The 4P *Approach to Dea*

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One often sees contradictory stories in the media from "reputable scientific sources" who claim, one day, that "Global warming will occur, and the results will be catastrophic unless something is done immediately," and, on another day, that "There is no direct evidence for global warming, and people should not waste money on something that may or may not happen." On yet another day, one hears that "Toxic chemical X causes cancer," followed on the next day by the statement that "Toxic chemical X occurs in too low a concentration in the environment to cause cancer." These seemingly contradictory statements from the scientific community send the social decisionmaking process into a tailspin. On the one hand, because scientists

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ıling with Scientific Uncertainty

By Robert Costanza and Laura Cornwell

cannot agree on what is happening, should policymakers wait until better information is available before acting? On the other hand, if society fails to act, the situation may deteriorate rapidly and irreversibly. What are people to do in these all-too-common situations, and why has science failed to provide the certain and unbiased answers on which good policymaking depends? What is wrong with the link between science and policy, and how can it be improved? Is a different, nonregulatory approach needed for managing the environment?

There are several lines of thought in environmental science and economics about how to develop an effective approach to dealing with uncertainty. Two of the most renowned are the "precautionary principle," which has gained wide acceptance in international environmental circles, and the "polluter pays principle," which has long been advocated by environmental economists.[1] Although both of these principles have gained wide acceptance in theory, practical applications have been severely hampered. One criticism is that, "though the precautionary principle provides a useful overall orientation, it is an insufficient basis for policy and largely lacks legal content."[2] Large uncertainties about ecological damages also have caused applications of the polluter pays principle to founder on questions of "how much" and "when." However, an environmental deposit-refund or assurance bonding system could shift the burden of proof, incorporate uncertainty into what the polluters pay for and when they pay it, and thus provide strong and effective economic incentives for both environmental precaution and technological innovation.

Scientific Uncertainty

One of the main reasons for the problems with current methods of environmental management is scientific uncertainty—not just its existence, but the radically different expectations and modes of operation that scientists and policymakers have developed to deal with it. To solve this problem, these differences must be exposed and understood, and better methods to incorporate uncertainty into policymaking and environmental management must be designed.

To understand the scope of the problem, it is necessary to differentiate between risk, which is an event with a known probability (sometimes referred to as statistical uncertainty), and true uncertainty, which is an event with an unknown probability (sometimes referred to as indeterminacy). For instance, every time you drive your car, you run the risk of having an accident because the probability of car accidents is known with very high certainty. The risk involved in driving is well known because there have been many car accidents with which to calculate the probabilities. These probabilities are known with enough certainty that they are used by insurance companies, for instance, to set rates that will assure those companies of a certain profit. There is little uncertainty about the possibility of car accidents. If you live near the disposal sight of some newly synthesized toxic chemical, however, your health may be in jeopardy, but no one knows to what extent. Because no one knows the probability of your getting cancer, for instance, or some other disease from this exposure, there is true uncertainty. Most important environmental problems suffer from true uncertainty, not merely risk.

Uncertainty may be thought of as a continuum ranging from zero for certain information to intermediate levels for information with statistical uncertainty and known probabilities (risk) to high levels for information

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with true uncertainty or indeterminacy. Risk assessment has become a central guiding principle at the U.S. Environmental Protection Agency (EPA) and other environmental management agencies,[3] but true uncertainty has yet to be adequately incorporated into environmental protection strategies.

Scientists treat uncertainty as a given, a characteristic of all information that must be honestly acknowledged and communicated. Over the years, scientists have developed increasingly sophisticated methods to measure and communicate uncertainty arising from various causes. In general, however, scientists have uncovered more uncertainty rather than the absolute precision that the lay public often mistakenly associates with scientific results. Scientific inquiry can only set boundaries on the limits of knowledge. It can define the edges of the envelope of known possibilities, but often the envelope is very large, and the probabilities of what's inside (the known possibilities) actually occurring can be a complete mystery. For instance, scientists can describe the range of uncertainty about global warming and toxic chemicals and maybe say something about the relative probabilities of different outcomes, but, in most important cases, they cannot say which of the possible outcomes will occur with any degree of accuracy.

Current approaches to environmental management and policymaking, however, avoid uncertainty and gravitate to the edges of the scientific envelope. The reasons for this bias are clear. Policymakers want to make unambiguous, defensible decisions, which are often codified into laws and regulations. Although legislative language is often open to interpretation, regulations are much easier to write and enforce if they are stated in absolutely certain terms. For most of criminal law, the system works reasonably well. Either Cain killed his brother or he did not; the only question is whether there is enough evidence to demonstrate guilt beyond a reasonable doubt (with essentially zero uncertainty). Because the burden of proof is on the prosecution, it does little good to conclude that there was an 80-percent chance that Cain killed his brother. But many scientific studies come to just these kinds of conclusions. Science defines the envelope while the policy process gravitates to an edge—usually the edge that best advances the policymaker's political agenda. But to use science rationally to make policy, the whole envelope and all of its contents must be dealt with.

The problem is most severe for environmental regulation. Building on the legal traditions of criminal law, policymakers and environmental regulators desire certain information when designing environmental regulations. But much of environmental policy is based on scientific studies of the likely health, safety, and ecological consequences of human actions. Information gained from these studies is therefore only certain within the studies' epistemological and methodological limits.[4] Regulators are increasingly confronted with decision-making outside the limits of scientific certainty, particularly with the recent shift in environmental concerns from visible, known pollution to more subtle threats, such as radon.[5]

Problems arise when regulators ask scientists for answers to unanswerable questions. For example, the law may mandate that the regulatory agency devise safety standards for all known toxins when little or no information is available on the impacts of these chemicals. When trying to enforce the regulations after they are drafted, governments confront the problem of true uncertainty about the impacts. It is usually impossible to determine with any certainty if the local chemical company contributed to the death of some of the people in the vicinity of its toxic waste dump. Similarly, one cannot prove the connection between smoking and lung cancer in any direct, causal way, at least in the legal sense, but only as a statistical relationship. And of course, global warming may or may not happen after all.

Most environmental regulations, particularly those in the United States, demand certainty. When scientists are pressured to supply this nonexistent commodity, there is not only frustration and poor communication but also mixed messages in the media. Because of uncertainty, environmental issues are often manipulated by political and economic interest groups. Uncertainty about global warming is perhaps the most visible current example of this phenomenon.

The precautionary principle describes one theory of how the environmental regulatory community should deal with the problem of true uncertainty. The principle states that, rather than await certainty, regulators should act in anticipation of any potential environmental harm to prevent it. The precautionary principle is so frequently invoked in international environmental resolutions that it has come to be seen by some as a basic normative principle of international environmental law.[6] But the principle offers no guidance as to what precautionary measures should be taken. It "implies the commitment of resources now to safeguard against the potentially adverse future outcomes of some decision"[7] but does not say how many resources should be committed or which adverse future outcomes are most important.

Yet the size of the stakes is a primary determinant of how uncertainty is dealt with in the political arena. Normal applied science applies only under circumstances of low uncertainty and low stakes. Higher uncertainty or higher stakes result in a much more politicized decisionmaking environment. Moderate uncertainty or stakes correspond to "applied engineering" and "professional consultancy," which allow a good measure of judgment and opinion to deal with risk. Currently, however, there is no way to deal with either high stakes or high uncertainty, which require a new approach that could be called "post-normal" or "second-order" science.[8] This "new" science is really just the application of the essence of the scientific method to new territory. The scientific method does not, in its basic form, imply anything about the precision of the results achieved. It does, however, imply a forum of free inquiry, without preconceived answers or agendas, aimed at determining the envelope of knowledge and the magnitude of ignorance.

Implementing second-order science requires a new approach to environmental protection, one that acknowledges the existence of true uncertainty rather than denying it and includes mechanisms to safeguard against potentially harmful effects but, at the same time, encourages the development of low-impact technologies and the reduction of uncertainty about impacts. The precautionary principle sets the stage for this approach, but the real challenge is to develop scientific methods to determine the potential costs of uncertainty and to adjust incentives so that the appropriate parties pay this cost of uncertainty and have appropriate incentives to reduce its detrimental effects. Without this adjustment, the full costs of environmental damage will continue to be left out of the accounting,[9] and the hidden subsidies from society to those who profit from environmental degradation will continue to provide strong incentives to degrade the environment beyond sustainable levels.

Dealing with Uncertainty

How should scientists and policymakers deal with the enormous uncertainty inherent in environmental issues? First, uncertainty should be accepted as a basic component of environmental decisionmaking at all levels and be better communicated. But environmental management should also change, and understanding of the link between ecological and economic systems must grow. Thus, economic and other incentives could be used more efficiently and effectively to achieve environmental goals.

The effort to integrate ecology and

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economics to improve environmental and economic management and to ensure long-term sustainability has become focused in the transdisciplinary field of ecological economics.[10] This new field promises to permit a deeper understanding of the ecological functions and values that the precautionary principle is intended to protect and the development of more efficient and effective mechanisms to implement the principle. One goal of ecological economics is to estimate the long-term social and ecological costs and benefits of various human activities for comparison with the private short-term costs and benefits that are too often the only consideration in decisionmaking. To do this, the field must develop methods for the valuation of ecological damage based on a second-order scientific understanding of the functioning of linked ecological economic systems at several temporal and spatial scales. This understanding involves developing a description of the envelope of knowledge and the boundaries of ignorance about these interactions. For the purposes of pricing ecological functions and values for use with the precautionary principle, the edge of this envelope that describes the worst-case scenario, as far as ecological impacts are concerned, is the one of primary interest. Research focused on the "worst edge" should lead to much more effective use of science in anticipating and heading off problems.

For example, were worst-edge research the norm, scientists could easily have anticipated the greenhouse effect and taken steps to minimize its potential impacts. Indeed, the effect and humanity's potential impact on it were first described almost 100 years ago,[11] but it remained a scientific curiosity until the 1980s, when enough data and models had been assembled to demonstrate that the effect was, in fact, likely to cause global warming. There is still much uncertainty about the magnitude of the warming and especially about its ultimate impacts, but science can do a very good job of anticipating potential problems if it focuses on that function rather than on demonstrating impacts that have already occurred. Current research should therefore focus on the worst edge of climatic and economic impacts that might result from releases of greenhouse gases, as well as on the range of uncertainty about these impacts and on ways to reduce the uncertainty.

Over the past two decades, there has been extensive discussion about the efficiency that theoretically can be achieved in environmental management through the use of market mechanisms.[12] These mechanisms are designed to alter the pricing structure of the present market system to incorporate the long-term social and ecological costs of an economic agent's activities. Suggested incentive-based mechanisms include pollution taxes, tradable pollution-discharge permits, financial responsibility requirements, and deposit-refund systems (see "Dealing with Pollution: Market-Based Incentives for Environmental Protection" in the September 1992 issue). Some new versions of these incentive-based alternatives should help policymakers deal in a precautionary way with the pervasive uncertainty inherent in environmental problems.

An innovative incentive-based instrument currently being researched to manage the environment for precaution under uncertainty is called a flexible environmental assurance bonding system.[13] This variation of the deposit-refund system is designed to incorporate both known and uncertain environmental costs into the incentive system and to induce positive environmental technological innovation. It works by charging an economic agent directly for known environmental damages and levying an assurance bond equal to the current best estimate of the largest potential future environmental damages. The bond would be kept in an interest-bearing escrow account for a predetermined length of time. In keeping with the precautionary principle, this system requires a commitment of resources up front to offset the potentially catastrophic future effects of current activity. Portions of the bond (plus interest) would be returned if and when the agent could demonstrate that the suspected worst-case damages had not occurred or would be less than was originally assessed. If damages did occur, portions of the bond would be used to rehabilitate or repair the environment and possibly to compensate injured parties. Funds tied up in bonds could still be used for other economic activities. The only cost would be the difference (plus or minus) between the interest on the bond and the return that could be earned by the business had it invested in other activities. On average, this difference would be minimal. In addition, the "forced savings" that the bond would require could actually improve overall economic performance in economies like that of the United States that chronically undersave.

By requiring the users of environmental resources to post a bond adequate to cover uncertain future environmental damages (with the possibility for refunds), the burden of proof and the cost of the uncertainty are shifted from the public to the resource user. At the same time, agents are not charged in any final way for uncertain future damages and can recover portions of their bond (with interest) in proportion to how much better their environmental performance is than the predicted worst-case scenario.

Deposit-refund systems are not a new concept; they have been successfully applied to a range of consumer, conservation, and environmental policy objectives.[14] The most well-known examples are the systems for beverage containers and used lubricating oils that have proven to be quite effective and efficient.

Another precedent for environmental assurance bonds are the producer-paid performance bonds often required for federal, state, or local government construction work. For example, the Miller Act (40 U.S.C. 270), a 1935 federal statute, requires contractors performing construction work for the federal government to secure performance bonds. Performance bonds provide a contractual guarantee that the principal (the entity that is doing the work or providing the service) will perform in a designated way. Bonds are frequently required for construction work done in the private sector as well.

Performance bonds are frequently posted in the form of corporate surety bonds. Surety companies, which cosign these bonds, are licensed under various insurance laws and, under their charter, have legal authority to act as a financial guarantee for those posting the bond. The unrecoverable cost of this service is usually from one to five percent of the bond amount. However, under the Miller Act, any contract above a designated amount ($25,000 in the case of construction) can be backed by other types of securities, such as U.S. bonds or notes, in lieu of a bond guaranteed by a surety company. In this case, the contractor provides a duly executed power of attorney and an agreement authorizing collection on the bond or notes if the contractor defaults on the contract.[15] If the contractor performs all of the obligations specified in the contract, the securities are returned to the contractor, and the usual cost of the surety is avoided.

Environmental assurance bonds would work in a similar manner, by providing a contractual guarantee that the principal would perform in an environmentally benign manner, but would be levied according to the best estimate of the largest potential future environmental damages. Funds in the bond would be invested and would produce interest that could be returned to the principal. An "environmentally benign" investment strategy would probably be most appropriate for such a bond.

These bonds could be administered by the regulatory authority that currently manages the operation or procedure. In the United States, for example, the EPA could be the primary authority. But a case can be made

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that it would be better to set up a completely independent agency to administer the bonds. Of course, the design of the administering agency is worthy of considerable additional thought and analysis and would depend on the details of the particular situation.

The bond would be held until some or all of the uncertainty was removed. This would provide a strong incentive for principals to reduce the uncertainty about their environmental impacts as quickly as possible, either by funding independent research or by changing their processes to ones that are less damaging. The establishment of a quasi-judicial body would be necessary to resolve disputes about when and how much of the bonds should be refunded. This body would use the latest independent scientific information on the worst-case ecological damages that could result from a business's activities, but the burden of proof would fall on the economic agent that stands to gain from the activity, not on the public. EPA already has a protocol for worst-case analysis. In 1977, the U.S. Council on Environmental Quality required worst-case analysis for implementing the National Environmental Policy Act of 1969. This requirement forced EPA to consider the worst environmental consequences of an action when scientific uncertainty was involved.[16]

One potential argument against the bond is that it would favor relatively large businesses that could afford to handle the financial responsibility of activities that are potentially hazardous to the environment. This is true, but it is exactly the desired effect, because businesses that cannot handle the financial responsibility should not be passing the cost of potential environmental damage on to the public. In the construction industry, the use of performance bonds would prevent small fly-by-night businesses from cutting corners and endangering the public to underbid responsible businesses.

This is not to say that small businesses would be eliminated; far from it. They could either band together to form associations to handle the financial responsibility for environmentally risky activities, or, preferably, they could change to more environmentally benign activities that did not require large assurance bonds. This encouragement of the development of new, environmentally benign technologies is one of the main attractions of the bonding system, and small, start-up businesses would certainly lead the way.

Applying the "4P" Approach

Strong economic incentives would be provided by the proposed environmental assurance bond to reduce pollution, to research the true costs of environmentally damaging activities, and to develop innovative, cost-effective pollution control technologies. The bonding system extends the polluter pays principle to make the polluter pay for uncertainty as well. Thus is born the "precautionary polluter pays principle" (4P), which would allow a much more proactive approach to environmental problems because the bond would be paid up front, before the damage is done. By unleashing the creative resources of businesses, 4P would foster pollution prevention and the development of new, cleaner technologies (rather than merely cleanup). Because these technologies would be economically attractive in the short run, competition in the marketplace would lead to environmental improvement rather than degradation. The 4P approach would deal more appropriately with scientific uncertainty than do the current command-and-control systems.

The 4P approach has several potential applications. Three of them—growth management, toxic chemicals, and global warming—are high-stakes, high-uncertainty problems for which effective management mechanisms do not currently exist.

Traditional approaches to growth management have centered on zoning and other forms of land-use restrictions. Although the results of planning and zoning are better than totally uncontrolled growth, the approach leaves much to be desired, and one can certainly argue that most planning and zoning have not improved environmental conditions. 4P suggests a flexible impact bond system in addition to regional planning. A developer would post an initial impact bond that is large enough to cover the worst-case environmental and economic impacts of the proposed development. The developer would be refunded portions of the bond to the extent that the possible impacts did not occur. Innovative developers who designed projects with lower environmental impacts would be directly rewarded by refunds of their impact bonds. Developers who defaulted on their bonds would do poorly in economic competition with their more innovative competitors, and their bonds would be used to pay for whatever impacts they caused. Impact fees have been tried before, but, in most cases, they have been flat, inflexible, one-time fees that offered no incentive to developers to produce anything but the standard fare. They also generally covered only a small fraction of the real impacts of the development. A flexible impact bonding system would solve these problems and help manage growth in a rational yet flexible way, without taking the right to develop away but merely imposing the true costs of that growth on the parties that stand to gain from it while providing strong economic incentives for them to reduce their impacts to a minimum.

Another particularly difficult environmental management problem is the control of toxic chemicals from both point sources, such as factories, and nonpoint sources, such as agricultural and urban areas. Toxic chemicals can be damaging to ecosystems and human health in extremely low concentrations, and there is enormous uncertainty about their cumulative and individual impacts. The standard management approach is to develop lists of toxic chemicals and standards for their allowable concentrations in the environment. But because the list is so long (there are thousands of such chemicals in common use) and there is so much uncertainty about setting safe standards—as well as about who is producing and releasing what quantities of which chemicals and how the chemicals interact once they come in contact in the environment—this approach has not been very effective.

4P suggests a flexible toxic chemical bonding system. The bond would be sized according to the best current estimates of the worst-case damages from the release of the chemicals. Refunds would be based on the extent to which each potential polluter performed better than the worst case. This system would give polluters strong incentives to reduce their releases through recycling and more efficient use. Farmers could no longer afford to overuse agricultural chemicals just to be sure they were killing all pests. Industries could no longer afford to release new chemicals with poorly known impacts into the environment. Individual home owners would pay a high price for using potentially dangerous chemicals on their lawns and would be forced to find more environmentally benign alternatives, which, under the bonding system, would be relatively cheaper. This system would be designed to complement other regulatory schemes; would be self-policing and self-funding; and would provide strong incentives to correct environmental problems for which there are few good management alternatives.

Finally, the problem of global warming is probably the most severe current example of a high-stakes, high-uncertainty problem. A tax on carbon dioxide emissions has been proposed as an economic incentive to lessen this problem, but current ideas about the tax do not account for uncertainty. The 4P approach suggests that a bond for carbon dioxide emissions, with the size of the bond based on worst-case estimates of the magnitude of future damages, would work

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better than a tax, whose size would be based on much more uncertain estimates of what levels of emissions will not produce long-term problems. In this way, the efficiency advantages of economic incentives can be reaped without unduly penalizing current economic agents for the costs of unknown future damages.

There are several other potential applications of 4P. Any situation with large true uncertainty is a likely candidate, and these situations abound in today's world. To deal with these situations, scientific understanding must grow, and approaches to environmental management must change accordingly. Scientists can only define the envelope of ignorance. Given that envelope, policymakers should plan for the worst while providing incentives for firms to produce the best.

The administrative details of how 4P would function for the various specific applications need to be worked out. These details are critical to the success of the proposal and should be given careful consideration. Several well-intentioned performance bonding systems have failed because of simple oversights in their implementation. For example, mine reclamation bonds have, in some cases, been set so low that it was cheaper for the mining companies to default than to reclaim the site. The bond must be large enough to cover the worst-case damages so that such malfunctions do not occur. Of course, 4P is not a general panacea that can completely replace the existing regulatory system. The bonding system is best thought of as a complement to management schemes of regulations and incentives that is better suited to handle those situations where uncertainty is high.

Which situations are most appropriate for a 4P approach and the administrative details of the particular applications can most effectively be determined through mediated policy dialogues involving all of the stakeholders affected by the system under consideration, including the environmental, business, regulatory, and scientific communities. Mediated policy dialogue techniques involve the use of impartial third parties in structured meetings to bring together people with different views and find areas of consensus.[17] Such dialogues are currently being planned by the Maryland International Institute for Ecological Economics in collaboration with EPA and other agencies to develop detailed protocols and administrative procedures for pilot studies of the 4P approach. Experimental work is also under way to elucidate the underlying incentive structures in 4P and to help in their effective design and use.[18]

Political Feasibility

The individual elements of the 4P approach have broad theoretical support and have been implemented previously in various forms. The precautionary principle is gaining wide acceptance in many areas where true uncertainty is important. Incentive-based environmental regulation schemes are also gaining acceptance as more efficient ways to achieve environmental goals. For example, the 1990 amendments to the U.S. Clean Air Act contain a tradable permit system for controlling air pollution. Both the precautionary and the polluter pays principles are also incorporated in the final resolutions of the 1992 United Nations Conference on Environment and Development.[19] By linking these two important principles, policymakers can begin to deal effectively with uncertainty in an economically efficient and ecologically sustainable way.

In a sense, the 4P approach is already becoming a reality. As strict liability for environmental damages becomes more the norm, far-sighted businesses have already started to protect themselves against possible future lawsuits and damage claims by setting aside funds. The 4P approach is, in effect, a requirement that businesses be far-sighted, and it is an improvement on strict liability because it

- explicitly moves the costs to the present, where they will have the

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The 4P approach is, in effect, a requirement that all businesses be far-sighted, and it is an improvement on strict liabilty.

Dealing with Uncertainty

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maximum impact on decisionmaking;[20]

- provides edge-focused, second-order scientific assessments of the potential impacts from a comprehensive ecological economic perspective to ensure that the size of the bond is large enough to cover the worst-case damages; and
- insures that funds are used appropriately in case of a partial or complete default.

Because of its logic, fairness, and efficiency and its ability to implement the precautionary and polluter pays principles in a practical way and to use legal and financial mechanisms with long and successful precedents, the 4P approach promises to be both practical and politically feasible. It could do much to help head off the current environmental crisis before it is too late.

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