Endogenous Risk and Environmental Policy

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Abstract

The concept of endogenous risk implies that an individual can privately influence many of the hazards he or she confronts. This realization has profound impacts on environmental policy, which in the past has been driven by an assumption of exogenous risk. Three key interdependencies now come to the forefront and must be addressed explicitly by environmental managers. First, accepting the presence of endogenous risk means rejecting the traditional risk assessment-risk management bifurcation currently applied to environmental hazards; instead, it requires a simultaneous physical-economical model approach. Second, endogenous risk requires that both private and collective risk reduction actions be considered in benefit-cost analysis. Otherwise, risk reduction is undervalued. Third, endogenous risk demands recognition of the interdependence among private agents, in that protective measures by one agent can take the form of simply transferring risk across space or time to another agent. Failure to account for these three interdependencies will result in unintended consequences from well-intended policies.

ENDOGENOUS RISK AND ENVIRONMENTAL POLICY

Risk is exogenous, beyond the control of the normal man or woman. This view dominates the risk assessment-risk management studies used to brace environmental policy. The view is inherent in the assessment-management bifurcation sanctified by the National Academy of Sciences (1) and now common in scientific and policy discussions about environmental risk (2). It has had a profound influence on how natural scientists, among others, describe risk, and on how economists formulate prescriptions for environmental policy.

But intuition and everyday evidence assert that people do try to influence the likelihood or the severity of an undesirable event. We invest significant resources in attempts to increase the probability that good things will happen and that bad things will not. If the unfavorable is likely to occur, we try to lessen its impact. Consider your own behavior toward risk. You may invest in a water filter, buy a membership to a health club, jog, eat food low in fat and high in fiber, or apply sunscreen. Each choice alters the risk you face to your health and welfare. How we actively alter our everyday risks and construct our set of opportunities to do so depends on both our attitudes toward risk and our technology to reduce risk. Risk, in fact, is endogenous.

Policies to reduce environmental risk must systematically incorporate the implications of endogenous risk into the decision-making framework. Otherwise, Zeckhauser and Viscusi's (3) plea for more "systematic strategies for assessing and responding to risk" will fall short. Recognition of endogenous risk opens the door to addressing interdependencies in the physical and economic world that have not been treated previously in a consistent, effective manner. This paper explores the key interdependencies that come to light in shaping the theory of endogenous risk. We offer potential avenues to incorporate the interdependencies into risk reduction policy.

There are three critical interdependencies that must be incorporated into future environmental policy. First, endogenous risk implies that the current risk assessment-management bifurcation has promoted misleading research exercises in the natural sciences and the risk management disciplines. Risk assessment exercises often will be misspecified unless they simultaneously include both physical and economic manifestations of environmental change.

Dismissal of the economic decision processes will result in underestimating benefits of risk reduction. Second, endogenous risk brings forth the interdependence between private and collective risk-reduction mechanisms. The current singular focus on collective reduction will result in the undervaluation of societal preference for risk reduction, thereby biasing downward the risk-benefit analyses central to environmental policy. Third, endogenous risk implies an interdependence among private parties or governments who self-protect. Self-protection may not resolve risk; it may simply transfer the risk through space to another locale or through time to another generation. Policymakers who treat risk as exogenous will promote excessive expenditures on self-protection.

Self-Protection and Environmental Risk

Over the past decade an increasing number of scientists have recognized that risk is endogenous. Psychologists concede that individuals perceive substantial control over uncertain events. Stallen and Tomas (4), for example, write that "the individual is not so much concerned with estimating uncertain parameters of a physical or material system as he is with estimating the uncertainty involved in his exposure to the threatening event and in opportunities to *influence* or *control* his exposure" (emphasis added). Starr (5), an engineer, makes much of the difference between voluntary (endogenous) and involuntary (exogenous) exposures to risk. Indeed, outside the field of economics, discussions of risk typically consider "measures that modify events or reduce the vulnerability to loss" (6). Examples of private self-protection abound. People move or reduce physical activities when air pollution becomes intolerable. They buy bottled water if they suspect alternative supplies are polluted. They chelate children who have high blood lead concentrations, and they apply sunscreen to protect their skin from UV radiation. Other organisms also self-protect. Plants employ genetic variations, premature abscissions, resource sinks, inhibitor proteins, and immune bodies such as granules, fibers, membrane fragments, and viruses. Similarly, animals self-protect by withdrawing to cover, using distractions and diversions, feigning death, releasing chemical repellents, and sending warning signals (7).

At the policy level, the success of collective mandates to promote safety often depends upon individual choices. Use of auto seat belts reduces both the probability and the severity of injury, but their mandatory installation cannot guarantee that passengers will choose to wear them. Highway speed limits also are effective at reducing fatalities only when drivers observe them. In the workplace, initiatives involving personal protective gear (e.g., hard hats) have the same problem: they protect only those workers who wear them. In each case, individual decisions influence both the probability and the magnitude of harm.

Individuals often substitute self-protection for the protection of collectively supplied safety programs. Burton et al. (8) enumerate diverse examples, including the use of higher strength building materials in response to prospective tornado, storm surge, and earthquake hazards; more thorough weeding and crop storage in response to the prospect of drought; sand-bagging and evacuation in anticipation of floods; and improved nutrition and exercise regimens to cope with health threats. These and similar private coping strategies reduce both the individual's chance of having a threat realized and its magnitude if realized.

Hirshleifer (9) and other economists have argued it is always possible to redefine a problem such that the state of nature is independent of human action. This position allows one, as Laffont (10) noted, to continue working within the highly tractable framework of exogenous risk. Consider, however, a situation in which bacterial groundwater contamination threatens a household's drinking water. The probability of illness among household members can be altered if they boil the water. An analyst might define the situation as independent of the household's actions by focusing solely on groundwater contamination, over which the household likely has no control. But this definition is economically irrelevant if the question is the household's response to and damages from groundwater contamination. The household is concerned about the probability of being made ill and the severity of any realized illness, and it is able to exercise some control over those events. The household's risk is endogenous because by expending its valuable resources it can influence probability and severity.

Ehrlich and Becker (11) define ex ante efforts to reduce probability as self-protection, s, and ex ante efforts to reduce prospective severity as self-insurance, x. The individual selects s and x to maximize his von Neumann-Morgenstern (12) expected utility index, EU; that is,

$$\max_{s,x} EU = [p(s)U(M - s - x) + (1 - p(s))U(M - L(x) - s - x)], \tag{1}$$

where p is probability, M is wealth, L is the money equivalent of realized severity, and s and x are expenditures on self-protection and self-insurance against the realization of an undesirable state. Assume $p' > 0$, $p'' < 0$, $L' < 0$, $L'' > 0$. Primes denote the relevant derivatives. The necessary conditions for the individual's optimal levels of self-protection and self-insurance are then

$$s:\ p'V - pU'(M - s - x) - (1 - p)U'(M - L(x) - s - x) = 0, \tag{2}$$

$$x:\ pU'(M - s - x) - (1 - p)U'(M - L(x) - x - s)(1 + L') = 0, \tag{3}$$

where $V = U(M - s - x) - U(M - L(x) - s - x) > 0$, $U' > 0$, and $|L'| > 1$.

Equations 2 and 3 state the standard result that an individual maximizes expected utility by equating the marginal cost of influencing probability or severity to the marginal wealth acquired. Within this framework, a few researchers have explored the theoretical underpinnings and the behavioral implications of endogenous risk (13). We now discuss the key interdependencies resulting from endogenous risk.

Risk Assessment and Risk Management

In studies of risk, it has come to be understood that risk assessment quantifies environmental risk; risk management regulates environmental risk. This is explicitly stated in National Academy of Sciences (1) and by the USEPA in the U.S. Federal Register (14). First, the level of any given risk is quantified by the natural and biomedical sciences. The findings are then made available to the fields of law, politics, philosophy, economics, and the sciences in order to be applied to the risk management process. Assessment occurs on one side, management on the other. But when endogenous risk is at issue, this strict bifurcation warrants considerable skepticism.

The term *endogenous risk* implies that observed risks are functions of natural science parameters and an individual's self-protection decisions. The basis by which people make decisions about risk will differ across individuals and across situations with the relative marginal productivities of their self-protection efforts, even though the properties of the natural phenomena that trigger these efforts may apply equally to everyone. It follows that attempts to assess risk levels solely in terms of natural science may be highly misleading—costly self-protection is endogenous and may, therefore, vary systematically in the observed risk data. The sources of the systematic variation are relative prices, incomes, and other economic (and social) parameters that influence individuals' self-protection decisions.

Risk management is usually interpreted to mean the *collective* provision of a more desirable state (15). But when individuals privately self-protect, risk assessment and risk management become inseparable. From the individual's perspective, private and collective provision are substitutes. Individual willingness to substitute one for the other will be influenced by relative productivities and relative prices. For example, a low or zero price for collective provision will lessen the proclivity to self-protect, thus increasing the level of observed risk. Similarly, if the individual cost of access to collective provision is high, the demand for self-protection will increase, thus reducing the observed risk levels that are the stuff of risk assessment. Setting the price and productivity of collective provision is the stuff of risk management.

In general, accurate risk assessment and effective risk management in the presence of endogenous risk require a full accounting of the input and output substitutions of producers and consumers when responding to environmental changes. The biological and physical phenomena that the risk assessor chooses to investigate define the set of opportunities of the individual's economic decision problem. An unrealistically restricted opportunity set limits the description of the producer's and consumer's alternatives for maximizing gains or minimizing losses from an environmental change. Such a restricted set causes economic estimates of the gains from reducing environmental risks to be understated. It also implies that the biological and physical manifestations of environmental change depend as much upon producer and consumer decision processes as upon the biological and physical phenomena that trigger the economic reactions (16). Endogenous risk implies that we must explicitly address the simultaneous nature of how economic decisions affect observed risk and how the natural science features affect economic decisions. Otherwise, environmental risk policy will be misdirected.

Incorporating the simultaneous system implied by endogenous risk into environmental policy decisions is achievable today. Recent advances in computer technology now allow use of computers as a creative research tool to integrate physical and economic processes into a unified system. An environmental economic modeling system that integrates the physical and economic interactions can be used to simulate the impacts of alternative policy scenarios and patterns of activity. An example of such a system currently is being developed for the U.S. Environmental Protection Agency (EPA) to evaluate the risk-benefit trade-offs of alternative pesticide policies. This integrated system, known as CEEPES, incorporates reciprocities between economic and environmental indicators of social welfare (17). Although there are several steps remaining before the system is completely specified, preliminary results suggest that the approach is feasible. It has already influenced pesticide policy in the EPA by redirecting attention away from restrictions on single chemicals to policies that consider a systems approach to weed control. But to effectively construct such a system in a time of declining research budgets, incentives must be provided to reward those who work within the multidisciplinary environment. More effective risk policy requires more interaction among disciplines whose members often regard each other with considerable skepticism.

Valuation of Environmental Risk

Restructuring the valuation exercises central to the benefit-cost analysis of environmental hazards is critical to a better accounting of endogenous risk in environmental policy. Restructuring cuts deeper than problems of measurement. It involves acknowledging fundamental deficiencies in perspective that inhibit development of the measures needed for reliable policy guidance. Assumptions of exogenous risk displace the search for the most pertinent data, bias interpretations of available data, and create uncertainty about the effectiveness of policy initiatives.

Specifically, the assumption of exogenous risk in benefit-cost analysis can lead to the undervaluation of reduced risk and the misidentification of those who value risk reductions most highly. There are several reasons for undervaluation, all involving the inability of an exogenous risk perspective to disentangle the relative values of private and collective contributions to risk reductions. When risk is considered exogenous to the individual, protection must be supplied collectively. Nonetheless, self-protection is often a viable substitute for collectively supplied protection; it can also expand an individual's opportunities to exploit personal gains from collective provision.

The valuation literature for exogenous risk characteristically assumes that the value of risk reductions declines as risk decreases (18). Empirical evidence that this marginal value actually increases is held to be a lapse from rational economic behavior. Shogren and Crocker (19) show, however, that endogenous risk within the traditional expected utility framework can generate behavior consistent with increasing marginal valuations of risk reductions. In particular, if the marginal productivity effects of self-protection on probability differ from the effects on severity, increasing marginal valuations can occur. This result challenges the standard view that those who are at greater risk and who have greater wealth must value a given risk reduction more highly. It also implies that the undervaluations caused by a singular focus on collective risk reductions could increase with the degree of success gained by these collective efforts.

When self-protection and collective protection are perfect substitutes—equally effective in reducing risk—the value of collective protection may be less than half the total value of protection. Shogren (20) observed in a series of controlled experiments possessing a perfect substitute that the upper bounds on the values participants attached to risk reductions were consistently associated with self-protection; collective protection always represented the lower bounds. In these experiments, participants could substitute between a single mechanism for self-protection and a single collective protection mechanism. Shogren and Crocker (21) show that these single-mechanism results are robust with respect to experiments involving multiple private and collective protection mechanisms.

By considering multiple risk reduction mechanisms, it is acknowledged that individuals have numerous ways in which they can alter risk privately. In contrast, when researchers employ the concept of the value of a statistical life or limb, benefit-cost analyses of reduced environmental risks do not acknowledge the existence of multiple or even single private risk reduction mechanisms. The value of a statistical life is defined as the cost of an unidentified single death weighted by a probability of death that is uniform across individuals. But even if individuals have identical preferences, substantial differences exist in their opportunities for or costs of altering risk. The statistical life or limb approach fails to address the differences in individual risks induced by self-protection. An individual who has ready access to private risk reduction mechanisms will value collective mechanisms less than otherwise. A complete assessment of this individual's value for a given risk reduction thus requires considering willingness to pay for self-provision as well as for collective provision. In essence, by virtue of its exclusive focus on collective provision, the statistical life or limb approach undervalues environmental threats to human health and endorses economically excessive levels of environmental degradation.

The undervaluation problem can be resolved by assessing the individual's preference for alternative risk reduction strategies. By allowing the individual to reveal whether he or she would prefer to reduce risk privately or collectively or both, or by reducing the probability or severity or both, we will have better measures of the value of risk reduction. Nonmarket valuation techniques such as the contingent valuation method (22) or laboratory experiments can be used further to elicit preferences for alterative risk reduction strategies. But without first understanding how people prefer to reduce risk, policy recommendations will be based on potentially precise but inaccurate, incomplete information. This produces an unnecessarily restrictive policy environment where a decision maker's prediction of the consequences of his policies may well differ from actual consequences.

Risk Abatement and Transferable Risks

Risks that are endogenous may also be transferable. The concept of transferable risk implies that the individual protects himself by simply transferring the risk through space to another location or through time to another generation. The physical or the utilitarian consequences of self-protection from environmental hazards are not limited to the self-protected. If self-protection enables risk to be transferred, policymakers who treat risk as exogenous will cause self-protection expenditures to be excessive.

For example, the midwestern industrial states have reduced regional air pollution problems by building tall stacks at emitter sites. Prevailing weather patterns then transport increased proportions of regional emissions to the northeastern states and to eastern Canada. Clearly, the midwestern states have reduced their damages by adopting abatement technologies that increase air pollution damages elsewhere. Other examples are plentiful. In agriculture, pollution from other sources encourages land, fertilizer, and pesticide substitutions, which produce pollution that affects others. Large present-day use of pesticides accelerates the development of immune insect strains with which future human generations must contend. Some governments forbid the storage of toxins within their jurisdictions, thereby causing the toxins to be stored (or dumped) elsewhere.

Indeed, from the materials balance perspective of Kneese et al. (23), most environmental policy does not reduce environmental problems. It does not reduce the mass of materials used or cause them to accumulate in the economy. While continuing to allow waste masses to flow into the environment, policy simply transfers these masses through time and across space. Future generations and other jurisdictions then suffer the damages.

Within the simple framework of this paper, transferable risks imply that the individual's expected utility problem in Equation 1 must be modified to include the self-protection actions, S, of another individual. The first individual's maximization problem then becomes

$$\max_{s,x} EU = [p(s, S)U(M - s - x) + (1 - p(s, S))U(M - L(x) - s - x)], \tag{4}$$

while the other individual's problem is

$$\max_{S,X} EU = [p(S, s)U(M - S - X) + (1 - p(S, s))U(M - L(X) - S - X)], \tag{5}$$

where X is the other individual's self-insurance expenditures.

Shogren and Crocker (24) use the system in Equations 4 and 5 to show that environmental policies that allow unilateral transfers of risk rather than encouraging cooperative resolutions will result in excessive expenditures on self-protection. In the absence of public limits to individuals' noncooperative self-protection activities, environmental risk reductions can be made prohibitively expensive. Collective strategies that encourage self-protection through risk transfers need to be reconsidered. When transfers are technically feasible, such strategies only intensify the inefficiencies inherent in the noncooperative behavior that caused the transfers in the first place.

Some environmental policies thought to be desirable within the framework of exogenous risk can be shown to accentuate the inefficiencies inherent in circumstances where transferable risks and noncooperation prevail. For example, Viscusi and Magat (25) and Smith et al. (26) suggest that publicly sponsored hazard information programs often will be efficient alternatives to direct regulation of environmental hazards. Although these authors readily grant that public information may cause individuals to self-protect, they do not address the possibility that this information may induce them to self-protect in inefficient ways. Shogren and Crocker (24) argue that this information policy can increase already excessive levels of self-protection. The sufficient condition for this result, given unilateral self-protection, is an inelastic damage function, a function in which damages are highly unresponsive to changes in self-protection effort.

Alternatively, policies that shift the time and space foci of environmental hazards will prompt strenuous protection efforts on the part of recipients who have an elastic damage function. Limited empirical evidence supports the existence of an elastic damage function for environmental aesthetics when pollution levels are low and an inelastic damage function when pollution levels are high (27). Therefore, in terms of the aesthetic and health impacts of pollution, noncooperative environmental improvements could be self-defeating when pollution levels and risks are already low. Aggregate expenditures on protection, then, may outweigh the environmental benefits. In contrast, some pollutants, such as ambient carbon monoxide, exhibit inelastic damages at low levels and elastic damages at high levels. It follows that accurate assessments of the benefits of policies to reduce environmental hazards require precise and accurate knowledge of the responsiveness of damages to noncooperative forms of self-protection. Damage function elasticities are likely to be hazard-specific and activity-specific, as well as concentration- or level-specific.

There are two broad ways to overcome the difficulties associated with transferable risk: legally imposed separability or institutionally sanctioned risk sharing. First, society can amend or reform the legal system to artificially impose separability. The structure of liability and negligence rules could be developed further to address transferable risk explicitly. New monitoring and enforcement schemes could be devised to detect and punish the guilty. This approach will require careful consideration of the new incentives that will be set in place and the new trade-offs that will develop. Second, if we acknowledge that critical interdependencies exist and that artificial separability may be costly to enforce, the alternative is to cooperate. While no panacea, societies could save considerable resources by developing risk sharing institutions, perhaps with side payments, that foster cooperation in their environmental protection efforts. Failure to do so results in the expenditure of valuable protection resources at no gain in environmental quality.

Conclusion

Acknowledging the endogeneity of some environmental risks holds important ramifications for environmental policy. Policies founded on an exogenous risk perspective are likely to be in error whenever endogenous risk prevails. The mistaken perspective induces errors in risk assessments, causes the benefits of risk reduction to be underestimated, and persuades those exposed to risk to spend excessively on self-protection. Society will expend scarce resources at no gain in environmental quality. Although endogenous risk has been implicitly discussed in terms of materials balance and energetic approaches to environmental policy, the behavioral implications have been ignored too long. This paper offers a systematic framework to reconsider how we view risk reduction and the consequent implications for environmental policy reform. The key to policy reform is to create new incentives that reward those who attempt to unify risk assessment and management into an integrated system, estimate individual preferences for alternative risk reduction strategies, and foster risk sharing institutions that explicitly address the nature of endogenous risk.

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