Risk and Its Consequences*

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I. JOINTLY DETERMINED SYSTEMS

Economic systems and environmental systems are jointly determined—our choices affect the productivity of nature, just as nature affects the productivity of our choices. If one views this as stating the obvious, recall that the person in the street and the natural scientist in the laboratory presume that the insertion of economics into natural science, or vice versa, will not change the core elements of either discipline. Recognize also the view that environmental risk is exogenous, beyond the control of everyday people, dominates the risk assessment/risk management studies that have received environmental policy. It is inherent in the risk assessment-management bifurcation sanctified by the National Research Council [22] and has had a profound influence on how natural scientists describe environmental risk, and on how economists, among others, evaluate environmental policy.

But intuition and everyday evidence undeniably show that human actions and reactions help determine the likelihood and the severity of events [8, 15]. Consider the risk to endangered species. Conservation biologists usually maintain that establishing the threshold of species endangerment is strictly a biological question as determined by the present sizes, trends, and distributions of populations and their likely interactions with the stochastic forces of nature. These stochastic events are said not to affect the productivity of human reactions to these risks. But this perspective is too narrow. Species survival depends on key economic parameters such as relative prices of sites and site users and community wealth; e.g., the rich have more resources to set aside quality critical habitat. Assessing the risk to species and setting a minimum acceptable probability of survival are economic as well as biological problems. Risk is endogenous.

This paper revisits the question of risk and its consequences. We argue that the presumed separability of random events and self-protection in the consequence function as used in [25] to derive sharp predictions is problematic for examining issues of endogenous environmental risk. Moreover, by adopting the separability restriction, economists may voluntarily relegate their expertise to a role that is decidedly passive and subordinate to that of natural scientists in environmental research and policy deliberations.

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II. MORE RISK, MORE SELF-PROTECTION?

We focus our discussion on the proposition that self-protection need not be a lower bound on the value of risk reductions. Suppose a person faces an uncertain monetary damage from a bad event, say a loss of species or a health hazard from exposure to toxic waste. Let $z \in Z$ represent the uncertain severity of the hazard, in which a cumulative distribution function, $F(z; x, r)$, bounded over the support $[a,b]$ registers this uncertainty [20]. The person can invest resources, $x \in X$, in self-protection such that he reduces his risk, $F_z > 0$, in the sense of first-order stochastic dominance, where a subscript represents the relevant derivative.\(^1\) Let $r$ represent an index of ambient riskiness such that an increase in $r \in R$ increases his risk, $F_r < 0$. A person obtains utility $u(w)$, from net wealth, $w = w_0 - z - x$, where $w_0$ is initial wealth, $u_w > 0$, and $u_{ww} < 0$.

By adopting a transformation originally proposed by Hirschleifer [12], one can map the cumulative distribution $F(z; x, r)$ into some recognized stochastic variable, $\theta \in [0,1]$, independent of the person’s actions [27], where $\theta$ is always uniform over [0,1] and has no point mass:

$$\theta = F(z; x, r).$$

(1)

Inverting (1) yields the consequence function, $c(\theta, x, r)$:

$$z = F^{-1}(\theta; x, r) = c(\theta, x, r).$$

(2)

Substitute the consequence function (2) into the person’s expected utility function such that his problem becomes

$$\max_{x \in X} \left\{ \int_0^1 u(w_0 - c(\theta, x, r) - x) d\theta \right\},$$

(3)

which yields the first-order condition

$$-E[u_x c_x] - Eu_w = 0,$$

(4)

where $E$ is the expectations operator. The first term in (4) is the expected marginal utility of self-protection given $c_x < 0$, and the second term is the expected marginal disutility.

Comparative static results of a change in ambient risk yield an ambiguous result when we proceed as if the random variable, $\theta$, and self-protection and ambient risk

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\(^1\)Examples abound. People move or reduce physical activities when air pollution becomes intolerable. They buy bottled water if they suspect that alternative supplies are polluted. They chafe children who have high blood lead concentrations, and they apply sunscreen to protect their skin from UV radiation. A person invests in a water filter, moves, buys a membership to a health club, jogs, eats food low in fat and high in fiber, or applies sunscreen—each choice alters the risk environmental hazards pose to his health and welfare.

\(^2\)This first-order change is a common definition of an increase in risk. The model can easily accommodate second-order stochastic dominance or mean-preserving spreads by integrating twice by parts.
are not additively separable in the consequence function
\[
\frac{\partial \pi}{\partial r} = -\frac{1}{D} \left[ E \left[ u_{ux} c_x c_r - u_{xr} c_x \right] + E \left[ u_{ux} c_r \right] \right],
\]
where \( D < 0 \) by the second-order condition is assumed to hold whenever (5) holds. How a person invests resources to increase the odds that good things happen depends on both his attitudes toward risk and his technology to reduce risk [2, 6, 14]. For self-protection to be an unambiguous lower bound, the sign of (5) must be positive. But this need not be the case. Although expected marginal disutility of self-protection, the second term in (5), is negative by assumption, the sign of expected marginal benefits, the first term, depends on how changes in the index of ambient riskiness affect marginal productivity, \( c_{cr} \).

Marginal productivity increases if self-protection increases with increased riskiness, i.e., self-protection and the index of ambient risk are technological complements, \( c_{cr} < 0 \), [see 3, 25]. But it is not obvious why self-protection must become more effective as ambient risk increases. The effectiveness of a life jacket does not increase in storm-tossed waters, nor does the effectiveness of a garden hose in putting out fires become greater as the risk of serious wildfires increases. If self-protection and the index of ambient risk are substitutes (\( c_{cr} > 0 \)), an increase in ambient risk raises both the marginal utility and the marginal disutility of self-protection. When disutility dominates, self-protection decreases as risk increases. When utility dominates, self-protection increases. \( A \ priori \), which term rules is unknown—the classic lulling effect. It is an empirical question influenced by properties of the risk reduction technology.³

III. ON THE ROLE OF AUXILIARY RESTRICTIONS

Perhaps because of the discipline’s near-universal use of the utility maximization paradigm, theoretical constructs in economics usually have a general character relative to any particular empirical observations we are asked to explain. A precise and robust explanation of empirical particulars thus requires that we impose more specific restrictions. These restrictions shape the theory to the particulars. Quiggin [25] obtains sharp predictions about risk by treating the relations between the random variable and self-protection in the consequence function as additively separable.⁴

To see this, rewrite (4) as
\[
-E u_u Ec_x - \text{cov}(u_u, c_x) - Eu_u = 0.
\]

³As a nonenvironmental but vivid example, consider the assistant professor in a shrinking academic job market. The shrinking market decreases the odds of getting promotion and tenure. In response the professor can put all energies into producing path-breaking research. Family, home, and refereed article count may suffer greatly. Yet success in the research endeavor practically guarantees entry into what the shrinking market makes an even more select and privileged lifetime career guarantee in a research-oriented university. If the opportunity losses of family and home dominate, research effort will decline; if access to lonely privilege rules, research effort will increase.

⁴A referee points out that this formulation also involves a separability restriction between sure health and sure wealth, implying that the marginal rate of substitution between the two is independent of wealth and thus that under certainty the income elasticity of demand for health is zero.
Now assume that the consequence function is additively separable in the recognized random variable, \( \theta \), and self-protection, \( x \), and the index of ambient riskiness, \( r \), such that \( c(\theta; x, r) = a(\theta) + \beta(x, r) \), which implies \( Ec_x = \beta_x \), and thus \( \text{cov}(u_x, c_x) = 0 \). Expression (6) collapses to
\[
-Ec_x - 1 = 0. \tag{7}
\]

Marginal benefit is represented entirely by the expected marginal productivity of self-protection, and expected marginal disutility erodes to a constant. The fetters that the separability condition puts on the robustness of expected utility theory so as to obtain sharp results is easily seen by revisiting the comparative static (5) given the stripped down first-order condition (7):
\[
\frac{\partial x}{\partial r} = -\frac{I}{D} \{ Ec_{x,r} \}. \tag{8}
\]

Signing (8) now strictly depends on the technical relationship between marginal productivity of self-protection and the index of ambient riskiness [also see 10, p. 249]. Forcing the realized state of nature not to affect the marginal productivity of self-protection causes marginal disutility and preferences to vanish.

A plausible circumstance in which separability of consequences might be a constant occurs when public protection is a perfect substitute.\(^5\) But this case has to be the exception, not the rule. Suppose two states of nature exist—calm or an earthquake. It is hard to imagine a case in which the realized state will not affect the marginal productivity of self-protection. Marginal productivity would be positively affected by an earthquake, negatively affected by calm.

This point can be generalized to nonnumerical examples as well, e.g., endangered or not. In ordinal notation, if the sign of the effect on marginal productivity is the same such that \( u(c(\theta; x_1, r)) \geq u(c(\theta; x_2, r)) \) for all \( \theta \), the person is wasting his time doing anything other than the dominant prospect, since he is not at the frontier. Separability essentially removes the risk from the risk-return trade-off. The critical question is what economists surrender by imposing this condition of a separable consequence function in environmental research and policy contexts. We turn to this next.

IV. ON ADDITIVELY SEPARABLE CONSEQUENCES

Consider now the practical usefulness of the separability assumption in assessing environmental problems.\(^6\) We adopt three heuristic evaluation criteria—tractability, specificity, and relevancy. Relevancy refers to the scope of opportunities for

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\(^5\)John Oiggin reminded us of this. Empirical evidence exists that suggests that people do not regard the two forms of protection as perfect substitutes [see 5, 15, 28, 31].

\(^6\)Note that multiple causes and their interactions, which are frequent in their environmental problems, could have a high dimensional state space. One might set a finite limit to potential expansion of this space, but doing so would set an upper bound on the odds of any given state. This would be an unacceptable restriction, since the concept of a state becomes difficult to grasp if its definition can be multiplied or reduced with its probability.
economists to participate as integral partners (rather than as an afterthought) in environmental science and policy deliberations.\(^7\)

*Tractability* with separability resides in a believable representation of cause and effect that excludes alternatives, e.g., exposure to a toxin is directly mapped into cancer damages.\(^8\) Given that cause and effect are uniquely identified, risk valuation is analytically more tractable if analytical tractability is interpreted to mean the derivation of mathematically sharp results—e.g., more ambient risk invariably leads to more self-protection. In most environmental settings, however, empirical tractability may be another matter. It is an open question whether a rigorous accounting of a complex constellation of multiple causes acting in concert is more readily grasped and communicated than the relatively simple expedient of constructing, using, and conveying a cumulative distribution based on directly observed events. Separability presumes that the researcher knows what evidence the decision agent used—gaps in scientific literacy cannot exist between the researcher and the agent.

If the goal is more tractability by eliminating unobservable utility from the model for empirical estimation purposes, the restriction is successful. The cost, however, is that with technology as the only driving force, the model may be too thin to organize the wide range of purportedly irrational behavior under uncertainty witnessed over the years [e.g., 33]. For instance, while implicitly invoking the separability restriction, Smith and Desvogues [32] regard the increasing marginal benefits of risk reduction that they observe as being a lapse from rational behavior. But without the separability restriction, it is possible to show that endogenous risk is fully consistent with increasing as well as decreasing marginal benefits to environmental risk reduction [30]. If a general theory explains purported anomalies and if the anomalies appear only when the general theory is burdened with particular auxiliary restrictions, the seeming anomalies must be due to the restrictions rather than the general theory—a classic case of the tail wagging the dog.

Of course, grasping the structure of cause and effect, including the relative primacy of multiple causes, as opposed to coping through a reduced form or a summary statistic, is the goal of all scientific inquiry. *Specificity* is sought. Specificity can be attained by repeated empirical observations under controlled conditions or by axiomatic methods. As for axiomatic methods, economists use the axioms of reflexivity, completeness, continuity, and transitivity to move from the soft idea of preferences to the precise notion of a utility function. The utility maximization paradigm singularly dominates economic analysis. In the application of the biological sciences to environmental phenomena, however, no single paradigm exists. For example, the presumed objective selected for the same biological system will differ for the same problem from one biological expert to another, e.g., from the passive genetic sorting device known as reproductive success [34], to the struggle for survival under scarcity [7, pp. 441–458], to net energy storage [16]. Economists who wish to impose separability to model the cause–effect structure of endogenous risk in environmental problems must choose among biological paradigms, given that their choice can influence that structure and even the assignment of cause and effect (i.e., states are paradigm-specific). Even within

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\(^7\)Note these criteria are not necessarily exhaustive or mutually exclusive.

\(^8\)When \(c_{ae} > 0\), unanticipated side effects of self-protection may make the cure worse than the disease.
their discipline, reputable ecologists [e.g., 17] explicitly state that ecology lacks broad generalizations useful for making environmental management decisions at the site-specific or field level.

The separability assumption has another problematic consequence in environmental research when the connections between cause and effect are complex and not easily pinpointed. If the connections are simple or if the transaction costs of science are trivial, the separability assumption is probably moot, since the states can then be contractually defined. As Marshall [19] and others have shown, risk is then exogenous. In the current discussion, if the economist readily identifies the "true" cause, it is certainly reasonable to presume that the market could do so as well. Essentially, another Coasean corollary exists—if the transaction costs of scientific inquiry are zero, one can always define the states of nature completely and accurately. Economists would then have no reason other than idle curiosity to study environmental problems.

Complexity causes errors in environmental assessment [4, 24, 35], and there are conflicts over proper scientific tests and protocols [9, 18, 23, 26]. Because the separability restriction requires that the true cause and thus the correct test be identified, assuming separability can immerse the economist in these conflicts. In contrast, confronting the complexity of the consequence function by mixing the probability distributions associated with each test or protocol has the potential to remove the economist at least one step from the conflicts [1, 29]. He does not have to settle on a particular scientific parable, but he still will be able to get around in the world.

Finally, whatever benefits the separability restriction provides in tractability and specificity may be at the cost of a serious disservice to relevant applications of the economics discipline to environmental problems. Natural scientists have no incentive to account for the impact of human behavioral responses to risk on natural phenomena if economists, by opting only for tractability through separability, allow the natural scientist to infer that the abstract artifact translates easily into a concrete practical conclusion that risk must be exogenous. Because of the limited applicability of the separability restriction, the endogenous risk perspective is properly skeptical about the popular risk assessment–management bifurcation. It insists that the separability that the bifurcation implies be systematically demonstrated rather than routinely invoked. In the absence of unequivocal evidence that separability applies, proper risk assessment incorporates parameters from both the biological and economic systems—we affect nature, nature affects us.

We disagree with an artifact like separability that noneconomists can interpret as saying that nature sets the pace and that people react and respond but do not alert its everyday workings or its genetic programming [21]. The perspective logically places economics in a passive and subordinate role in the totem of environmental policy. Rather than opting for abstract mathematical artifacts that produce great tractability and the appearance if not the reality of specificity, economists will have more opportunities to participate in environmental research and policy if, as Harsanyi [11] urges, they make the least arbitrary, most coherent set of modeling choices. With but few rather exceptional cases, we believe that assuming a noneparable consequence function represents this set for endogenous risk and the natural environment. The approach may make us more like the aforementioned ecologists [17] who lack broad generalizations, but we will be less arbitrary and will remain coherent.
V. RELEVANCE

E. O. Wilson [36, p. 202] says that "economics...is still largely irrelevant" to environmental knowledge because we have hobbed ourselves by avoiding the complexities of the "foundation sciences" such as psychology and biology. This is inaccurate—we hobble ourselves by not convincing these so-called foundation sciences to connect mind to matter by including economic parameters in their core frameworks. Economists have a responsibility to correct this omission from environmental policy debates. Otherwise we make our job harder by appearing to confirm the predisposition of noneconomists to treat natural systems and economic systems as recursive.

This is why we do not view the separability of events and self-protection as just one more inevitable restriction in a long line of judicious trade-offs between tractability and completeness. The separability question runs deeper—its invocation removes our obligation to help define the environmental thresholds of human and ecosystem health that underpin policy, and we shilly settle for a secondary role. If we do not challenge the position that biology is destiny in risk assessment, we abdicate too much authority to the natural scientists to preempt a nation's environmental agenda. Actions and reactions of humans and nature to each other have a role in determining the form of the events that shape our lives—a subtle but meaningful difference in the stance from the economist's current role in environmental research agendas and policy debates. By asking that separability be justified whenever invoked, we increase our odds of moving from the foyer to the table where most environmental research is designed.

REFERENCES
