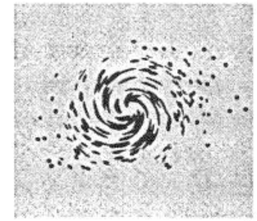

Introduction: Death, Taxes, and Environmental Policy

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"In this world," said Ben Franklin, "nothing is certain but death and taxes." More than two centuries later, his prediction has lost none of its robustness, and we take it as our unlikely starting place. Looming like a dark cloud on the American political horizon is the nation's Social Security program. The problem, in brief, is death and taxes—a predicted deficiency of both. The dynamics are obvious: As people live longer, they spend more time in retirement; as birth rates go down, the number of retirees increases faster than the number of workers. Ultimately, the government's financial obligations to an ever expanding population of retired people outstrip the ability of the working population to finance those obligations. Either taxes must be raised, or retirement benefits must be curtailed. As a political matter, what dilemma could be more horrific?

Predictions allow us to come to grips with the problem. For a single individual, death and taxes are utterly certain, but the date of the former and the magnitude of the latter are considerably less so. At the level of a population, however, regularity and predictability begin to emerge. If the nation is to manage the financial future of Social Security, policy makers must know something about future revenues, life expectancy, fertility rates, unemployment, and immigration. Historical trends provide helpful guidance in anticipating how these factors will behave in coming years. And demographic reality determines an inescapable future: Fertility rates, the age distribution of the population, and current life expectancies dictate that middle-aged baby boomers will before long fuel unprecedented growth of the retired population. Only catastrophe can alter this fate: pandemic, global war, environmental collapse, asteroid impact—in which case, the solvency of Social Security will be the least of our problems.

Efforts to craft a nonpartisan solution to the Social Security dilemma are invariably torn asunder by a political process that often penalizes those who make hard decisions. The vitriolic partisanship that characterizes American politics at the turn of the millennium has rendered neither political party willing to take the lead on a proposal that could make it vulnerable to attack. At the same time, politicians of opposing stripe latch on to the uncertainties in the economic and demographic predictions—perhaps the economy will grow faster, or people will work until they are older—to argue that the problem may not be as serious as it seems. But when it comes to Social Security, our picture of the future is fairly sharp, and all reasonable projections of future demographic and economic trends converge on a similar conclusion: insolvency thirty years or so into the new century. Such insolvency would create an economic and political crisis of enormous proportions. Yet politicians are thus far entirely unable or unwilling to come to grips with this reality and craft a workable solution.

The difficulty of turning reasonably reliable knowledge about the future into positive action on Social Security highlights the central theme of this book: The value of predictions in public policy is not simply a technical question—it is much more than a problem of reducing uncertainties, of getting the numbers "right." Rather, it is a complex mixture of interdependent scientific, political, and social factors. Technically reliable predictions in and of themselves do not translate into successful decisions. That being said, we must further muddy the waters by observing that even the very idea of technical "reliability" can be damnably difficult to evaluate at the time that a decision must be made. To illustrate this point, we offer a parting shot about Social Security before abandoning the issue for good. Once upon a time, Congress actually did manage to grapple successfully with an impending insolvency crisis. It sought to guarantee actuarial solvency well into the future by raising taxes and making other structural changes to the program. Nonpartisan technical analysis, based on solid demographic and economic data, predicted that such changes would ensure solvency for seventy-five years. Secure in the reliability of that prediction, politicians took action and passed the 1983 Social Security amendments. But by 1998, nonpartisan technical analysis showed that the correct number would have been closer to fifty years. The original prediction was off by 33 percent. This enormous error was revealed only by the passage of time. Even predictions made with great confidence and understanding can be wrong.

With these lessons in mind, we now turn to the issue at hand: the application of scientific predictions to problems of the environment. Fundamental to our concerns is the observation that *decision making is a forward-looking process*. From an individual choosing whether to carry an umbrella, to a large international body debating a global environmental treaty, the basic idea is to achieve a goal in the future—keeping one's hair dry or protecting the planet from global warming. And if decision making is the attempt to achieve a desired future, then any such attempt must include, implicitly or explicitly, a vision of what that future will look like.

Dewey (1991) captured the issue well: "The very essence of civilized culture is that we . . . deliberately institute, in advance of the happening of various contingencies and emergencies of life, devices for detecting their approach and registering their nature, for warding off what is unfavorable, or at least for protecting ourselves from its full impact, and for making more secure and extensive what is favorable."

Two general strategies are employed in this effort: adaptation and prevention. If an event seems inevitable and unavoidable, we often have no choice but to adapt. Thus, we carry an umbrella if there is a threat of rain, or we provide federal insurance for houses on floodplains (or perhaps we prohibit construction in such locations), or we enforce seismic building codes in California, where earthquakes are common. The rain, the flood, the earthquake still come, and we are prepared. In other cases we may actually try to change an anticipated future through conscious action, and thus prevent undesirable impacts. Flood-control projects, for example, are aimed at actually preventing dangerous floods, through hydraulic engineering. Similarly, we may try to use technologies and regulations to reduce carbon dioxide emissions so that we can forestall—rather than adapt to—global warming.

In reality, of course, adaptation and prevention are not mutually exclusive. Earthquakes can be neither prevented nor predicted, but clever engineering can ensure that buildings withstand severe ground motions. This is an adaptation to earthquakes that also prevents an earthquake hazard—that is, the propensity of buildings to fall down.

But a fundamental question remains: If decision making is a forward-looking process, what enables us to look forward? What allows us to anticipate the "contingencies and emergencies of life" and make successful decisions to prepare for or forestall them? Experience and judgment, of course. We know from experience that floods occur on floodplains, and we can exercise our judgment in determining how to reduce flood losses through zoning, construction practices, or hydraulic engineering. But experience and judgment can now be augmented by explicitly predictive scientific information. The path and behavior of a major storm are predicted by weather forecasters; the height of the flood crest and its rate of movement downstream are predicted by hydrologists. Based on such scientific information, we can decide where we need to pile sandbags, how high the pile will need to be, and whether evacuation will be necessary—at least in principle.

Science increasingly predicts occurrences that cannot easily be inferred from experience and judgment alone. An early example was Thomas Malthus's predictions that exponential population growth would outstrip agricultural capacity and lead to famine. Thankfully, the prediction has thus far been wrong; indeed, it has helped to stimulate advances in agriculture that ensure its continued erroneousness. More recently, scientific documentation of acidified lakes in the northeastern United States helped sound the alarm over the prospective environmental dangers of acid rain, and the measurement of rising atmospheric carbon dioxide levels fueled predictions of global warming. Meanwhile, telescopes sweep the sky in search of asteroids that could collide, catastrophically, with the earth. The future of nature has become the business of scientists.

Science, with its promise of prediction, seems to be a perfect mate for decision making, with its forward-looking essence. Environmental policy making tests this new marriage. If the marriage were obviously and inevitably a harmonious one, our book would not be necessary. In fact, the relationship between predictive science and environmental decision making is rocky. To begin with, each activity is complex and difficult in its own right. The theoretical and technical difficulties of predicting complex natural systems are immense, and the magnitudes of the uncertainties associated with such predictions may be not only large, but also themselves highly uncertain. At the same time, the process of making environmental decisions, which often brings together a mix of violently conflicting interests and values, has given rise to some of the most intractable political disputes of the last half century. The idea that predictive science can simplify the decision-making process by creating a clearer picture of the future is deeply appealing in principle, but deeply problematic in practice.

Prediction: Science, Decision Making, and the Future of Nature attempts to paint a comprehensive portrait of the troubled relationship between predictive science and environmental decision making. The goals of the book are to provide insights into the promise and limitations of prediction as a tool for decision makers, to explore alternatives to prediction, to present fresh perspectives about the interface between science and environmental decision making, to develop a usable analytical framework—including specific principles—that govern that interface, and to make concrete recommendations that can increase the likelihood of effective environmental decisions.

At the outset, let us clarify a few basic terms. The phrase *decision*

making in our title encompasses the broadest scale of action, from individual responses to a weather forecast, to multinational bodies concerned with global environmental threats. However, we also frequently use the term *policy making*, by which we mean organized decision making that is often codified in regulations, laws, formal recommendations, and treaties and other types of agreements. The phrase *the future of nature* captures a diverse set of interactions between society and the environment, including phenomena that are largely unmediated by human intervention (such as asteroid impacts and earthquakes) and those that bear a significant anthropogenic signature (such as acid rain and the behavior of waste from hard rock mines and nuclear reactors). We have limited our concerns to policy problems involving physical and chemical earth-system processes and resources, and excluded biological ones, in part to make our job more manageable, but also because some progress has already been made in understanding the difficulties of using predictive information to manage biological systems (for example, see Lee 1993, and Gunderson, Holling, and Light 1995). We have also, as a matter of practicality, focused our discussion on prediction activities in the United States.

The following three chapters investigate the marriage of prediction and decision making from political, historical, and behavioral perspectives. These chapters first establish that science and prediction are not the same thing; they then go on to explore the attributes of nature, on the one hand, and *human nature*, on the other, that define the promise and the limits of prediction in environmental policy. These foundation-setting discussions are followed by ten narrative case studies that constitute the heart of the book. The cases fall rather naturally into three separate but related groups:

1. "natural" hazards that are perceived by decision makers as largely unavoidable: short-term weather, floods, asteroids, and earthquakes;

2. environmental problems for which predictions are generated to support a course of action that already has strong political momentum: beach erosion, mining impacts, and nuclear waste disposal;

3. multifaceted environmental issues that respond to—and raise—complex, unresolved policy dilemmas: oil and gas reserves, acid rain, and global climate change.

Central to this disparate and almost biblical-sounding assortment of plagues and problems is society's effort to generate reliable scientific predictions that can be used as a basis for making decisions about humanity's relationship with complex natural systems. The ten cases provide the empirical base for the final chapters of the book, which focus on policy implications, analytical frameworks and principles, and recommendations.

We have worked hard to eliminate jargon and superfluous technical information from the book. The reader does not have to be a hydrologist to understand the chapters on floods and nuclear waste disposal, or a climatologist to understand the chapters on weather and climate change. Basic literacy and interest in science, the environment, and public policy are the only prerequisites for full comprehension and, we hope, for enjoyment, edification, and practical value.

Before turning the reader over to our capable authors (whose biographical sketches can be found at the end of the book), a word on the issue of uncertainty is appropriate. Scientists, decision makers, and analysts have often suggested that effective linkage between science and environmental decisions depends upon the achievement of two goals: First, scientific uncertainties must be reduced (that is, predictions need to be more accurate); and second, technical experts must effectively communicate the nature and magnitude of those uncertainties to people who must take action. This intuitively attractive perspective treats uncertainty as something to be overcome, and prediction as a technical product that must be successfully integrated into the decision-making process prior to taking effective action. It also explicitly justifies tens of billions of dollars of publicly funded scientific research into problems as diverse as hydrocarbon reserve estimates, the behavior of nuclear waste in geological repositories, and the future behavior of the earth's climate.

All the same, it is often impossible to assign meaningful uncertainties to predictions of complex natural processes. One good hurricane can obliterate a beach that was predicted to last for a decade, a single debris-clogged bridge can cause a flood to rise far above its predicted crest, and a huge volcano can instantly negate a decades-long global warming trend. Such "surprises" are an expected—yet unpredictable—reality of open natural systems. Moreover, the complex interactions among the multiple components of such systems may render their detailed behavior unpredictable even in principle, as the continued inability to predict weather more than two weeks in advance starkly demonstrates.

But such technical concerns—which have been addressed in many scholarly and popular studies of "complex" phenomena (e.g., Gallagher and Appenzeller 1999)—are only part of the problem, and perhaps the less significant part. The case studies in this book indicate little obvious correlation between the quality of a prediction as judged by scientific standards and the success of decisions as judged by the achievement of desired societal outcomes. Earthquakes and acid rain provide conceptual bookends to this point. A complete failure to predict the occurrence of specific earthquakes—infinite uncertainty—forced decision makers to turn their attention from prediction to prevention of earthquake damage, thus stimulating successful policy action. Conversely, a scientifically successful acid rain research program yielded predictions that were largely irrelevant to the information needs of policy makers. In many cases, reducing and communicating scientific uncertainty associated with predictions are neither necessary nor sufficient conditions for creating a decision environment that is conducive to beneficial action. Thus, as we will see, a central challenge for decision makers is to understand how to distinguish problems that are likely to be amenable to prediction-based solutions from those that demand alternative approaches. Meeting this challenge requires an understanding of the broad context—the interrelated scientific, socioeconomic, and political environments—in which decisions are made.

In other words, the idea of a prediction as a disembodied number modified by an uncertainty is entirely too abstract to have any meaning in the real world. This book is not about numbers, but about the social and political processes in which numbers are inextricably enmeshed. In the end, we hope to provide usable insight about how desired societal outcomes can emerge from these processes. Given the magnitude of the environmental challenges that face society today, and the likelihood that this magnitude will grow in the future, our decision-making capability needs all the help it can get. The predictive promise of the earth sciences, and the forward-looking character of decision making, tempts us to simply turn to scientists and say: "Tell us what will happen in the future, so we can know what action to take now." If only it were so simple.

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Molecular biologists have not, as far as we know, identified a "prediction gene," but the quest to predict seems as deeply instinctive to the human condition as language, self-consciousness, and artistic expression. Unlike these other characterizing traits, however, the instinct to predict has not always been expressed in effective performance. Oracles, prophets, and stock market forecasters have been accorded a status in society that is commensurate with the promise—not the delivery—of tomorrow revealed.

Scientists today seek to turn prediction into a reputable profession. They bring impressive tools to the quest: powerful theoretical understanding of fundamental processes; advanced monitoring technologies that digitize nature in all its rich profusion; supercomputers that crunch gigabyte-sized databases and spit out a vision of the future. Indeed, these days, science without prediction hardly seems like science at all.

Still, even the most sophisticated scientific predictions are plagued with uncertainties. But unlike predictions based on entrails or the stars, these uncertainties can be quantified (although quantifications of uncertainty are often themselves highly uncertain). We may therefore ask: What characteristics of a scientific prediction will allow us to make a decision that is better than the one we would have made without the prediction? (Of course, the answer to this question, too, may be highly uncertain.)

1 Prediction in Science and Policy

Daniel Sarewitz and Roger A. Pielke, Jr.

Policy makers have called upon scientists to predict the occurrence, magnitude, and impacts of natural and human-induced environmental phenomena ranging from hurricanes and earthquakes to global climate change and the behavior of hazardous waste. In the United States, billions of federal dollars are spent each year on such activities. These expenditures are justified in large part by the belief that scientific predictions are a valuable tool for crafting environmental and related policies. But the increased demand for policy-relevant scientific prediction has not been accompanied by adequate understanding of the appropriate use of prediction in policy making.

In modern society, prediction serves two important goals. First, prediction is a test of scientific understanding, and as such has come to occupy a position of authority and legitimacy. Scientific hypotheses are tested by comparing what is expected to occur with what actually occurs. When expectations coincide with events, it lends support to the power of scientific understanding to explain how things work. "[Being] predictive of unknown facts is essential to the process of empirical testing of hypotheses, the most distinctive feature of the scientific enterprise," observes biologist Francisco Ayala (1996).

Second, prediction is also a potential guide for decision making. We may seek to know the future in the belief that such knowledge will stimulate and enable beneficial action in the present. Such beliefs are supported by a long—if often mythic—history, predating modern science. For instance, armed with knowledge of the coming flood, Noah was able to build the ark and avoid the catastrophic end that befell those without such foresight. Today, as decision makers debate alternative courses of action, such as the need for a new law or the design of a new