

*Postnormal Science, Precautionary Principle, and Worst Cases: The Challenge of Twenty-First Century Catastrophes**

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Considering the damage caused by the recent spate of catastrophic events (e.g., Hurricane Katrina, 9/11 terrorist attacks of 2001, and the Indian Ocean tsunami of 2004), it is increasingly clear that complex, large-scale environmental problems will characterize the twenty-first century. We contend that the ability of science to address these problems is attenuated by the ideological embrace of scientific-technical rationality. With scientific and technological pursuits increasingly marching to the drum beat of economic growth, is there a place for science to operate driven not by short-term profitability, but the long-term interests of the public and needs of the environment? Can the problems associated with complex, large-scale catastrophes be addressed adequately by science and technology alone, especially considering that technological failure may be the primary cause of the catastrophe? The purpose of this article is to provide answers to these questions and to offer a tenable solution to the challenges posed by recent catastrophes. First, we outline a framework to better understand the changing relationship between science, stakeholders, and environmental problems. Second, we make the case that recent catastrophes are qualitatively different from past disasters. As a result, we discuss (1) the reasons why dichotomizing disasters as natural or technological is increasingly problematic empirically; and (2) the inability of traditional science to effectively address issues, damages, and problems stemming from recent catastrophes. Finally, we suggest that the more participatory approach of postnormal science, strengthened by the precautionary principle and worst-case analysis, is a viable strategy for addressing complex, large-scale catastrophes.

With a primary focus on the historical transition from traditional societies to modern capitalist societies, Max Weber distilled from a complex analysis, rich in historical detail, an argument that centers on rationality. The defining feature of the mode of rationality responsible for the emergence of modern capitalist societies is the centrality of selecting the most efficient means to achieve a desired end. The forces of rationalization—science, technology, economic growth, and especially bureaucracy—pervade ever more spheres of life, supplanting preexisting social institutions and traditions. Another central feature of modernity involves the spread of diverse organizations into all dimensions of social life. In particular, the dependence on organizations to solve social problems has

increased dramatically, especially problems that are complex and technical (Clarke 1999).

Science and technology have both assumed an increasingly prominent role in the modern world. Since the sixteenth and seventeenth centuries, not only has science challenged religion and tradition as the only legitimate epistemology, but science itself has also emerged as one of the dominant ideologies of the modern era. As Habermas (1970) argued, in the modern world:

Traditional legitimations could now be criticized against the standards of rationality of means–ends relations. . . . We have followed this process of “rationalization from above” up to the point where technology and science themselves in the form of a common positivistic way of thinking, articulated as technocratic consciousness, began to take the role of a substitute ideology for the demolished bourgeois ideologies. (P. 114)

During the twentieth century, scientific research has become increasingly wedded to the state, technology, and industry. More importantly, scientific-technical rationality has become as hegemonic as the ideologies it supplanted. As such, the pursuit of knowledge *via* science and the application of this knowledge (technology) have become the appropriate means of achieving a desired end.

The scientific method “perpetuates and extends itself not only through technology but *as* technology, and the latter provides the great legitimation of the expanding political power, which absorbs all spheres of culture” (Marcuse 1964:158). Marcuse (1964), on one hand, acknowledged that the application of science to management and to the division of labor yielded an increased productivity of the economic, political, and cultural enterprise. On the other hand, he pointed out that “this enterprise produced a pattern of mind and behavior which justified and absolved even the most destructive and oppressive features of the enterprise.” “Scientific-technical rationality,” he argued, “are welded together into new forms of social control” (Marcuse 1964:146).

In Robert Merton’s seminal account of the “ethos of science,” he suggested that “there was a necessary tension between the way science was internally organized and the way the capitalist economy worked. This [tension] was managed by preserving a certain autonomy for science” (quote from Calhoun 2006:16). Since this classic account, the autonomy of science in academia and government has been steadily compromised by commercial interests (Ravetz 2004). For example, the cooptation of scientific-rationality and the method of science in industry is manifest in what researchers refer to as the “triple helix,” that is, the “tight intertwining and mutual affinity of the government, commercial, and academic sectors . . .” (Guston 2006:19). In a meta-analysis, Bekelman, Li, and Gross (2003) found strong evidence that biomedical research directly sponsored by industry is more likely to produce proindustrial conclusions. However, most would assume that scientists employed in academia and government would operate with relative autonomy.

Western universities, developed during the twelfth and thirteenth centuries, were legally autonomous institutions, relatively free from outside forces and unique in world historical development (Huff 2006). For example, one historic advantage of academic science, primarily subsidized by U.S. taxpayers, was the creation and protection of a “public research” space, within which scholars could conduct research for the sake of the public good, free of the short-term constraints of commercial interests (Calhoun 2006; Washburn 2005). To whatever degree this “space” existed, it was undermined in the 1970s by a decrease in state funding, the restructuring of universities by corporate capitalism, and the passage of the Bayh-Dole Act in 1980 (Calhoun 2006). The Bayh-Dole Act increased the integration of the university system and business, primarily through the narrow provision of federal funds for academic research which generate commercially viable products (Calhoun 2006). Although only 7.7 percent of university research in 2000 was funded by industry, patents granted to U.S. universities have increased dramatically, from only 96 patents in 1965 to 3200 in 2000 (Krimsky 2006). This trend suggests a more commercialized character has emerged in academic research.

The autonomy of governmental scientists is also suspect, as they report “greater constraints on their scientific autonomy than academic scientists . . .” and those “who speak freely end up either taking the role of ‘whistle blower’ or becoming marginalized by their federal agency” (Krimsky 2006:25). Furthermore, in the United States, some evidence indicates that the regulatory process can be subverted *via* “agency capture,” that is when “a regulatory agency comes to hold views more similar to the industry it is supposed to be regulating than the public it is supposed to protect” (Gramling and Krogman 1997:21; see also, Freudenburg and Gramling 1994). As such, the autonomy of science in “captured” regulatory agencies is undoubtedly biased and constrained.

We argue that the ability of science to address complex, large-scale environmental problems of our own making is attenuated by the ideological embrace of scientific-technical rationality, as it precludes reflexivity and discourages critical discourse. With scientific and technological pursuits increasingly marching to the drum beat of economic growth, is there a place for science to operate, driven not by short-term profitability, but the long-term interests of the public and needs of the environment? Can the problems associated with complex, large-scale catastrophes be addressed adequately by science and technology alone, especially considering that technological failure may be the primary cause of the catastrophe?

The purpose of this article is to further explicate the issues above and to offer a tenable solution to the challenges posed by complex, large-scale catastrophes. First, we outline a framework in an effort to better understanding the changing relationship between science, stakeholders, and environmental problems.

Second, we make the case that recent catastrophes are qualitatively different from past disasters. As a result, we discuss (1) the reasons why dichotomizing disasters as natural or technological is increasingly problematic empirically; and (2) the inability of traditional science (applied science and professional consultancy) to effectively address issues, damages, and problems stemming from recent catastrophes. Finally, we suggest that the more participatory approach of postnormal science, strengthened by the precautionary principle and worst-case analysis, is a viable strategy for addressing the complex, large-scale catastrophes of the twenty-first century.

Evolving Role of Science

Funtowics and Ravetz (1992) distinguish between three different types of problem-solving strategies: applied science, professional consultancy, and postnormal science. In their framework, the horizontal axis in Figure 1 moves outward, from low to high systems uncertainty. Funtowics and Ravetz (1992) make a distinction between three levels of systems uncertainty. First, problems can be solved at the “technical” level, when uncertainty is managed *via* the standard procedures of applied science. With relatively low uncertainty, gathering appropriate empirical evidence and developing sound theories is possible and routine, thus allowing organizations to effectively plan for the future (Clarke 1999).

Second, when problems are more complex and characterized by moderate levels of systems uncertainty, rigorous science may be conducted by multiple interests and presented in a politically contested arena where planning may be difficult, but not impossible (Clarke 1999). As such, the skills and personal judgments of professional consultants are required to solve the methodological problems of uncertainty, a solution that typically includes a debate about values and/or reliability (Funtowics and Ravetz 1992). Third, when the complexity of problems force the scientist to question the reducibility of uncertainties (or the uncertainty of uncertainty), and the knowability and controllability of risk, solutions are required at the “epistemological” level and must be solved through postnormal science (Funtowics and Ravetz 1992). Under such conditions the “promise and apparatus of rational planning itself becomes mainly rhetorical, becomes a means by which plans—independent of their functional relevance to the task—can be justified as reasonable promises that exigencies can be controlled” (Clarke 1999:4).

The vertical axis in Figure 1 moves upward, from low to high decision stakes. Decision stakes are understood as the costs and benefits of various policy decisions for all parties that are impacted by the issue at hand. Applied science is an adequate strategy when systems uncertainty and decision stakes are low. When systems uncertainty and decision stakes are medium, professional consultancy is necessary and may supplement applied science. Taken together,

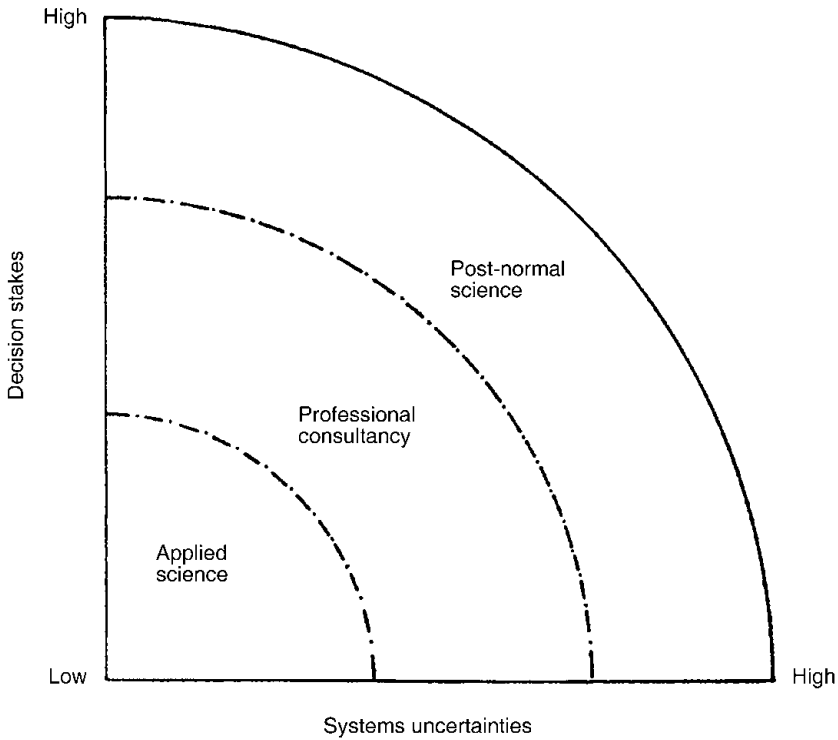


Figure 1
 Problem-Solving Strategies.
 (Used with authors' permission; Funtowics and Ravetz 1992.)

applied science and professional consultancy form what is commonly known as traditional science. Finally, the strategy of postnormal science becomes critical when systems uncertainty and decision stakes are high. The necessity of using one of these three strategies for problem solving does not preclude the necessity of using the others. In fact, some complex problems may require the use of all three strategies. We will now discuss the problem-solving strategies of applied science and professional consultancy in greater detail.

Applied Science

The first problem-solving strategy identified by Funtowics and Ravetz (1992) is “applied science” or in Kuhn’s (1962) parlance, “puzzle-solving.” Applied science adheres to the canons of science advocated since the seventeenth

century and is based on a reductionistic, linear, mechanistic model of the empirical world. Applied science produced “objective” knowledge through scientific expertise, marginalized the public as nonexperts, and discounted lay knowledge as value-laden (Marshall and Goldstein 2006). In policy debates, scientific experts opted for a role of value neutrality. In general, scientific claims of expertise were not questioned by the public. Most accepted science as the dominant epistemology and believed that the method of science produced empirical evidence devoid of biases related to personality, politics, and commercialism. Legitimate knowledge was built largely on trust in expert systems located in organizations (Marshall and Goldstein 2006).

Although applied science is not overtly politicized, strict adherence to the canons of science does have policy implications. For example, convention suggests that scientists must be reasonably confident that a hypothesized relationship exists empirically before the findings are added to an accumulated body of knowledge. As such, scientists would rather commit a Type I error, not finding a relationship when it exists, than a Type II error, finding a relationship when it does not exist (Lemons, Shrader-Frechette, and Cranor 1997). This convention, although cogent when the goal is to accumulate knowledge, is problematic when decision stakes and systems uncertainty are high. For example, if the task of the researcher is to assess whether or not the industrial release of a toxic chemical into the environment will have adverse effects on people living in that environment, privileging Type I errors over Type II errors is at odds with the health concerns of the community. Of course, the community would rather have scientists’ error on the side of caution—that is, finding a relationship when it does not exist, rather than not finding a relationship when it does exist. More broadly and critically, privileging Type I errors over Type II errors is a methodological choice that, intentionally or unintentionally, supports a political-economic system which places a higher value on economic growth than the health of the environment and/or people (Ravetz 2004).

Another example of the ramifications of following the conventions of applied science is the 95 percent rule in community health cases. The implications were evocatively captured by Beverly Paigen (as quoted in Brown 1997), a New York state geneticist who worked with victims of Love Canal. In describing her epiphany, Paigen states that:

Before Love Canal, I also needed a 95 percent certainty before I was convinced of a result. But seeing this rigorously applied in a situation where the consequences of an error meant that pregnancies were resulting in miscarriages, stillbirths, and children with medical problems, I realized I was making a value judgment . . . whether to make errors on the side of protecting human health or on the side of conserving state resources. (P. 16)

In both the hypothetical case and at Love Canal, the decision by scientists to follow the canons of science is a value judgment that privileges scientific

rigor over individual and community health. In the United States, rather than requiring proof of *pre hoc* nontoxicity before certain toxic chemicals are released into the environment, the regulatory/legal system requires proof of *post hoc* toxicity when assessing whether or not community health problems are a result of toxic chemical exposure. Methodologically, the burden is shifted from proving that a cause-and-effect relationship does not exist between chemical exposure and health in a laboratory setting, where experimental designs allow for control of external factors, to the field, where it is impossible to control for numerous external factors with any degree of certainty. While shifting the burden of proof benefits those who produce and release hazardous materials, it harms the environment, individuals, and communities. This shift is a concrete example of the CCPP game (Hardin 1985) through which the *costs* of industrial and agricultural production are *commonized* (CC), while the *profits* are *privatized* (PP).

Beginning in World War II and rapidly developing in the 1950s, applied science blurred the distinction between “scientific validity” and “engineering feasibility” which, in turn, resulted in the unleashing of unanticipated environmental risks (Funtowics and Ravetz 1992). The emergence of unanticipated environmental problems, characterized by medium levels of systems uncertainty and decision stakes, pointed to the inadequacy of applied science and thus the necessity for alternative problem-solving strategies.

Professional Consultancy

“Professional consultancy” entered the public decision-making arena in the United States in response to technological disasters, especially Love Canal, Three Mile Island, Times Beach, and Bhopal. These failures of technology, which elevated risks to human health, exposed the fallibility and inadequacy of applied science, thereby creating conditions conducive for the emergence of the strategy of professional consultancy (Funtowics and Ravetz 1992). Applied scientists and professional consultants analyze problems as employees of formal organizations. A key difference between the applied scientist and professional consultant is that “the [applied] scientist’s task is completed when he has solved a problem that in principle can function as a contribution to a body of knowledge, the professional’s task involves the welfare of a client, and the science that is deployed for that is subsidiary to that goal” (Funtowics and Ravetz 1992:256).

Organizations analyze problems by transforming scientific uncertainty into risks (Clarke 1999). Simply defined, risk refers to the “combination of two factors: the probability that a potentially harmful event will occur; and the potential damage such an occurrence would cause” (Organisation for Economic Co-operation and Development, OECD, 2003:30). Ideally, for organizations to

maintain legitimacy as problem solvers astutely guided by scientific-technical rationality, they must (1) *solve* problems as reservoirs of expert knowledge and wielders of instrumental rationality; and (2) *convince* others that they can solve problems as purveyors of symbolic rationality (Clarke 1999). We suggest that when scientific uncertainty and decision stakes are low, applied scientists can effectively maintain instrumental and symbolic rationality and, as a result, organizational legitimacy is not threatened. As scientific uncertainty increases, organizations are charged with the “onerous task of effectively transforming uncertainty into risk *even without a sufficient experiential base or conceptual scheme appropriate for interpreting history*” (Clarke 1999:12, italics in original). Under such conditions, the uncertainty-to-risk transformation fails to solve the problem and the professional consultant may forsake instrumental rationality, instead seeking to maintain organizational legitimacy through symbolic planning and the creation of “fantasy documents” (Clarke 1999).

Even when problems are characterized by low uncertainty and organizations develop plans that are operational, planning is symbolic in the sense that it serves to convince the public that organizations have the expertise necessary to solve problems (Clarke 1999). In his book, *Mission Improbable: Using Fantasy Documents to Tame Disaster*, Clarke (1999) argues that when scientific uncertainty is high and risks are unknowable and uncontrollable, organizations develop plans that symbolically transform uncertainty into risk by using rhetoric. Scientific expertise, in this case, is manufactured and hoarded by generating esoteric knowledge and discounting competing perspectives. Fantasy documents are symbolic plans that are completely fabricated to convince people that risks of technology are controllable and acceptable (Clarke and Perrow 1996). As decision stakes increase, coupled with the public recognizing that fantasy documents are a facade of control, then organizations potentially face a legitimation crisis.

Professional consultancy exposed science for being a value-laden process, operating in an arena with multiple stakeholders, each armed with professionals making truth claims backed by “science.” Skeptics of traditional science argue that the ideal of the objective scientist is a myth, research may be value-laden, most research is politicized, and funded research projects are increasingly wedded to commercial interests (Marshall and Goldstein 2006). Furthermore, as the relationship between environmental problems and technological failure became increasingly apparent, the public’s faith in science and trust of scientists has waned (Edelstein 1988; Flynn et al. 1992; Greenberg and Williams 1999; Marshall and Goldstein 2006; Piller 1991). Also, the public’s trust in organizations responsible for risk management and regulation has steadily eroded over the past several decades (Dunlap and Mertig 1992; Lipset and Schneider 1983). Some research has found evidence of a relationship between low levels of trust

in organizations and heightened levels of environmental concern (Freudenberg 1993; Hoban, Woodrum, and Czaja 1992; Marshall 1995; Slovic 1992).

Ulrich Beck (1992) presents a thesis that further explicates the tendency of citizens to question the exalted status of traditional science. For instance, Beck's (1992) idea of the "demystification of science" illustrates the trend that people no longer blindly accept the truth claims and objectivity of traditional science. He argues that the history of the growing consciousness and social recognition of (postnormal) environmental risks coincide with the history of the demystification of the (traditional) sciences. Counter to postmodern claims, many have suggested that the method of (traditional) science is not being forsaken, but rather the method of science and scientific-technical rationality are being disembedded from the institution itself (Beck 1992; Brown 1987, 1992, 1997; Kroll-Smith and Floyd 1997). The usefulness of traditional science to solve some problems is not questioned; what is questioned is the status of science as the only legitimate problem-solving strategy and as a strategy that must reside in expert systems.

Citizens themselves have become "lay scientists" in environmental risk areas that are directly related to their health, welfare, and community well-being. Kroll-Smith and Floyd (1997) provide evidence that supports the idea of emergent lay scientists. They found that individuals afflicted with environmental illness, by adopting biomedical terminology, were able to shift the source of the problem from themselves, as victims, to the chemical environment. By redefining environmental illness, the afflicted were able to persuade government officials to change public policies accommodating their illness, despite the medical profession's continued refusal to legitimize the affliction. The grass-roots process referred to as "popular epidemiology" is another example of the growing legitimacy of claims made by lay scientists (Brown 1987, 1992, 1997). Popular epidemiology documents the process by which the lay public translates their situated understanding of the relationship of health problems and environmental contamination into the more universal and accepted language of science.

In sum, Funtowics and Ravetz (1992:258) suggest that "just as industrial risk assessment exposed the inadequacy of the *applied science* approach, so the newer risk problems, either global environment on the one hand, or toxics on the other, show the need for a form of practice that both includes and goes beyond applied science and professional consultancy." One potential source of citizen distrust of government and loss of institutional legitimacy may stem from the inability of traditional scientific strategies to address problems associated with complex, large-scale processes and disasters. Given the ineffectiveness of traditional science in addressing these problems, it is not surprising that new problem-solving strategies are needed.

Challenges of the Twenty-First Century

A new record for disasters worldwide was set during the decade of 1990s, with an estimated \$608 billion in economic losses due to natural disasters (Abramovitz 2001). With Hurricane Katrina and the Indian Ocean tsunami, there is no doubt that the first decade of the twenty-first century will surpass this mark. Considering the global reach of the mass media and 24/7 news cycle, horrific images of the damage caused by the recent spate of worst-case events—Hurricane Katrina, 9/11 terrorist attacks of 2001, and the Indian Ocean tsunami of 2004—will be etched in the minds of people worldwide for some time to come. It is abundantly clear that catastrophic events, experienced either directly or indirectly *via* the media, will characterize social life in the twenty-first century. The number of people directly experiencing worst cases will undoubtedly rise because of two global trends—coastal migration and urbanization.

More than two billion people, approximately 37 percent of the world's population, live within 100 kilometers of a coastline. In the hurricane-prone areas of the United States, 47 percent of people live in coastal counties on the Gulf and the Atlantic Coast (Abramovitz 2001). The urban population of the world has increased fourfold since 1950, with nearly half of the people in the world today living in urban areas (Abramovitz 2001). With urban migration and high birth rates, it is estimated that nearly all of the 2.2 billion added to world population by 2030 will end up in urban centers of the developing world. Most of these new inhabitants will be concentrated in slums that surround large urban areas (Sheehan 2003). The confluence of these demographic trends is evident, considering that 13 of 19 of the world's megacities (10 million or more) are located in coastal zones (Abramovitz 2001). In absolute and relative terms, an increasing number of people in the world will be vulnerable to the negative consequences of anticipated and unanticipated catastrophic events.

Disaster Research

Recent catastrophic events have presented a challenge to researchers studying disasters, environmental risks, and risk perceptions. For example, disaster researchers are beginning to question the natural–technological disaster distinction and, more generally, efforts to neatly categorize such events (Marshall et al. 2003; Picou and Marshall 2007). Marshall, Picou, and Gill (2003:77) argue that “an *a priori* categorization of an event as either a natural or technological disaster is possible analytically, but increasingly difficult in the real world and is counterproductive.” This claim is based on three premises (Picou and Marshall 2007).

First, some disasters traditionally thought to be natural are increasingly viewed as anthropogenic. For example, with emerging consensus on the human

contribution to global warming, previous distinctions between geological disasters (earthquakes, volcanoes, etc.) as natural and meteorological disasters (hurricanes, tornadoes, floods, etc.) as human-caused may become more politically, legally, and social psychologically salient (Picou and Marshall 2007). Second, although the disaster itself may be viewed as an “act of nature” or “God,” the subsequent chronic disaster impacts may be a result of anthropogenic factors and thus accurately perceived by victims as anthropogenic (Picou, Marshall, and Gill 2004; for a seminal example, see Erikson 1976). More generally, if the biophysical environment is increasingly perceived as contaminated by human endeavors, responsibility for producing the disaster may be ascribed to industry and/or government and the responsibility for the severity and duration of postdisaster problems may reflect organizational decisions (Picou and Marshall 2007).

Third, another argument for the necessity of moving beyond rigid classification schemes in disaster research is the recent emergence of two catastrophic events, the 9/11 terrorist attacks and Hurricane Katrina. With history as a guide, these two twenty-first century disasters cannot be characterized as natural or technological, or even as some combination of the two. For instance, the short-term responses by victims, disaster researchers, governmental agencies, and volunteer organizations to the 9/11 terrorist attacks were similar to response patterns observed in the aftermath of natural disasters (Webb 2002). However, processes identified in technological disaster research as causing collective trauma and impeding timely recovery emerged nearly one year after the attacks (Marshall et al. 2003; Picou and Marshall 2007). Further, some characteristics of the 9/11 terrorist attacks render it unlike any preceding disaster in the United States. Unique aspects include the motives behind the attacks, the “rally around the flag” effect, the disaster scene as crime scene, and postdisaster anxiety experienced on the society level (Marshall et al. 2003). We suggest that when other large-scale, postnormal problems and challenges—for example, the Indian Ocean tsunami, global warming, earthquake in Bam, Iran, the looming Avian Flu pandemic, HIV/AIDS crisis in Africa, etc.—are added to this list, the futility of categorization becomes more apparent.

The number of new concepts developed to describe the environmental problems of the late twentieth and early twenty-first centuries provides further evidence that these risks are qualitatively different from those of the past. For instance, the scale and complexity of modern risks has been captured by Beck’s “megahazards” (1992) and “worst disasters imaginable” (1999) found in the risk society, Erikson’s (1994) characterization of technological disasters as a “new species” of trouble, Quarantelli’s (2006) call to refer to recent calamitous events as “catastrophes,” not disasters, OECD’s (2003) discussion of emerging

“systemic risks” and, most important for the purposes of this article, Clarke’s (2006) delineation of “worst cases.” The environmental problems described by these concepts cannot be addressed using the problem-solving strategies of applied science and professional consultancy.

Postnormal Science

Problems that require the use of “post-normal science are ones where, typically, facts are uncertain, values in dispute, stakes high, and decisions urgent” (Funtowics and Ravetz 1992:254). As a strategy, postnormal science requires the formation of an “extended peer community” in which a discourse occurs among all stakeholders affected by a problem. In such a participatory arena, science is but one of many sources of evidence, which together inform policy decisions made by the extended peer community (Funtowics and Ravetz 1992). The necessity of an extended peer community becomes apparent when it is recognized that science is value-laden and that many contemporary problems are characterized by high degrees of uncertainty.

Funtowics and Ravetz (1992:267) also note that traditional science still has utility, “but when the responsible experts are unable to produce . . . an epidemiology that identifies environmentally caused illnesses without protracted political and legal struggles, then by default we are in the realm of post-normal science, and we need an extension of the peer community for the exercise of quality assurance.” Clearly, the protracted social, political, and legal struggles that follow a technological disaster, the siting of locally undesirable land uses (LULUs), and claims of environmental injustice have dramatically increased the decision stakes of environmental decision making. These postnormal problems have created contested situations in which citizens express their frustration through grassroots mobilization. In a sense, the grassroots and environmental justice movements in the United States may be a reactionary response by citizens to the inability of science and government to address problems in the community. As such, the creation of extended peer communities—as a consensus-building, bottom-up, participatory model—may diffuse contested situations, rebuild citizen trust of science and government, and lessen the problems of living in contaminated communities.

The applied science strategy manages the problems of scientific uncertainty through experimental control in a laboratory setting and by relying on statistical probabilities. The professional consultancy strategy manages the problems of scientific uncertainty through the skilled judgment of professionals and insurance. The problem of scientific uncertainty for postnormal science is of a different sort. The critical question is not how do we reduce uncertainty, but rather how do we make better decisions in a world of irreducible uncertainties? We will attempt to answer this question below.

Funtowics and Ravetz (1992) provide a useful framework for examining the changing characteristics of environmental problems and the scientific strategies used to address those problems. We will expand this framework by arguing that the inclusion of the precautionary approach and worst-case analysis would strengthen postnormal science as a problem-solving strategy. Since the early 1990s, the precautionary approach has been lauded as the most important new policy approach in international environmental cooperation (Maguire and Ellis 2005) and has been included in most treaty and policy documents regarding the protection and preservation of the environment (Freestone and Hay 1996). As articulated in Principle 15 of the 1992 Rio Declaration on Environment and Development, the precautionary approach states that:

In order to protect the environment, the precautionary approach shall be widely applied to States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (See Maguire and Ellis 2005:507)

Skeptics of the precautionary approach suggest that its application may serve as a barrier to the development of scientific knowledge and hinder technological development that could improve the quality of life for people across the globe (see Feintuck 2005). As suggested earlier, scientific knowledge is increasingly tied to commercial interests and corporations have a fiduciary responsibility to shareholders to invest in new technologies for profit rather than improving quality of life. Clearly, the precautionary approach may serve as a barrier to certain types of agricultural and industrial production, but arguably is not a barrier in making policy decisions that reflect the interests of the public.

Besides, there are other benefits of the precautionary approach. For instance, the precautionary approach shifts the methodological burden of scientific uncertainty and the legal burden of proof from vulnerable populations potentially exposed to hazardous waste to the producers and distributors of that waste (Maguire and Ellis 2005). The precautionary approach privileges Type II over Type I errors and would question the 95 percent rule when people are at risk. When the precautionary approach is applied within the broader context of postnormal science, methodological debates regarding Type I and Type II errors and the 95 percent rule become policy debates among members of the extended peer community.

Also, Feintuck (2005) suggests that the broader role of the precautionary approach, despite scientific and legal limitations, lies with its implicit connection to democratic interests and the public domain, serving as counterforce against private interests. In this sense, the precautionary approach is well suited to operate within the participatory arena of postnormal science. Under conditions of high uncertainty, the extended peer community is uniquely situated to determine and prioritize under what circumstances the application

of the precautionary approach would be most appropriate. As such, a significant benefit of the precautionary approach is its ability to act proactively and, when necessary, preemptively to prevent the occurrence of irreversible harm to the environment and/or humans. The preemptive aspect of the precautionary approach, as a central component of postnormal science, may be more effective if members of the extended peer community engage in worst-case analysis and thinking.

Another integral component of postnormal science is what Clarke (2006) refers to as worst-case analysis and worst-case thinking. Worst cases are disasters, by definition, that are unimaginable and inconceivable until they occur. Conventional organizational planning for disasters is predicated on probabilities, estimated in part on the patterns observed for past disasters (Clarke 2006). A common critique from those concerned about disaster preparedness is that new plans are constructed only to deal with the last disaster that occurred. While postnormal problems include local technological disasters, such as contaminated communities, that occur relatively frequently, worst cases are particularly challenging and require a postnormal science approach. Put differently, worst cases are a special subset of postnormal problems because they exist outside of probabilistic thinking and overwhelm all available resources. For worst cases, decision stakes and systems uncertainty are at the highest levels.

Clarke (2006) also makes the distinction between retrospective and prospective worst cases. The construction of retrospective worst cases may be therapeutic in that it is an attempt to make sense of the disaster which may facilitate the return to normalcy. As an integral component of postnormal science, we suggest that prospective worst-case analysis by experts and prospective worst-case thinking by nonexperts serve as precautionary inputs into the decision-making process regarding the production and distribution of risk and disaster preparedness. Clarke (2006:97) argues that “thinking about counterfactuals leads us to the paradox of worst cases,” because once a name is given to “that which was previously inconceivable” it ceases to be a worst case. While this may be a paradox on a conceptual level, thinking about counterfactuals as part of the precautionary approach is critical in a world where the “inconceivable” happens all the time.

Conclusion

In the modern era, scientific-technical rationality has emerged as a dominant ideology and the method of science has become the prevailing epistemology. Concomitantly, diverse organizations have interpenetrated all aspects of social life and society has become increasingly dependent on these organizations to solve a wide array of social and environmental problems. Undeniably, scientific and technological advances have been integral to economic growth over the

past century, but these same advances tend to manufacture environmental problems that are increasingly complex, large-scale, and destructive. This is the paradox of the twenty-first century. We are increasingly reliant on science and technology to solve “normal” environmental problems, but some of these solutions in turn create “postnormal” environmental problems. Scientific-technical solutions (e.g., the levee system in New Orleans) to “postnormal” problems may generate “worst cases” (e.g., the flooding of New Orleans after Hurricane Katrina).

Scientific uncertainty is a central theme in this article. Applied scientists strive to reduce uncertainty by using a variety of experimental designs in a laboratory setting. Although applied scientists are not thought of as overtly biased, strict adherence to the canons of science has policy implications which generally benefit the producers and distributors of environmental risks and harm at-risk vulnerable populations. Under conditions of low uncertainty and decision stakes, organizations can effectively plan for the future. However, under cover of moderate uncertainty, professional consultants are able to produce findings that reflect the interests of their clients without necessarily having to violate scientific canon. In the highly contested legal or political arena of competing scientific truth claims, those with deep pockets (producers and distributors of risk) can employ a cadre of scientists and thus have the upper hand. As scientific uncertainty and decision stakes increase, organizational efforts to transform uncertainty into risk fails, but this failure may be glossed over through symbolic planning and the creation of fantasy documents.

In this article, we suggest that the relative autonomy of traditional scientists working in academia and government has been steadily eroded by the short-term, profit-driven interests of corporations. As a result of this erosion, traditional science has been ineffective in addressing the long-term problems associated with the emergence of complex, large-scale environmental problems. We are not suggesting that it is through postnormal science that scientists reclaim autonomy, but rather through postnormal science that the biases of traditional science becomes transparent and problematized. While this may not be the idealized autonomous space for scientists, it may be a sufficient political space within which the extended peer community can make effective decisions, grounded in an acknowledged world of irreducible and unknowable uncertainty, that better reflect the interests of the public, future generations, and the environment. In the participatory framework of postnormal science, prospective worst-case analysis by experts and prospective worst-case thinking by nonexperts may serve as precautionary inputs in the decision-making process about the production and distribution of environmental risks and how communities prepare for twenty-first century catastrophes.

ENDNOTE

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Post-normal science (PNS) represents a novel approach for the use of science on issues where "facts [are] uncertain, values in dispute, stakes high and decisions urgent". PNS was developed in the 1990s by Silvio Funtowicz and Jerome R. Ravetz. It can be considered as a reaction to the styles of analysis based on risk and cost-benefit analysis prevailing at that time, and as an embodiment of concepts of a new "critical science" developed in previous works by the same authors. In a more recent work *Turning to post-normal science*, I find myself more closely aligned with Mr Lock but, even here, I feel that his article misrepresents. The kinship between post-normal science and the precautionary principle lies in the fact that they are both attempts to address the same problem – how to proceed when uncertainty and expedience conspire to undermine confidence. However, whereas fear and various conceptions of political pragmatism may lie behind both, post-normal science differs in claiming epistemological roots. Concerns regarding the precautionary principle and post-normal science are valid enough without overstating the case.

Notes.

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