a proxy-based test is unjustifiable. Consider ACE's three-feet-of-freeboard test, used as a factor to ensure that levees built to protect communities from the one hundred-year flood are not overtopped. Determining the flood elevation in a settled area that would occur in the event of the one hundred-year flood entails a complicated, quantitative, model-driven analysis by ACE. Why, then, use a safety factor in calculating levee height, rather than directly calculating the height that achieves some given level of protection (for example, a five percent chance of being overtopped in the one hundred-year flood)?[72] It is very hard to see why the three-feet-of-freeboard rule substantially lowers the decision costs of ACE decisionmaking, or makes it less manipulable. By contrast, the use of no-collapse tests in designing building codes plausibly has substantial institutional advantages as opposed to, for example, cost-benefit analysis. Determining the no-collapse level, by contrast with cost-benefit analysis, does not require determining the lives saved or direct or indirect economic costs avoided by various possible degrees of building strength. So there is some apparent economy in terms of decision and manipulability costs.

C. Do Not Ignore Population Size (AGIR)

A policy-analytic criterion is insensitive to population size when it chooses a policy without reference to the number of individuals harmed by, or exposed to, the environmental or natural hazard that the policy is redressing.[73] In the area of environmental and natural

72. An even more straightforward criterion would be that the levee must reduce the annual probability of flooding in the protected area to one-in-one hundred. On these points, and the subtle difference between the annual probability of flooding in the protected area (which looks to the full range of possible floods that the levee might encounter) and the probability of protection from the one hundred-year flood (which looks to the chance that the levee will be overtopped by a flood of a particular magnitude, namely that magnitude the annual exceedance probability of which is 1/100), see FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 139–58.

73. Population-size sensitivity, as I define it, is a matter of the conceptual structure of policy-analytic criteria. A criterion that will choose the same policy when the size of the exposed population is varied, and everything else is held constant, is "population size insensitive." In practice, larger populations may correlate with other factors to which the criterion *is* sensitive. For example, industries that affect larger populations may tend to develop more advanced

hazards policy, this typically occurs in two ways. First, the agency might employ a proxy test (such as a technology-based or reliability-based proxy) for selecting policies, specifically one that does not attend to a policy's efficacy with respect to safety, property, psychological well-being, or the other dimensions of well-being affected by natural hazards.[74] Second, the agency might employ a policy-analytic criterion that does focus on some or all of these dimensions, but is structured in a population-size-insensitive way.

An environmental-policy example of the first, proxy-based variant of population-size insensitivity would be a requirement that the agency set emissions levels for new sources in each industrial category at a level achievable by the best available technology, or by the top quartile of polluters. This criterion makes no reference to the safety impacts of a given industrial category's emissions and, in particular, to the number of individuals exposed to or killed by its pollutants. Two industrial categories that emit pollutant *X* will be required to reduce *X* to the same level even if one of the categories has many more firms, and affects a much larger population, than the other.

A natural-hazards example of the population-size insensitivity that flows from a proxy test would be a reliability-based criterion for designing structures which stipulates that the structure must not fail except in a specified extreme event. Consider, for example, the criterion that seismic codes should ensure that no building collapse except in a 475-year earthquake. This criterion does not attend to whether the building being strengthened will contain a few individuals, a few dozens, hundreds, or thousands.

Population-size insensitivity of the second kind routinely occurs in environmental law, by virtue of "individual risk" tests.[75] These tests characterize an environmental hazard's safety impact by looking to the incremental individual fatality risk borne by some individual in

technologies—something that a test of technological feasibility *would* attend to. Still, it is important to distinguish between criteria that are structured so as to be attuned to population size, and criteria whose application may simply have some correlation with population size. Absent institutional considerations, our government's policy-analytic criteria *should* have population-size sensitivity built into them.

74. A hybrid test that *both* incorporates proxy considerations *and* attends to a hazard's well-being impact could be sensitive to population size—for example, "use all technologically feasible measures to reduce emissions of the toxin, up to the point where the expected number of deaths caused by the toxin is less than one."

75. *See* Adler, *supra* note 8, at 1147–79.

the exposure distribution, such as the average, maximally exposed, or highly exposed (e.g., 90th percentile) individual, rather than to the number of deaths caused by the hazard.[76] For example, the EPA's rules for remedying hazardous waste sites under the Superfund statute mandate that a site cleanup must occur whenever the maximally exposed individual incurs an incremental lifetime fatality risk exceeding one in ten thousand, and must bring his risk below that level.[77] This is true regardless of whether the site is in a remote or settled area.[78]

"Individual risk" tests, although sometimes mooted in the scholarly literature on natural hazards,[79] seem not to have been explicitly used by natural hazards regulators. But they have a very close analogue in a criterion that is sometimes used in choosing policies (such as building levees or floodwalls or evacuating residents) to protect settled areas from floods and hurricanes. Call this the "area-protection" criterion. It says that a policy must be chosen that protects the settled area from all but extreme events (from all but the one hundred-year flood, the one hundred-year hurricane, the probable maximum flood, the probable maximum hurricane). Although ACE's current stated policy is not to use the area-protection criterion in selecting its preferred projects, relying instead on cost-benefit analysis,[80] the area-protection criterion is important under the National Flood Insurance Program[81] and has been

76. An "individual risk" test *could* be structured in a population-size-sensitive fashion—for example, minimize the number of individuals with an "individual risk" above some level. However, "individual risk" tests currently employed in environmental policy are not generally thus structured. Also, it should be clarified that "individual risk" tests are sometimes one element in a broader decisionmaking procedure, where other components *are* population-size sensitive, but the "individual risk" test itself is not—and that needs justification.

77. *See* Adler, *supra* note 8, at 1156–58.

78. EPA does have discretion in choosing the target "individual risk" for the remedy, which can lie anywhere in the range from one in ten thousand to one in one million. It appears that EPA gives little weight to the size of the population exposed to the waste site in exercising this discretion. *See id.*

79. *See, e.g.*, Edmund Penning-Rowsell et al., *Estimating Injury and Loss of Life in Floods: A Deterministic Framework*, 36 NAT. HAZARDS 43 (2005).

80. *See* sources cited *supra* note 6; U.S. ARMY CORPS OF ENG'RS, PUB. NO. ER 1105-2-101, PLANNING: RISK ANALYSIS FOR FLOOD DAMAGE REDUCTION STUDIES 3–4 (2006), *available at* http://www.usace.army.mil/publications/eng-regs/er1105-2-101/entire.pdf.

81. More precisely, the National Flood Insurance Program (NFIP) creates an incentive for localities to pay the costs of constructing levees that will protect one hundred-year floodplains. Removing an area from the one hundred-year floodplain means that buildings within the area are no longer subject to the mandatory purchase of flood insurance, and that the community (if it wants to continue participating in the NFIP, which provides subsidized insurance for certain

employed in other contexts as well.[82] In effect, the area-protection criterion says that the annual risk of death or property damage to anyone in the settled area must not exceed one in one hundred (if the

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buildings within the one hundred-year floodplain) is no longer required to regulate construction in the area in accordance with the NFIP. Because these incentives are stronger for communities with more densely settled floodplains, the levee construction generated by the NFIP can be expected to correlate with population size. On the NFIP, see Edward T. Pasterick, *The National Flood Insurance Program*, *in* PAYING THE PRICE: THE STATUS AND ROLE OF INSURANCE AGAINST NATURAL DISASTERS IN THE UNITED STATES 125 (Howard Kunreuther & Richard J. Roth, Sr. eds., 1998); RUTHERFORD H. PLATT, DISASTERS AND DEMOCRACY: THE POLITICS OF EXTREME NATURAL EVENTS 28–33 (1999); FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 139–47.

82. It appears that levees to protect cities have generally been built to withstand something like the probable maximum flood.

> Another magnitude of flood that can occur is one that results from the standard project flood (SPF) discharge. This event is not assigned a frequency or recurrence interval, although it is often used by hydrologic engineers to approximate the 0.2 percent annual chance (500-year) flood. The SPF discharge in a river represents the flow that can be expected from the most severe combination of meteorologic and hydrologic conditions reasonably characteristic of the geographic region involved . . . . The SPF discharge is currently used for design of engineered structures, which, if compromised, could result in catastrophic flooding. The SPF discharge is generally used to determine the level of protection for urban population centers where there is great threat of loss of life and of damage to critical infrastructure.

INTERAGENCY FLOODPLAIN MGMT. REVIEW COMM., SHARING THE CHALLENGE: FLOODPLAIN MANAGEMENT INTO THE 21ST CENTURY 60 (1994); *see also id.* at 70–72 (suggesting that the goal of floodplain management, for population centers and critical infrastructure—but not in general—should be to reduce vulnerability from an SPF discharge); NAT'L RESEARCH COUNCIL, FLOOD RISK MANAGEMENT AND THE AMERICAN RIVER BASIN 115 (1995). Note how a decision rule that says "build levees to protect cities from the probable maximum flood" incorporates a crude kind of population-size sensitivity. It sorts settlements into two categories—cities, i.e., settlements with large populations, versus other settlements—but does not distinguish among cities with respect to population size.

It is notable that the urban portions of the New Orleans levee system were designed with reference to the "Standard Project Hurricane":

> For [the] Lake Pontchartrain and Vicinity [project] and [the] West Bank and Vicinity [project], the Standard Project Hurricane (SPH) was selected as the design hurricane because of the urban nature of the project area. The Standard Project Hurricane was defined as a hypothetical hurricane intended to represent the most severe combination of hurricane parameters that [was] reasonably characteristic of a specified region.

3 U.S. ARMY CORPS OF ENG'RS, PERFORMANCE EVALUATION OF THE NEW ORLEANS AND SOUTHEAST LOUISIANA HURRICANE PROTECTION SYSTEM: DRAFT FINAL REPORT OF THE INTERAGENCY PERFORMANCE EVALUATION TASK FORCE, at III-12 (2006).

Finally, it should be noted the construct of the SPF or SPH is not, strictly, the same as that of the probable maximum flood or hurricane. *See id.* at III-33 to III-35 (describing the SPH as looking to the most severe meteorological conditions that are "reasonably characteristic" of the region, whereas the probable maximum hurricane looks to the most severe combination that is "reasonably possible"). That distinction is not material to my analysis here. Whether defined in terms of the one hundred-year event, the standard project event, or the probable maximum event, the area-protection criterion is population-size insensitive.

one hundred-year cutoff is used) or zero (if the probable maximum event is used), regardless of the number of individuals living in the settled area or owning property there.

Should weak welfarists be troubled by policy-analytic criteria that are insensitive to population size? I suggest that they should be. A plausible case can be made that all the moral criteria subsumed under weak welfarism are sensitive to population size.[83] This is clearly true of overall well-being. Increase the size of the population that occupies some building, or that is endangered by a flood or hurricane, and the expected benefit to overall welfare of strengthening the building or constructing a protective levee increases as well.

It is also quite plausible that equity is sensitive to population size. Demonstrating this in detail would require me to work through the various plausible specifications of "equity"—comparative versus noncomparative, ex ante versus ex post, welfare-based versus resource-based. Because I lack space to do so, let me focus on the particular specification that I have argued for elsewhere: namely that "equity" above all means identifying "poverty lines" with respect to different well-being dimensions, and reducing the extent to which individuals fall below these lines.[84] Clearly, this approach to equity is population-size sensitive. Double the number of individuals expected to suffer grave psychological trauma, or protracted homelessness or unemployment, or income poverty, or death as a result of a structural collapse, and the *equity* benefits of avoiding collapse increase.

Finally, and perhaps surprisingly, a strong case can be made that moral rights are population-size sensitive. Consider, first, the moral right not to be wrongly killed—a moral right that all deontologists accept.[85] *P* wrongly kills *Q* if *P* causes *Q*'s death *and* further conditions are satisfied (the nature of which is a matter of dispute among deontologists). The point to see here is that the number of people who will be killed, or wrongly killed, if some building collapses or some community is hit by a flood or hurricane depends on the number of individuals in the building or community. Now, it might be objected that, because deontological rights are absolute, the number of wrongful killings is irrelevant—government has an absolute duty to prevent even one. But no one really believes this, at least when the

83. *See* Adler, *supra* note 8, at 1240–46.
84. *See* Adler, *supra* note 33.
85. *See* Adler, *supra* note 8, at 1225–27.

victims are not identified ex ante: who believes that government has an absolute obligation to stop wrongful homicides? At least in the case of unidentified victims, the weight of government's deontological reason to prevent the wrongful killings that would occur as a consequence of natural hazards must be (in part) a function of the expected number of such killings.

What if we supplement the right not to be killed with a right not to be wrongly put at risk of death? On the first view, only those who are actually killed by the structure's collapse have their rights violated; on the second, individuals who don't die still might suffer rights infringements, given the risk imposed on them. A deontologist who adopts this latter view will need to specify the conditions under which *P*'s action increasing *Q*'s risk of death is deontologically wrongful.[86] However those conditions are specified, it is surely not the case that government has an absolute obligation to prevent wrongful risk impositions—which would be even less plausible than the view that it has an absolute obligation to prevent wrongful killings. At most it has a defeasible deontological obligation to prevent wrongful risk impositions, the strength of which presumably depends on the number of individuals at risk.

If overall welfare, equity, and rights are sensitive to population size, it follows that size-insensitive policy-analytic criteria are justifiable only on institutional grounds.

It would seem that proxy tests can, sometimes, meet this burden of justification. Proxy tests focus the decisionmaker on some feature of policies other than well-being, and population-size insensitivity is one consequence of this refocusing, but the refocusing may be warranted, if the proxy test has sufficient advantages in terms of decision costs and bureaucratic error. Still, it is important for agency overseers and academics to be attentive to the disadvantages of proxy tests, *including* population-size insensitivity. Note also that a proxy test might incorporate administrable proxies for population size—for example, using a more extreme earthquake in defining the no-collapse criterion for large as opposed to small structures.[87]

86. *See id.* at 1227–32.

87. Indeed, seismic codes typically do this. "[B]uilding codes distinguish in terms of building use. In general, structures that serve critical functions (e.g., hospitals) or house large numbers of people (e.g., schools) are held to a higher standard than are less important, more thinly occupied buildings." REDUCING EARTHQUAKE LOSSES, *supra* note 57, at 106.

What about the second kind of population-size insensitivity, exemplified by "individual risk" tests in environmental law or by the closely analogous "area protection" criterion for natural hazards which says that flood- or hurricane-prone communities must be defended by physical structures, relocated, or otherwise protected so that the risk of harm to anyone in the community is reduced to some cutoff? These approaches seem hard to justify. On the one hand, the agency is told to consider policy effects in mitigating hazard impacts along some welfare dimension(s). Yet the agency is also instructed to ignore the number of individuals who would be benefited by the policy. Why expect that the institutional benefits of this relatively modest truncation of the analysis will be substantial?

To be more concrete, let us imagine that cost-benefit analysis has proven too elastic and manipulable in the hands of ACE, and that the agency is best instructed to focus on safety. "Choose protective measures for flood- or hurricane-prone settlements so as to minimize safety risks." That directive could be specified in population-size-insensitive terms ("Ensure that flooding will not occur in any settled area, except in the *X*-year flood"), or in size-sensitive terms ("Ensure that the expected number of annual deaths from flooding in any given community is below *D***"). *D*** could be one, or it could be a number keyed to the average costs of building levees in many communities.

Both the size-insensitive technique and the size-sensitive technique require the levee designer to estimate the frequency of floods and hurricanes of various magnitudes, and the efficacy of different policies in preventing flood or hurricane waters from reaching the settlement. The latter technique requires, in addition, that the system designer consider how many individuals reside in the settlement, and how many are likely to die if it is flooded. Given the current state of our information about population patterns and our models for predicting population impacts, the institutional costs of this incremental step would seem to be pretty small.

D. Do Not Use Arbitrary Non-Zero Numerical Cutoffs

Environmental policy analysis frequently uses non-zero numerical cutoffs, particularly in specifying "individual risk" tests. When regulatory intervention to mitigate some toxin or radiation source is keyed to the incremental "individual risk" incurred by the maximally exposed individual or someone else in the exposure distribution, it becomes crucial to specify what the relevant "individual risk" level is. In the case of carcinogens, different levels are used, depending on the agency and program. The most frequent cutoffs are incremental lifetime fatality risks of one in one million, one in one hundred thousand, one in ten thousand or one in one thousand (the last, used by OSHA).[88]

Noncarcinogens are treated differently. Why? By contrast with carcinogens, noncarcinogens are traditionally believed to have a toxicity threshold: a dose level below which the noncarcinogen will not cause harm. But non-zero cutoffs creep into policy analysis, even here—given uncertainty about what the threshold level for a particular noncarcinogen is. Imagine that an environmental agency aims to bring the maximally exposed individual or some other person in the exposure distribution below his toxicity threshold, but also wishes to avoid the massive costs of requiring zero exposure. Then it will need to employ some non-zero cutoff to specify an acceptable degree of uncertainty about whether the relevant individual is above the toxicity threshold—because at any exposure above zero, the agency cannot be completely certain that the threshold is not exceeded. In practice, programs that regulate noncarcinogens typically take the NOAEL observed in rodent experiments—the level of the toxin that produces no observed incremental frequency of death—and then divide that by some safety factor (ten, one hundred, or one thousand) to estimate a "reference" level of the noncarcinogen. These safety factors are non-zero cutoffs that are meant to ensure a high—but not complete—degree of certainty that the relevant individual is below his toxicity threshold.[89]

Natural hazards policymakers also use cutoffs. As we have seen, various criteria require policymakers to protect against natural hazard events up to some extreme point. Sometimes, the extreme point is set at some non-zero number. The National Flood Insurance Program is structured around the one hundred-year flood.[90] Earthquake codes are often designed to avoid building collapse in a 475-year earthquake.[91]

Sometimes, the extreme point is set with reference to the probable maximum event. Levees are sometimes built to withstand

88. *See* Adler, *supra* note 8, at 1147–79.
89. *See id.* at 1161–65.
90. *See* sources cited *supra* note 81.
91. *See* Bommer, *supra* note 58, at 60.

the "standard project flood" or "probable maximum flood." "The SPF discharge in a river represents the flow that can be expected from the most severe combination of meteorologic and hydrologic conditions reasonably characteristic of the geographic region involved."[92] Similarly, structures might be strengthened to resist the "probable maximum earthquake."[93] The probable maximum event represents a kind of zero risk level.[94] *If* the causal laws governing floods or hurricanes are deterministic, then it is intelligible to try to identify a maximal event—an event that cannot be exceeded at a given location, given those causal laws—and to design to that. But even here, non-zero numerical cutoffs may creep in, given our uncertainty about the causal laws or about the strength of structures—just as non-zero cutoffs creep into the regulation of noncarcinogens via the "safety factors." For example, an agency decisionmaker told to design, or specify regulations for, a class of structures sufficient to ensure that they survive the probable maximum event might be told that he should be 95 percent certain of survival.[95]

Non-zero cutoffs *may* be justifiable. First, it is possible that weak-welfarist morality itself incorporates non-zero cutoffs. Overall well-being does not. If a given person is benefited or harmed, even a little bit, by some event or policy, then overall well-being goes up or down too. Any positive or negative change in how some individual fares with respect to some welfare dimension can change that individual's well-being; any positive or negative change to an individual's well-being can change overall well-being. Zero is the natural threshold for purposes of the overall-welfare construct.

But equity may have non-zero cutoffs. For example, a threshold-based conception of equity—one that seeks to bring individuals above "poverty lines," representing minimum levels of achievement with respect to different well-being dimensions—contains non-zero cutoffs, namely the levels of the thresholds. Some specifications of moral

92. INTERAGENCY FLOODPLAIN MGMT. REVIEW COMM., *supra* note 82, at 60.

93. *See* NAT'L RESEARCH COUNCIL, ESTIMATING LOSSES FROM FUTURE EARTHQUAKES 20–25 (1989); NAT'L RESEARCH COUNCIL, SAFETY OF DAMS, *supra* note 59, at 61–63; Bommer, *supra* note 58.

94. *See* Moser, *supra* note 59, at 2.

95. *Cf.* FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 139–58 (describing levee certification criteria that look to 0.90 or 0.95 probability of passing the one hundred-year flood); Ellingwood, *supra* note 52, at 259 (suggesting 0.90 probability of surviving the five hundred-year earthquake as a possible goal for building design).

rights, too, involve non-zero cutoffs. Deontological theorists who recognize a right not to be exposed to risk might conceivably specify that as a right not to be exposed to a *high* risk.[96]

Second, it is possible that non-zero cutoffs may be justifiable on institutional grounds. For example, a commission might perform a cost-benefit analysis for a sample of toxic waste dumps; ascertain which remedial standard *R** (defined in terms of "individual risk" to the maximally exposed individual) maximizes the net benefits of cleaning up all the dumps; and then advise that the cleanup agency be instructed to use that *R** in performing its cleanups (not trusting the agency to do cost-benefit analysis of individual waste sites).

In point of fact, however, the actual "individual risk" numbers employed by environmental policy agencies—one in one million, one in one hundred thousand, one in ten thousand, one in one thousand—seem to be pretty arbitrary.[97] As far as I am aware, neither the agencies that use these cutoffs nor academics have persuasively defended these particular numbers as either corresponding to morally fundamental cutoffs, or as the numbers that optimize overall well-being (or equity or rights) across a range of administrative programs.

One might similarly worry about the arbitrariness of the non-numerical cutoffs employed in natural hazards policymaking. The one hundred-year recurrence interval, central to the National Flood Insurance Program, was apparently set in an intuitive way, without any systematic analysis.[98] As for the return intervals used for seismic design:

> [T]he almost universal use of the 475-year return period in [seismic] codes can be traced back to the hazard study for the USA produced by Algermissen and Perkins, which was based on an exposure period of 50 years (a typical design life) and a probability of 10% of exceedance, whose selection has not been explained. . . . A review of seismic design regulations around the world reveals a host of design return periods, the origin of which is rarely if ever explained. [One set of g]uidelines specify 500 years for "essential" bridges, 2500 years for "critical" bridges. In [another] proposal for a framework for performance-based seismic design, return periods of 72, 244, 475 and

96. *See* Adler, *supra* note 8, at 1227–32.

97. *See, e.g.*, Frank B. Cross et al., *Discernible Risk—A Proposed Standard for Significant Risk in Carcinogen Regulation*, 43 ADMIN. L. REV. 61, 78–80 (1991).

98. *See* FLOOD DAMAGE REDUCTION STUDIES, *supra* note 6, at 142–43.

974 years have been specified . . . . It is hard not to feel that some of these values have been almost pulled from a hat . . . .[99]

E. Do Not Conflate Moral Rights Infringements with Welfare Setbacks (Even to Vital Interests)

Some of the scholarly literature on environmental policy seems to take the view that virtually any death or injury resulting from an environmental hazard implicates moral rights.[100] Such a view is problematic.

Deontological accounts of policymaking face the general difficulty of explaining why government has a deontological reason to prevent rights infringements by others.[101] Very plausibly, if government itself builds an inadequate levee without informing the exposed population, then it has committed a deontological wrong and has a deontological obligation to repair the levee. But consider the case in which private developers in Mississippi, knowing of the hurricane risk, build inadequate buildings without informing the occupants. If Matt Adler, a private citizen of Mississippi, is aware of these events but declines to bear private costs to warn the occupants, he has not deontologically wronged the occupants. He has simply failed to perform the supererogatory action of rescuing them. Why, then, is the government of Mississippi or the United States deontologically obliged to take steps to help the occupants—thereby imposing costs on the private citizens of Mississippi or the United States which, individually, they would have no deontological obligation to bear?

This is a general problem, and may well have a satisfying general answer. But even if it does, at most the answer would show that government has a deontological duty of some kind to stop deontological *rights violations* by private actors. This is not the same as a deontological duty to stop all *harms*. A harm or expected harm—an actual or expected setback to some aspect of well-being—is not sufficient for a rights violation. Harms or expected harms will be

99. Bommer, *supra* note 58, at 60–61 (internal citations omitted); *see also* NAT'L RESEARCH COUNCIL, SAFETY OF DAMS, *supra* note 59, at 23 (noting use of arbitrary criteria in designing dams, such as an arbitrary percentage of the one hundred-year flood or the probable maximum flood).

100. *See, e.g.*, K.S. SHRADER-FRECHETTE, RISK AND RATIONALITY: PHILOSOPHICAL FOUNDATIONS FOR POPULIST REFORMS 117–18 (1991).

101. *See* Adler, *supra* note 8, at 1224–25.

rights invasions only if there are wrongdoers. Identifying wrongdoers in the case of natural hazards is particularly tricky, because a large part of the causal chain leading to harm will be some meteorological or seismic event rather than a human action. Of course, humans *will* sometimes be wrongdoers here; humans can wrongfully make others more vulnerable to hurricanes, earthquakes, floods, and so on. On the other hand, there will be cases—at a minimum, cases where the harmed parties knowingly and voluntarily assumed the risk of a natural hazard—in which the harm or expected harm of a natural hazard violates no rights.

Specifying these cases more fully involves an account of deontological wrongdoing—a controversial matter that I cannot engage at any length here.[102] But it seems quite clear that all deontologists, whatever their particular accounts, would strongly resist conflating the category of harm or expected harm (even to a very important interest, such as life) with the category of rights infringement.

II. Risk Assessment

The main thrust of Part I was that policy analysis for environmental and natural hazards should be welfare-focused, multidimensional, and sensitive to population size at some level. Policy analysis is welfare-focused if it directly attends to the impact of possible policies on human interests, rather than employing some proxy criterion. It is multidimensional if it attends to the full range of human interests, rather than giving priority to one or a few. It is sensitive to population size if it makes reference to the number of individuals harmed by hazards. Administrative decision procedures that do not fulfill these desiderata may be justifiable, but only on institutional grounds, if the procedures are sufficiently accurate in tracking overall well-being, equity, and rights, and if the decision costs and bureaucratic error rates of welfare-focused, multidimensional, and size-sensitive procedures are too high.

Further, in the case where agencies justifiably employ truncated procedures, the locus of welfare-focused, multidimensional, and population-size-sensitive decisionmaking is simply shifted to some other decisionmaker or advisor: from agencies to Congress or the

102. For further discussion, see Heidi M. Hurd, *What in the World is Wrong?*, 5 J. CONTEMP. LEGAL ISSUES 157 (1994).

President, or from Congress and the President to governmental commissions, think tanks, and scholars.

These points have much relevance for risk assessment. It is critical to develop and maintain risk assessment techniques that can subserve welfare-focused, multidimensional, and population-size-sensitive policy analysis for environmental and natural hazards—if not to inform agency decisionmakers, then at least to inform their overseers, or the individuals who advise the overseers. Further, risk assessments can be more or less simplified—meaning that they may ignore relevant scientific data, employ simplified models, or adopt a simplified approach to the treatment of uncertainty. Simplified assessments may, in principle, be justifiable—on the now-familiar grounds of decision cost and bureaucratic error—but should be critically scrutinized.

A. Develop Techniques Suitable for Multidimensional, Population-Size-Sensitive Policy Analysis

A risk assessment is a characterization of the harms that an environmental or natural hazard can be expected to cause, either in the status quo or in the event that various mitigating interventions are adopted. Proxy-based policy-analytic criteria may not necessitate a risk assessment. Policy-analytic criteria that focus on one dimension of well-being will require a risk assessment only with respect to that dimension. Policy-analytic criteria that are insensitive to population size will not require a risk assessment that estimates the total amount of harm caused by a hazard. But, because environmental and natural hazards decisionmaking should be welfare-focused, multidimensional, and sensitive to population size *at some level*, risk assessment techniques to inform that sort of policy analysis need to be maintained and improved. The cautionary lesson, here, is directed at the risk assessment community—in effect, at those who maintain a certain kind of intellectual capital, namely the scholars who develop risk assessment techniques and the agencies or other bodies which fund that scholarly work.

To begin, the safety-focused conception of environmental risk assessment needs to be broadened to encompass a fuller range of harms. The *Red Book* framework says that a "risk assessment" means "the characterization of the potential adverse *health* effects of human exposures to [an] environmental hazard[],"[103] encompassing a hazard identification, a dose-response assessment, and an exposure assessment, all leading up to a risk characterization (that is, a characterization of individual or population fatality and health risks). This remains the standard framework for conceptualizing risk assessment of toxins and radiation.[104]

It might be thought that this conception is adequate for environmental hazards—that non-safety impacts occur as a result of policies to mitigate environmental hazards (for example, when regulations impose economic costs on shareholders, workers, and consumers), rather than being caused by the hazards themselves. This is not true: toxins and radiation causally impact a variety of human interests other than health and longevity, for example, by causing smells, poor visibility, physical damage to property, loss of property value, and the degradation of recreational and other "use" values attendant upon ecosystem harm.

In any event, the safety-focused conceptualization, or any unidimensional conceptualization, is too narrow for purposes of natural hazards risk assessment. As already stated, natural hazards causally impact a wide range of human interests, and the natural hazards risk assessment community needs to develop models and techniques to characterize all those types of impacts. Much work has been done on quantifying the economic effects of natural hazards—both direct property damage and more indirect effects, such as business interruption or macroeconomic effects. This includes ACE's efforts and that of many scholars. Substantial scholarly work has also been undertaken to estimate the deaths and injuries caused by natural hazards.[105] "HAZUS," a computer program for earthquake,

103. NAT'L RESEARCH COUNCIL, RISK ASSESSMENT IN THE FEDERAL GOVERNMENT, *supra* note 3, at 18 (emphasis added).

104. *See, e.g.*, Paustenbach, *supra* note 19, at 7–9; NAT'L RESEARCH COUNCIL, SCIENCE AND JUDGMENT IN RISK ASSESSMENT 4–5 (1994).

105. On ACE practices, see *supra* note 6. For scholarship concerning the estimation of losses caused by natural hazards, including economic losses, injuries and casualties and (to some extent) other losses as well, see, for example, ECONOMICS AND THE WIND, *supra* note 40; FED. EMERGENCY MGMT. AGENCY, INDIRECT ECONOMIC CONSEQUENCES OF A CATASTROPHIC EARTHQUAKE (1992); FLOODS AND LANDSLIDES, *supra* note 2; NAT'L INST. OF BLDG. SCIS., *supra* note 2; NAT'L RESEARCH COUNCIL, THE ECONOMIC CONSEQUENCES OF A CATASTROPHIC EARTHQUAKE (1992); José Badal et al., *Preliminary Quantitative Assessment of Earthquake Casualties and Damages*, 34 NAT. HAZARDS 353 (2005); 13 EARTHQUAKE SPECTRA 565 (1997); J.W. Hall et al., *A Methodology for National-Scale Flood Risk Assessment*, 156 WATER & MAR. ENGINEERING 235 (2003); Penning-Rowsell et al., *supra* note 79.

hurricane, and flood risk assessment developed by FEMA for distribution to states, localities, and the private sector, allows some estimation of physical damage ("damage to residential and commercial buildings, schools, critical facilities, and infrastructure"), economic loss ("lost jobs, business interruptions, repair and reconstruction costs"), and certain "social impacts" ("estimates for shelter requirements," "displaced households" and casualties).[106] Risk assessment techniques to quantify a broader range of "social impacts" of natural hazards—such as psychological trauma, destruction of cultural heritage, family separation, or the disruption of schooling—would also be useful.[107]

A second cautionary lesson concerns population-size insensitivity. Particular policy-analytic criteria may ignore some welfare dimension entirely, or may attend to that dimension in a size-insensitive manner (for example, through an "individual risk" test). But, ideally, risk assessment techniques should be available to predict aggregate losses with respect to the variety of welfare dimensions that environmental and natural hazards do causally impact.

Risk assessment of noncarcinogens dramatically illustrates the point. Because these substances have been thought to possess a threshold below which no harm will ensue, risk assessment techniques here have been traditionally focused on estimating that threshold—specifically, on identifying the NOAEL—and not on providing quantitative estimates of "individual risk" or total deaths.

> For many years, there has been a fundamental dichotomy in risk assessment. Since the 1970s, the potential carcinogenic hazards of chemicals have generally been characterized by quantitative estimates of the increased lifetime risk of cancer associated with a given exposure. On the other hand, the potential hazards of chemicals for toxic endpoints other than cancer have generally been

106. HAZUS: FEMA's Software Program for Estimating Potential Losses from Disasters, *supra* note 7. The precise capabilities of HAZUS depend on whether the hazard being evaluated is an earthquake, flood or hurricane. FEMA's web site, *supra*, provides links that describe the earthquake, flood and hurricane components of HAZUS.

107. ACE's report on the impact of Katrina is a good step in this direction. In addition to characterizing the economic consequences, human health and safety consequences, and environmental consequences of the hurricane, it also characterizes social and cultural consequences. *See generally* 7 U.S. ARMY CORPS OF ENG'RS, *supra* note 82.

> characterized only by the specification of an exposure level considered to be without appreciable risk . . . .[108]

The upshot is that no consensus technique currently exists for estimating the total deaths or diseases caused by exposures to noncarcinogens.[109]

This lacuna in risk assessment techniques does not undermine certain policy-analytic criteria. For example, the estimation of the NOAEL is sufficient information for a decisionmaker who seeks to reduce the exposure of the maximally exposed individual to a level equaling the NOAEL divided by some safety factor. But the lacuna does undermine cost-benefit analysis or other criteria that do require information about total deaths or diseases. "[W]ithout readily available means for quantifying noncancer risks, the focus [in cost-benefit analysis] is often solely on cancer risks, while noncancer health risks are ignored."[110] A good example is EPA's cost-benefit analysis for arsenic under the Safe Drinking Water Act. Arsenic at low doses causes bladder and liver cancer, and also life-threatening noncancer effects such as ischemic heart disease (ISHD). EPA quantified the cancer reduction benefits of lowering the level of arsenic in drinking water, but not the reduction in noncancer effects—even though it appears that "the mortality risk of ISHD from drinking water may be greater than the mortality risk from cancer."[111] The agency's "failure to quantify the noncancer effects of arsenic appears to result from the fact that there is not a generally accepted practice, or expectation, of performing low-dose extrapolation for noncancer endpoints."[112]

Fortunately, the NOAEL example appears to have no analogue in natural hazards risk assessment. There appears to be no general resistance to estimating aggregate effects with respect to some kind of harm.

108. Harvey J. Clewell & Kenny S. Crump, *Quantitative Estimates of Risk for Noncancer Endpoints*, 25 RISK ANALYSIS 285, 285 (2005).

109. *See id.* at 288.

110. *Id.* at 285.

111. *Id.* at 287.

112. *Id.* Another context in which NOAEL-type information would be inadequate is an emergency response agency's choice among different responses to a widespread toxic exposure. Information about expected casualties would be crucial for this choice. *See generally* Kenneth T. Bogen, *Risk Analysis for Environmental Health Triage*, 25 RISK ANALYSIS 1085 (2005).

B. Do Not Exclude Relevant Information (AGIR)

Predicting the harm caused by a toxin or radiation means combining an exposure assessment (describing how much of the toxin or radiation various individuals receive) and a dose-response assessment (predicting the incremental "individual risk" for a given dose and a given type of individual). Environmental agencies have often excluded relevant information at both these stages of risk assessment.

First, at the exposure assessment stage, environmental agencies tend to ignore some relevant social science data. The exposure of humans to a dangerous substance contained in a waste dump or emitted by a factory or nuclear plant depends not merely on hard science (the physical laws governing the transport of the substance through the air, ground, and water) but also on demographics (the number of humans present at various distances from the dump, factory, or plant). This is, of course, a point that environmental agencies have recognized; but their demographic and, more generally, social-scientific models have often been quite simplistic. For example, a comprehensive review by the National Research Council of EPA's risk assessment techniques for air pollutants reached the following conclusion:

> EPA has not previously used population activity, population mobility, and demographics in modeling exposure to hazardous air pollutants and has not adequately evaluated the effects of assuming that the population of a census enumeration district is all at the location of the district's population center.
>
> EPA should use population-activity models in exposure assessments when there is reason to believe that the exposure estimate might be inaccurate . . . if the default option is applied. This is particularly important in the case of potential underestimation of risk. Population mobility and demographics will also play a role in determining risk and lifetime exposures.[113]

Second, at the dose-response assessment stage, environmental agencies tend to ignore personal characteristics. A repeated theme in commission reports and the academic literature is that environmental agencies should consider employing dose-response models that reflect

113. NAT'L RESEARCH COUNCIL, SCIENCE AND JUDGMENT IN RISK ASSESSMENT, *supra* note 104, at 139.

heterogeneity in individual susceptibility to toxins—be it because of age, gender, health history, or identifiable genetic factors.[114]

Ignoring relevant data is one way to simplify risk assessment. Simplification has potential benefits (in lower decision costs and bureaucratic error), but also costs (in producing inaccurate risk assessments). Those who design agency risk assessment techniques, and the scholars who advise the designers, need to try to balance these costs and benefits. Substantial scholarly commentary suggests that the risk assessment techniques currently employed by environmental agencies are unjustifiably abstemious in their use of relevant data.[115]

Social science data is, of course, crucial to natural hazards risk assessment. The term often used in the literature is population "vulnerability": earthquakes, floods, hurricanes, droughts, tornadoes, and avalanches harm humans because of an interaction between a natural event and a human population that is "vulnerable," to some extent, to that event. Vulnerability is a matter of social, not physical, science. And, just as individuals are heterogeneous in their susceptibility to toxins, so they are heterogeneous in their vulnerability to natural hazards—a point that the natural hazards literature stresses.

> A major approach to hazards research over the past two decades has looked at the way in which a variety of socioeconomic characteristics of people affect . . . their vulnerability to hazards and disasters over time. . . .
>
> In the United States the key characteristics that seem to influence disaster vulnerability most are socioeconomic status, gender, and race or ethnicity. Differences in these characteristics result in a complicated system of stratification of wealth, power, and status. This stratification, in turn, results in an uneven distribution of exposure and vulnerability to hazards, disaster losses, and other

114. *See, e.g.*, *id.* at 188–223; Adler, *supra* note 8, at 1145 n.86 (citing sources).

115. *See, e.g.*, 2 THE PRESIDENTIAL/CONGRESSIONAL COMMISSION ON RISK ASSESSMENT AND RISK MANAGEMENT, RISK ASSESSMENT AND RISK MANAGEMENT IN REGULATORY DECISION-MAKING 71–85 (1997); NAT'L RESEARCH COUNCIL, SCIENCE AND JUDGMENT IN RISK ASSESSMENT, *supra* note 104, at 138–40, 218–19; Adam M. Finkel, *A Quantitative Estimate of the Variations in Human Susceptibility to Cancer and Its Implications for Risk Management*, *in* LOW-DOSE EXTRAPOLATION OF CANCER RISKS: ISSUES AND PERSPECTIVES 297 (Stephen Olin et al. eds., 1995); Lauren Zeise et al., *Improving Risk Assessment: Research Opportunities in Dose Response Modeling to Improve Risk Assessment*, 8 HUM. & ECOLOGICAL RISK ASSESSMENT 1421, 1423–30 (2002).

> impacts and access to aid, recovery, and reconstruction. For example, the poor are more likely to occupy old and more hazardous housing, ethnic minorities are less likely to receive disaster warnings and are more likely to have language barriers to the information they receive, and developing nations are less able to afford disaster detection technology and resilient construction practices.[116]

Worries about undue simplification are just as relevant for natural hazards as for environmental risk assessment. An important example involves the endogeneity of human activity to risk reduction measures. Salient measures to decrease the impacts of a natural hazard in some location, such as levees or other visible structural measures, can reduce the perceived risks in that location and thus induce increased settlement or building. Individuals may respond to enhanced government protection from natural hazards with "compensatory" behaviors that reduce the protection, thereby producing a smaller reduction in death, property loss, and other harm than would occur absent "compensation."[117] ACE needs to be sensitive to these points in undertaking cost-benefit analyses of flood reduction measures.[118]

C. Use Probabilistic Rather than Deterministic Risk Assessment (AGIR)

The models, parameters, and other inputs that the risk assessor uses to predict the impacts of environmental and natural hazards—on safety or other human interests—will typically be uncertain.[119] Bracketing institutional considerations, this uncertainty should be represented through a probability distribution.[120] An alternative is to use a "point value" for the uncertain input: for example, picking the

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116. MILETI, *supra* note 5, at 122–23.

117. *See* Nicole Cornell Sadowski & Daniel Sutter, *Natural Hazards, Fatality Rates and Societal Vulnerability*, *in* ECONOMICS AND THE WIND, *supra* note 40, at 149.

118. *Cf.* NAT'L ACAD. OF SCIS., *supra* note 6, at 55–59 (discussing ACE's traditional preference for structural rather than nonstructural flood control measures); WATER RESOURCES PLANNING, *supra* note 6, at 61–63 (same).

119. On uncertainty and risk assessment, see, for example, VINCENT T. COVELLO & MILEY W. MERKHOFER, RISK ASSESSMENT METHODS: APPROACHES FOR ASSESSING HEALTH AND ENVIRONMENTAL RISKS 203–37 (1993); Pamela R.D. Williams & Dennis J. Paustenbach, *Risk Characterization*, *in* HUMAN AND ECOLOGICAL RISK ASSESSMENT, *supra* note 4, at 336, 336–45.

120. *See, e.g.*, Dennis J. Paustenbach, *Retrospective on U.S. Health Risk Assessment: How Others Can Benefit*, 6 RISK: HEALTH, SAFETY & ENV'T 283, 318–19 (1995).

most likely model, or the mean of a model parameter. The problem with this approach is twofold. First, using "point values" rather than probability distributions as inputs to risk assessments suppresses some of the uncertainty about the output of the assessment, thereby depriving the policy analyst of information that may be useful.[121] For example, imagine that the total deaths *D* from an earthquake in a given location is a function of *X*, *Y*, and *Z*. If *X*, *Y*, and *Z* are all assigned point values equaling their means, then $D = F(X, Y, Z)$ is a point value too.[122] Uncertainty about the distribution of *D* is not communicated to the decisionmaker. This may well be relevant information, depending on how the policy-analytic criterion is structured. For example, it is conceivable that overall welfare, and policy-analytic criteria that implement overall welfare, are not "risk-neutral" in the number of deaths. A very-low-probability, very-high-consequence earthquake that has a 0.01 percent annual probability and would cause one million deaths may be worse for expected overall welfare (and merit greater ex ante mitigation efforts) than a higher-probability, lower-consequence earthquake that has a 10 percent annual probability and would cause one thousand deaths, even though both seismic hazards have the same expected number of annual deaths (one hundred).

Second, even if the policy-analytic criteria are risk-neutral in the output of the risk assessment—so that the output distribution can, without loss of relevant information, be summarized as its expected value—using point values rather than probability distributions as inputs to the risk assessment may generate incorrect results.[123] Although it is true that the expectation of the *sum* of random variables is the sum of their expectations, it is not generally true that the expectation of some arbitrary function of random variables is that function applied to their expectations.

Indeed, so-called "probabilistic" risk assessment—which characterizes uncertainties in inputs and outputs using probability distributions, as opposed to "deterministic" assessment, which uses point estimates—has been the focus of much scholarly work in recent

121. *See* Judson Jaffe & Robert N. Stavins, *On the Value of Formal Assessment of Uncertainty in Regulatory Analysis* (Feb. 2006), at 8–11 (on file with the *Duke Law Journal*).

122. And if *X* is assigned a point value equaling its mean, but *Y* and *Z* are represented as random variables, the probability distribution of *D* may not be the same as if *X* were also represented as a random variable.

123. *See* Jaffe & Stavins, *supra* note 121, at 8–11.

years. However, environmental agencies have often been resistant to "probabilistic" risk assessment. An exemplary case is EPA's treatment of model uncertainty in drawing dose-response curves for carcinogens. Many substances are possible rather than clear carcinogens, given existing epidemiological and experimental evidence. In other words, there is a nontrivial probability that they cause cancer but also a nontrivial probability that they don't—that their dose-response curves are flat lines. And, even if carcinogenicity is quite clear, there may be much uncertainty about which particular form the dose-response relationship takes. EPA has traditionally refrained from quantifying uncertainty about carcinogenicity and about the dose-response functional form. Instead, its approach has been to use one particular model (the linearized multistage model) for predicting fatalities from toxins that, as a qualitative mater, are judged sufficiently likely to be carcinogens.[124]

Natural hazards risk assessment should, to some extent, employ "probabilistic" rather than "deterministic" techniques. Indeed, ACE has been considerably more receptive to "probabilistic" risk assessment than EPA.[125] To be sure, decision costs remain an important reason for limiting the use of probabilistic techniques. It may well be cheaper to estimate a point value for some input than to trace a probability distribution. On the other hand, advances in computers and software—in particular, the development of so-called Monte Carlo techniques—have made it much easier to determine the *output* of "probabilistic" risk assessments, i.e., to determine the probability distribution that results from any given function of input random variables. Further, as Judson Jaffe and Robert Stavins observe:

> [C]haracterizations of uncertainty may be necessary just to develop an accurate point estimate for an input. If a point estimate represents an input's expected value, the development of that point estimate requires an implicit judgment about that input's probability distribution. Characterizations of uncertainty . . . simply make those implicit judgments explicit.[126]

124. On EPA practices, see Adler, *supra* note 8, at 1148 n.91 (citing sources). The possibility of quantifying model uncertainty is an important theme in the literature on Bayesian approaches to risk assessment. *See id.* at 1209 & n.330.

125. *See* sources cited *supra* note 6; Moser, *supra* note 59; U.S. ARMY CORPS OF ENG'RS, *supra* note 80.

126. Jaffe & Stavins, *supra* note 121, at 18.

Because estimating a point value of some item given uncertainty always involves some kind of probabilistic assessment, if only qualitative or implicit rather than quantitative and explicit, the incremental decision costs of a quantitative representation will often not be large. Professors Jaffe and Stavins' observation also suggests that "probabilistic" risk assessment may actually be less subject to agency manipulation. Explicitly articulating a probability distribution would seem to be more transparent to agency overseers than making a judgment about the mean or most likely value of an item without articulating the distribution.

A different reason for the traditional resistance to "probabilistic" risk assessment goes deep into the theory of probability and statistics. Traditional statistical methods are "frequentist" rather than "Bayesian." They refuse to employ probabilities as measures of *beliefs*; instead, probabilities are seen as solely representing objective *frequencies*. On this view, it would be appropriate to represent the occurrence of cancer in an individual as a random variable. With some objective long-run frequency, individuals exposed to a given dose of a toxin develop cancer—a frequency that can be estimated using sampling techniques. On the other hand, traditional statisticians would refuse to assign a probability to one or another model of carcinogenicity. Imagine that the risk assessor is unsure whether the toxin produces cancer by means of genotoxicity or some other mechanism. Because there is no objective frequency here—in reality, the substance is either genotoxic or not—attaching a "probability" to genotoxicity is meaningless on the frequentist account.

For reasons I have explored at length elsewhere, an exclusively frequentist account of probability is problematic in the domain of policy analysis.[127] Beliefs, like objective frequencies, can be quantified probabilistically. Further, beliefs (and not just objective frequencies) are a crucial input to risk assessment. The notion of using *merely* frequency information to make predictions is chimerical. For example, EPA's dose-response procedures *combine* frequency data (the frequency with which rats exposed to different doses of a substance incur cancer) and expert beliefs (the belief that the substance is a likely carcinogen and that, based on all the evidence to date, the linearized multistage model is a plausible model of dose-

127. *See* Adler, *supra* note 8, at 1183–239.

response relationships). So expert beliefs *are* part of the picture—they are simply not represented probabilistically.

To be sure, in some cases, experts may disagree, or may have difficulty expressing their uncertainty as a probability distribution. These phenomena represent a kind of decision cost, which may well argue for "deterministic" rather than "probabilistic" approaches for handling *particular* uncertain items. The point I wish to make is that risk assessors should not be *globally* resistant to employing probabilities as measures of beliefs. However appropriate a wholly frequentist approach to probability and statistics may be for scientific inquiry, it is too abstemious for policy analysis.

D. Do Not Adopt a Global Posture of "Conservatism" in Handling Uncertainty

EPA has historically employed a "conservative" approach to risk assessment.

> The agency's [risk assessment principles] are for the most part intended to be conservative—that is, they represent an implicit choice by the agency, in dealing with competing plausible assumptions, to use (as default options) the assumptions that lead to risk estimates that, although plausible, are believed to be more likely to overestimate than to underestimate the risk to human health and the environment. EPA's risk estimates thus are intended to reflect the upper region of the range of risks suggested by current scientific knowledge.[128]

One well-known example is the use of the linearized multistage dose-response model, which is linear at low doses (rather than being sublinear or having a threshold) and is "one of the most conservative of the dose extrapolation models."[129] Another is EPA's frequent use of an upper bound estimate on the slope of this line, rather than the maximum likelihood estimate, as the number employed to generate predictions of individual and population risks.[130] Other important examples are the assumptions that "[h]umans are as sensitive as the most sensitive animal species, strain, or sex evaluated in a bioassay";

128. NAT'L RESEARCH COUNCIL, SCIENCE AND JUDGMENT IN RISK ASSESSMENT, *supra* note 104, at 89.

129. Williams & Paustenbach, *supra* note 119, at 313.

130. *See* Lorenz R. Rhomberg, *A Survey of Methods for Chemical Health Risk Assessment Among Federal Regulatory Method Agencies*, 3 HUM. & ECOLOGICAL RISK ASSESSMENT 1029, 1100–02 (1997).

that "benign and malignant tumors are added in evaluating whether a chemical is carcinogenic and in assessing its potency"; and that "[w]hen extrapolating metabolic data from laboratory animals to humans, one may use the relationship of surface area [not body weight] in the test species to that in humans in modifying the laboratory animal data."[131]

In thinking about "conservatism," it is important to distinguish between "conservatism" at the level of policy analysis and "conservatism" in the preparation of risk assessments. Policy-analytic techniques, themselves, may be justifiably "conservative," in the sense that they may appropriately incorporate an ancillary instruction to handle uncertainty about inputs by employing conservative rather than central-tendency estimates. It is hard to see why this would be true of cost-benefit analysis, but it may be true of other criteria. For example, it is possible that institutional considerations justify natural hazards agencies in employing criteria that make reference to extreme events: "Ensure that building codes prevent collapse except in the 475-year earthquake," or "Build levees to prevent flooding in cities except in the probable maximum flood." Those same institutional considerations *could*, in principle, mean that the agency is justifiably instructed to employ upper bound estimates in estimating the size of the extreme event or the adequacy of measures to contain it. Why assume that the appropriate instruction is "Design a structure that has a 0.50 probability of surviving the *X*-year flood or earthquake," rather than "Design a structure that has a 0.95 probability of surviving the *X*-year flood or earthquake"?

It is therefore difficult to make general statements about the appropriate degree of conservatism for policy-analytic criteria. By contrast, the question of the appropriate conservatism of *risk assessment* is easier to resolve. If uncertainty about an input item is represented probabilistically, as a random variable, the answer seems easy: use Monte Carlo techniques to combine this input random variable with other inputs, producing an output probability distribution (of total deaths, property loss, trauma, and so forth)

131. NAT'L RESEARCH COUNCIL, SCIENCE AND JUDGMENT IN RISK ASSESSMENT, *supra* note 104, at 88–89.

which the policy-analytic technique can incorporate *together with whatever rule for handling uncertainty it employs*.[132]

The more difficult issue arises when uncertainty about some input isn't represented probabilistically—when a "point estimate" rather than a probability distribution for that input is used. Here, we should distinguish between the case where a risk assessment of a hazard is performed apart from any particular policy choice, and the case where it is performed as part and parcel of policy analysis. In the latter case, the answer to whether point estimates should be "conservative" or rather central tendencies (or, for that matter, anti-conservative) is straightforward: use whichever approach the policy-analytic technique demands. In the former case, risk assessment is meant to provide generic information, for a variety of policy choices and policy-analytic techniques—so the answer here is that risk assessment should not merely use conservative values. It should also inform the analyst what the hazard impact (or probability distribution of impacts) would be if the point estimate for the input item were estimated less conservatively.

In short, although the issues turn out to be complicated, it seems clear that natural hazards risk assessment should eschew a general preference for "conservative" estimates of the size of natural hazards and of their impact on humans. The problem of conservatism can be sidestepped by using probability distributions rather than point values for uncertain quantities; and when point values *are* justifiably employed (given decision costs), a global posture of estimating them "conservatively" will produce risk assessments that are not useful for policy-analytic criteria, such as cost-benefit analysis, that prefer central-tendency estimates.

CONCLUSION

Environmental risk assessment and management is, in many ways, an impressive accomplishment, but should not be reflexively duplicated by natural hazards policymakers. This Article has attempted to delineate the most important aspects of environmental agencies' decisionmaking practices that are problematic, or at least demand an institutional justification—one that examines the decision

132. *See* Paustenbach, *supra* note 120, at 310 ("[T]he problems associated with the repeated use of overly conservative assumptions . . . can now be overcome with Monte Carlo techniques.").

costs, bureaucratic error rates, and accuracy (in tracking underlying moral considerations) associated with different possible policy-analytic criteria. The suggestions here are supposed to be relatively uncontroversial. They are meant to proceed from a relatively broad-gauged moral framework—weak welfarism—which has room for distributive considerations and moral rights, as well as overall well-being. Still, even placing to one side controversial moral questions and difficult problems of optimal institutional design, it seems possible to glean certain nontrivial cautionary lessons for natural hazards policy analysis and risk assessment from the environmental case. To summarize:

For Natural Hazards Policy Analysis

- Do Not Give Priority to Safety or Any Particular Aspect of Well-Being (AGIR)[133]
- Do Not Use Proxy Tests (AGIR)
- Do Not Ignore Population Size (AGIR)
- Do Not Use Arbitrary Non-Zero Numerical Cutoffs
- Do Not Conflate Moral Rights Infringements with Welfare Setbacks (Even to Vital Interests)

For Natural Hazards Risk Assessment

- Develop Techniques Suitable for Multidimensional, Population-Size-Sensitive Policy Analysis
- Do Not Exclude Relevant Information (AGIR)
- Use Probabilistic Rather than Deterministic Risk Assessment (AGIR)
- Do Not Adopt a Global Posture of "Conservatism" in Handling Uncertainty

133 "AGIR," again, means "absent good institutional reason." *See supra* text accompanying note 36 (discussing role of institutional considerations in justifying policy-analytic criteria).