ENVIRONMENTAL HAZARDS OF FARMING: THINKING ABOUT THE MANAGEMENT CHALLENGE

Leonard A. Shabman

Abstract

What an economist argues about managing the hazards of new production technologies depends on that individual's beliefs about the scientific credibility of assessed risk of new technologies, about the meaning of voluntary risk and compensations, and about the meaning of "progress" and "nature." None of these beliefs is derived from the core of the economics discipline. Indeed, the economist's arguments often rest not on economic considerations, but on these matters of belief that are established outside the discipline.

Key words: agricultural production, environment, risk, technological change

From the use of antibiotics to animal feed to the recent debate over Alar, the perceived or potential health damages of farm chemicals have become the concern of consumers, farmers, and elected officials alike. At the same time the possible negative effects of farm chemicals on aquatic and terrestrial ecosystems have been noted. Drainage of wetlands and clearing of forests, which used to be seen as landscape modifications, now are called threats to regional, national, and even global ecosystems. Emerging recombinant DNA technology—release of "ice minus" bacteria and introduction of the bovine growth hormone "BST," for examples,—have been caught up in this critical scrutiny.

A social consensus on the merits of these concerns has not been achieved, and the public debate has no near-term prospect of resolution. Public officials, agricultural interest groups, environmental groups, and consumer groups accuse each other of "environmental terrorism" or "short sightedness" as the public debate is engaged. Meanwhile, differences of opinion are found within government. For example, the Food and Drug Administration consistently reports that, based on residues in tested food products, pesticides pose no significant risk to health. At the same time the Environmental Protection Agency (EPA), without considering the residues on food, reports that many pesticides used in farming are probable causes of cancer in humans (Committee on Scientific and Regulatory Issues; Gladwell).

Differences of view are not confined to government regulators and the constellation of interest groups they attract. The scientists—chemical, biological, and policy—are also unsettled. The literature is rich with reports seeking to establish a conceptual and experimental basis for defining the hazards, even in the face of the scientific uncertainties. Not to be left out, the social sciences have become intrigued with the question, "What is an acceptable risk?", but no consensus has emerged, either among scientists or policymakers.

The common theme in all these examples of agricultural hazards is the general concern about the effects on the "natural world" of current and future technology employed in production agriculture. In turn I suspect that the concerns about agricultural technologies are simply a subset of the concerns expressed about all technology and its perceived hazards—from nuclear power to global warming. In this paper agricultural illustrations of this general concern are employed. This essay's limited purpose is to review the varied strands of economic argument about technological hazard and relate these arguments to current regulation of technological hazard—a philosophy of regulation based upon what I will term "strong risk aversion." Because the treatment of the topic is at the broadest level, I recognize at the outset that I may oversimplify a complex problem.

ANTICIPATING HARM: THE REGULATORS' WORLD

Consider a proposal to allow field use of a newly developed pest control chemical on fruit crops. Advocates for the chemical say it will benefit fruit growers and their customers by increasing yields and lowering prices, and there is no evidence to establish whether the pesticide is harmful to humans

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or the ecosystem. Arguments against using the chemical are that the benefits are modest, but use of the pesticide may have devastating effects on aquatic plant life, and any residues that remain with the harvested crop after processing may be carcinogenic. However, these adverse effects are admittedly speculative. The advocates for allowing use argue that the remote and unproven probability of harm make the risk worth the promise of benefits received now and in the future.

Confronted with the arguments, a regulatory body is expected to *anticipate* the desirable and undesirable effects of pesticide use and determine whether that use should be allowed. Data are collected, interpreted with the best technical theories and models available, and a decision is made—yes or no—to allow the pesticide's use. A former EPA administrator describes an ideal two-part decision process on chemicals this way (Ruckelshaus, p. 1027).

> Scientists assess a risk to find out what the problems are. The process of deciding what to do about the problems is risk management. ...In risk management it is assumed that we have assessed the health risks of a suspect chemical. We must then factor in benefits, the costs of various methods for its control, and the statutory framework for a decision.

The task of scientific risk assessment is to identify potential harms. Armed with this knowledge, risk managers can determine whether the benefits override potential harms.

THE EXPECTED NET BENEFITS RULE: AN ECONOMIC TOUCHSTONE?

The economist can then use the probability estimates from the risk assessment to make an expected net benefit calculation (ENB) to answer the risk management question, "Is the risk socially acceptable?" The ENB decision rule is the analog of the "perfect" risk market, in which individuals informed about risks bargain until a pareto efficient level of risk bearing is achieved. Given unchanging resources, technology, preferences, and distributions of rights and low costs of transaction among all affected parties, compensation to risk bearers is made through wage differentials in hazardous occupations, through discounts in asset and product prices, or through contingent claims markets (insurance). A strong conclusion about socially acceptable risk is drawn from this simplified model. Page notes that "... for risk markets, whether implicit or explicit, to work well enough to define acceptable risk, the nature of the risks must be understood and the acceptance must be voluntary" (Page, p. 230).

Page's statement establishes the conditions for identifying "market failure" in defining acceptable risk. First, inadequate hazard information or inability to interpret hazard information rationalizes government responsibility for anticipating harms through risk assessment. High cost of transaction rationalizes government action, rather than market exchange, defining acceptable risk (risk management) through an ENB analysis. After an optimal level of risk is established, price signals are appropriately manipulated (taxes, tradable rights, etc.), or direct resource allocation decisions made, to achieve the efficient outcomes.

Perfecting the ENB analysis offers a series of interesting intellectual puzzles and is the subject of an extensive research program in the economics of risk management, including the measurement of benefits and the measurement of risk preferences (Smith). Much of this work has included applications of contingent valuation methods and market wage and asset value data to estimate damage to flora and fauna and to value human health and morbidity.

A positive estimate of ENB means that risk generators and risk bearers could employ compensation payments to reach agreement on acceptable risk. However, as Page reminds us, efficient risk markets require the voluntary assumption of risk bearing. If compensation were not actually made, would risk bearing be efficient? This question is simply a version of the Kalder-Hicks potential compensation conundrum. However, because uncompensated costs include the possibility of personal injury or widespread ecosystem degradation, there has been a renewed interest in the investigation of alternatives to the potential compensation test (Kneese, Ben-David, and Shultze; Shultze and Kneese). A strict compensation rule requires actual compensation either in advance for risk taking or after-the-fact for injuries incurred through liability rules. For example, Viscusi in a recent paper reviews the efficiency of different risk management institutions (markets for advanced compensation and tort law and social insurance for *ex post* compensation) where efficiency is defined in terms of compensation for risk bearing.

ALTERNATIVE DECISION RULES BLEND RISK ASSESSMENT AND RISK MANAGEMENT

Application of the ENB rule requires confidence in a separate risk assessment, which quantifies the extent and likelihood of harm if the pesticide is used. However, this scientific assessment often is "soft." Consider the pesticide example. There is a limited basis for understanding the way the pesticide will interact with the environmental and economic systems. From the actual carcinogenic effects to the possible misuse of the pesticide by the farm operator to the inability of the food processing and distribution system to remove residues from the crop, there are many opportunities for the pesticide to cause harm, but as the system gets more complex it becomes less predictable.

Thus, in making the risk-based decision, two mutually exclusive outcomes must be considered. One is that the environmental effect of the pesticide will prove benign and that there will be only benefits realized. The alternative outcome is that environmental and human health costs will far exceed benefits. This fundamental uncertainty about the potential for harm is the defining characteristic of "environmental hazard" and distinguishes it from a more straightforward risk management problem. However, the choice-under-uncertainty problem is not foreign to decision sciences. If we act as Bayesians we simply establish prior subjective probabilities, gather new information to revise our priors, and, when satisfied with the information base, make a decision. However, even if we think in probabilities, it does not follow that a two-part decision process, including an ENB decision rule, can be applied in the case of environmental hazards. The recognition that the probability estimates are "soft" suggests that risk management decision variables—the potential cost of the risk assessment being wrong—get blended into the risk assessment process.

One approach to the technical uncertainty for harm is to assume that use of the pesticide is benign and to require evidence showing that it is harmful. By placing the burden on the evidence to show potential for harm, a risk management decision is made to limit false positive errors, that is, to avoid the error of concluding something is harmful when it is not. Of course the failure to find evidence of harm does not guarantee the absence of ill effects. A decision rule of limiting false positives implicitly asserts that the cost of a false positive is a very high opportunity cost of not using the pesticide; we are willing to use the product and accept a possibility that there may be harm. However, a decision to allow use is not taken without consideration of the potential for harm. Indeed, there may be some element of risk aversion in the decision process, but there is a willingness to use the pesticide even though a potential for occasional harm is recognized. This decision rule is characterized as *"weak risk aversion."*

An alternative approach to the technical uncertainty is to assert that the pesticide is harmful and require evidence that it is benign. The pesticide would not be used unless there is compelling evidence that it will do no harm. Requiring the evidence to show that the pesticide is not harmful before its use is a risk management decision rule to limit false negative errors, that is, to avoid the error of concluding something is not harmful when it is. The rule to limit false negatives implicitly asserts that the cost of a false negative is a very high opportunity cost of pesticide damage. We are not willing to allow a trial of the product and accept the possibility that there may be harm. In this approach even circumstantial and indirect evidence of harm is treated as a presupposition of harm, unless proven otherwise. This can be termed the "wait and see" approach. Because we are not willing to allow a trial of the product and accept the possibility that there may be harm, the wait-and-see decision rule is characterized as *"strong risk aversion."*

Thinking about the decision process in terms of degrees of risk aversion blurs the sharp distinction between risk assessment and risk management. Risk management decision rules specify the way in which evidence is considered in the risk assessment process. However, by strong risk aversion I do not mean a zero risk decision rule. The purpose in distinguishing between strong and weak risk aversion is not to seek an appropriate level of risk, but rather is to illustrate that the "science" of risk assessment is never divorced from "judgments" in risk management.

ENB AND THE CURRENT RISK MANAGEMENT APPROACH

Many a frustrated benefit-cost analyst can attest to the ineffectiveness of an ENB argument in the making of risk management decisions, and even where one night expect to find support for ENB analysis there is skepticism. For example, the editor of *Agrichemical Age* rejects the call for benefit analysis in the pesticide regulation process. He argues that we simply need to reach a decision on whether the risk from a pesticide is "negligible" and that the market will tell us if the product has any benefits. Benefit analysis is seen as an analytically intractable and unnecessary activity (Richardson).

Another basis for rejecting the ENB decision rule, whether viewed as a decision heuristic or a call for quantification, is that ENB looks to market exchange for defining acceptable social risk. Thus, the risk management choice is in the hands of members of the society acting as self-interested individuals. Economists say they recognize the limits of this argument but also argue that the virtue of the ENB rule is that it makes a decision to be inefficient explicit (Freeman and Portney, 1989 and 1989a). Others are not convinced that efficiency should be treated as the rebuttable presumption against which nonefficiency arguments must be tested (Sagoff).

However, the most frequent reason for rejecting the ENB approach is the distinction between uncertainty (hazards) and risk. If we knew an action would be catastrophic, we would not take the action. If we knew the necessary probabilities and appropriate rules for considering the pros and cons of an action, a more formal two-part risk analysis might be employed. However, fundamental uncertainty about potential for harm limits the applicability of the two-part decision model, instead directing risk management to the framing of the harm question in terms of false positives versus false negatives.

At present, the statutory and public expectation is that the appropriate social response is to do all possible to *anticipate* problems before they occur, rather than *react* after the harm is done. To "proceed with caution" requires being convinced that there is little likelihood of harm *before* any action is permitted. While situations vary, the current decision process can be characterized as strongly risk averse. Two related arguments have been widely accepted as supporting this situation: (1) irreversible and latent effects and (2) the need for voluntary risk bearing. What is striking is the extent to which arguments from the economic efficiency framework underlying the ENB rule can be, and have been, enlisted to support strong risk aversion.

The irreversibility argument is that if we determine that a technology is harmless, and later discover that it causes damage, the error cannot be repaired or rectified. Human life loss or loss of species are offered as examples of irreversible losses. Furthermore, many of these irreversible effects may be "latent," taking a long time to manifest themselves. For this reason also caution should be exercised in concluding that the technology will not cause harm. Faced with the prospect of irreversible and latent harms, we can argue that the prudent course is to be skeptical of data showing harmlessness and to seek continually more confirmation.

The irreversibility argument is not foreign to an economic model that associates "rational" choice with informed choice. In fact, the economic model defends government regulation of environmental hazards as a remedy for the market's inability to generate risk information. To act in government on less than the best information, when the costs of error are believed to be so high, would be inconsistent with the very economic logic offered for government intervention in the first instance.

The imposition of "involuntary" risk is deemed unacceptable as social policy and strong risk aversion can be defended by adopting the economic argument that risk bearing should be voluntary to be efficient and equitable. In some special instances (window washers on skyscrapers), risk markets may be able to function. However, environmental hazards are collective consumption goods (bads?). As with any collective consumption good, high transaction cost (within and across generations) makes it impossible to gain agreement on acceptable risk bearing through exchange. At the same time the problems of possible latent and irreversible damage are said to limit the applicability of social insurance or liability law for damage compensation. Thus most risk bearing is likely to be involuntary, says this argument.

The arguments that it will be easy to err, that error may be irreversible, and that risk bearing will be involuntary rationalize a strongly risk-averse decision posture. The cost of waiting and more study is said to be small relative to the irreversible and potentially large costs of a decision based on inadequate understanding.

THE CONCEPT OF RESILIENCY AND THE CASE FOR WEAK RISK AVERSION

The strong risk aversion of current hazards management policy has its critics.

> We know so little about so many potential risks and a natural impulse says: hold up until you learn far more. But next year we will only know just a trifle more and if we remain paralyzed, then our inactions will merely displace one risk with another risk. We should continue to worry about risk assessments—and learn how to do these better—but I believe the real improvements, for the time being, will come in the better management of risks. *We need a more experimental societal approach, a more adaptive approach. We need to remain loose, flexible and resilient.* (emphasis added) (Raiffa, p. 339).

For the critics of strong risk aversion, the only certainty about a new technology is that there may be a "surprise"—the occurrence of the totally unexpected effect (positive or negative), as distinct from events that we know will occur with some probability but for which we cannot predict a specific occurrence (Wildavsky). Thus we might anticipate that planting a crop in a flood plain will cause some unpredictable, but expected, loss to flooding. In contrast we were surprised to discover that DDT altered the reproductive success of birds of prey. All might agree that use of new technology is accompanied by possible hazards; the disagreement is over how much we can learn about a technology before its use. The critics of wait-and-see (strong risk aversion) argue that we just cannot know enough to identify in advance all beneficial and adverse consequences of a technology.

However, the inability to know is not the central point argued by critics of strong risk aversion. The critics believe that if we determine that a new technology is safe, allow its use, and later discover that it causes damage, the error can be corrected by repairing the damage or rectifying the harm. This ability to rectify a harm is the resiliency Raiffa is advocating. "Resilience is the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back" (p. 77), says Wildavsky. A confidence in resilience will mitigate against strong risk aversion, not because risks are taken without consideration of possible adverse consequences, but because a belief in resiliency instills a confidence to proceed with a new technology while the potential for harm is not fully determined. Belief in resiliency does not speak against conservatism in risk taking, but it does speak against a reactionary position in which any possibility of error or harm can halt all change (Wildavsky).

Advocates of resiliency argue that trying to anticipate all hazards is not only impossible, but is counterproductive to the goal of increasing safety. Safety means increasing human health and longevity and managing the natural environment toward the achievement of human purposes. For advocates of resiliency, strong risk aversion inhibits technological "progress" and technological progress is essential to achieving a safer society. In Wildavsky's phrase "wealthier is healthier," he rejects the balancing metaphor used in the current regulatory debate (and the core of the argument for an ENB decision rule), in which material wealth is sacrificed to gain health (reduced hazard). Health comes with wealth, not at the expense of wealth (Simon), and wealth comes from technological change. Thus a resilient society is defined as one of increasing wealth and health, driven by technological change. However, each new technology brings both benefits and potential hazards, in joint supply. Thus, the benefits of technological change are inseparable from technological hazards that may arise.

Advocates of resiliency argue that the ability to detect and react to technological hazards is rooted in the continuous creation of new knowledge. For agricultural production new knowledge requires biotechnology and chemical research capacity to develop rapidly and continuously alternative pest control approaches as hazards of old approaches are found. This new knowledge is partly founded in basic research in private and public laboratories, but full knowledge of the technologies comes only with their use. Here is the challenge. Discovering which technologies have a desirable balance cannot be anticipated in the laboratory but can only be discovered through actual trial, realized error, and effective feedback to ensure learning.

Learning errors are welcome as long as they are "small" and not cumulative. The potential for actual technological trials to have catastrophic errors is said to be reduced if there is an increase in diversity of trials. Diversity means encouraging many experimental technologies, not limiting technologies to only those we think are "safe." A particular concern about the strongly risk averse position is that because it limits trials it increases the potential for harm. The following reflection on sweeteners adequately conveys the basic argument that, over time, safety comes from diversity:

> Everyone is aware of the attacks on sugar and sugar substitutes, such as saccharin and cyclamates, as harmful for our health. Enter fructose, a sugar found in fruit and honey, touted as a natural and therefore wholesome sweetener. ... Now, "new research indicates that high levels of fructose exacerbate the effects of copper deficiency, a factor that has already been linked to coronary problems, including high cholesterol levels." Given that "Nature sometimes seems to have a malicious sense of humor," I do not expect anyone to have known of this indirect connection, but I do think that if matters had been allowed to run their course, it is likely that a variety of sweeteners would have a share of the market so that very large populations would not be subject to the unanticipated consequences of the few that, for the moment, are favored (Wildavsky, p. 86).

A belief in resiliency will encourage weak risk aversion in the consideration of technological hazards and the allowance of trials of technology without absolute assurance that there will be no harm. Examples from agriculture can be imagined. Resiliency means diversification of cropping practices to limit the geographic scope of errors that do arise; monoculture over large geographic expanses may be the enemy of resiliency. A resilient agriculture will use multiple pest control strategies, including perhaps more varieties of chemicals in order to reduce the problems of pest resistance that can be a function of limiting allowable chemicals and increasing dosage of what we do use (Gianessi and Puffer).

RESILIENCY: THE ECONOMIC TOUCHSTONE?

Economists could be comfortable with the resiliency argument. Resiliency is analogous to a conception of the market as an engine of evolutionary change. The evolutionary perspective requires that the economist depart from a model of markets that presumes full knowledge and unchanging resources, technology, and preferences. Instead knowledge grows with time and with changing technology and preferences. The market economy, for the Austrians, or the larger cultural system including markets, for the institutionalists, is the social search system where we collectively explore the future of what we can achieve (technology) and what we desire (preferences) in a trial and error process (Hamilton).

Search, at least partly through markets, results in coevolution of humans with nature (Boulding; Norgaard). In coevolution human modifications are made to nature and humans in turn remake our preferences for the state of the natural world as it changes in response to human intervention. This coevolutionary process characterizes "human progress." The evidence of human history is that while there has been no discernible evolution of the human organism, human modifications and manipulations of the environment—agriculture, medicine, water control structures, and the like—made us richer and healthier. We have made our environment serve human ends as much as we have adapted to our environment.

In the evolutionary view technological progress is discovered, not planned, because no amount of prior investigation will yield "perfect" information about alternative courses of action.

> The problem in economic life is not calculating what to do after knowing all that you need to know. The problem is to know.... The Austrians see the economy with the metaphor of fog, the fog in which we maximize what the neoclassicals so confidently describe as "objective functions"... the main problem is acquiring knowledge, not exploiting it (Klamer and McCloskey, p. 10).

Once the information assumption of the static economic model is cast aside, the question of how knowledge is acquired and grows is answered in a remarkably consistent manner across the various schools in the discipline. Simply put, new knowledge, acquired from trial and error experimentation, motivates technical change.

> Knowledge has to be acquired ... The acquisition of knowledge is what is usually termed "learning" ... I do not think that the picture of technical change as a vast and prolonged process of learning about the environment in which we operate is in any way a far-fetched analogy... there are sharp differences of opinion about the processes of learning. But one empirical generalization is so clear that all schools of thought must accept it, although they interpret it in different fashions: Learning is the product of experience. Learning can only take place by trying to solve a problem. ... A second generalization that can be gleaned ... is that to have steadily increasing performance ... the stimulus situations themselves must be steadily evolving rather than merely repeating... (Arrow).

How does the market fit into this search for progress and the achievement of safety? The market model can be cited, not for its static allocative properties, but rather for the way the price system creates needed incentives for discovery and application of new technology (Mowery and Tosenberg). How do we ensure that market risk taking is conservative and not "radical"? One argument is that a competitive world is not homogeneous, and resiliency is secured because failure in one part of the economy is not failure for the whole economy. Thus, it may be the public policies toward agriculture that give us monoculture and agricultural systems dependent on a limited number of chemicals. A more market-oriented agricultural economy might be more resilient and less likely to become an environmental hazard.

However, there is more to the defense of markets than that if atomistic they can spread risk. Because a market does not operate outside a legal context, basic concepts of liability law are required as adjuncts to the search process. In order to appreciate how liability law might be structured, we need to recall the distinction between surprise and expected harms. Expected harm is risk, and surprise is hazard. Liability law is first about requiring compensation for expected harms. If harm were foreseeable (if not predictable with precision), the user of the technology would be obligated to compensate for the harms when they occur. To ensure that this compensation is possible, the user must either self insure or purchase insurance. The cost of insurance is an incentive to make investments (1) to reduce the potential for harm (given relative costs), (2) to search out new and less potentially harmful technologies, and (3) to develop information on the actuarial risks of any technology. In this way the market searches for not only new technologies but also safer technologies (Bardach and Kagan; Katzman).

The evolutionary perspective dismisses the possibility of knowing before acting, presumes that errors will be made and corrected in the development and application of technology, and sees technical change as the defining feature of human progress. An evolutionary economics perspective can be used to support the resiliency argument and the weak risk aversion decision rule for allowing new technologies. The design of optimal rules for the application of markets for defining "acceptable" technological change can be a matter for debate, but there is a case to be made for the use of markets as search institutions.

IS THERE A CASE FOR WEAK RISK AVERSION?

Advocates of strong risk aversion make their case by arguing that we should know before acting, avoid involuntary risk bearing, and avoid irreversible harms. However, if we acknowledge the resiliency argument, this rhetoric of strong risk aversion warrants critical examination.

IS RISK ASSESSMENT SCIENCE?

Advocates of strong risk aversion want to wait for an improved scientific understanding of a technology's potential for harm before permitting its use. However, improving a risk assessment is not a simple matter of spending more time and analyzing more data, because our "models of harm" are poorly developed. At some point in the risk assessment the damaging properties must be "guessed at." The rules for making the guesses are what has been termed "science policy," that is, the "science" of risk assessment includes risk management judgments (Ricci and Molton).

There is evidence that "science policy" is strongly risk averse in the United States. Rather than using "best guesses" at points of poor understanding, a decision is often made to use "worst cases," and the "cascading" of worst cases can substantially increase estimates of harm. Defenders of the current approach are unambiguous in their defense. One defender (Finkel, 1989 and 1989a) of this approach states:

> Although conservative estimates have been widely described as policy choices masquerading as scientific facts, central or average estimates themselves embody subtle value judgments regarding the implicit social costs of erring on the high or low sides. *In this respect, best estimates are no better than conservative ones, which simply strike the balance in favor of caution about underestimation. (emphasis added) (Finkel, 1989).*

This statement affirms the fact that risk assessment is not separate from social judgment on acceptable risk and then argues for the desirability of strong risk aversion.

Risk assessment is a culturally dependent process. In a fascinating case study, anthropologist Shelia Jasanoff reports that, using the same data, U.S. and British scientists reached entirely different conclusions about the hazards of asbestos, formaldehyde, airborne lead, and 2,4,5 -T. She concludes

> ... acceptance or rejection of particular studies, the development of evaluation criteria, the decision to wait for more evidence or to commission new studies are all colored by varying degrees of risk averseness in different countries. Scientists, no less than policymakers or the general public, share in the prevailing national attitudes toward risk, and these values are reflected in the way they filter and organize scientific knowledge.

The rhetoric about awaiting the scientific purity of the risk assessment process is misleading (Wynne). There is a tendency to strong risk aversion among technical risk assessors, blurring the distinction between risk management and risk assessment. The arguments used to justify strong risk aversion are familiar ones: avoiding imposition of voluntary harm and avoiding irreversibility. So we need to examine these arguments once more.

IS POSSIBILITY OF INVOLUNTARY RISK A MEANINGFUL POLICY GUIDE?

Strong risk aversion is defended as a decision rule to avoid imposing involuntary (uncompensated) risk. For advocates of weak risk aversion, the integration of existing liability law for health risk (Abraham), the newer concept of the "environmental bond" for damages to natural environments (Perrings), and concepts of social insurance (Abraham and Merrill; Viscusi) can allow newer technologies to be employed with the promise of compensation for the harms that may arise.

However, if one defines harms as "irreversible" then the insurance alternative for compensation would be rejected because the very concept of irreversible harm makes compensation meaningless. Thus, when harms do arise there has been a tendency in the court system to make liability damage awards that exceed measured damages and to include punitive penalties for presumably irresponsible social behavior by the users of the technology. Also, benefits and risk exist jointly in any technology; there will be surprises, effects the user of the technology could not have "reasonably" expected. Should the harms from surprise outcomes be compensated, and by whom? Increasingly our society has determined that all harms must be compensated by the user of the technology. This is the "strict liability rule," which is increasingly imposed on the users of farm chemicals (Batie).

The defense offered for punitive damage awards and strict liability is the undesirability of involuntary risk bearing, but the result of strict liability, combined with punitive damage awards, is the weakening of insurance markets as costs of future claims become unpredictable for the insuring agents. Meanwhile, outside the courts, in political discourse and in regulatory hearings, demands are made to limit "involuntary risk bearing" (Hiskes; Kennedy).

For the advocates of resiliency, the emphasis on limiting involuntary risk bearing slows the search for and development of technology that can increase human welfare. These critics of strong risk aversion remind us that potential hazards coexist with benefits in all technologies, existing and new. However, as a society we often reject the new technology and implicitly accept the hazards of the old (Huber). Examples are the decision to produce power with coal and accept its hazards while rejecting nuclear power or decisions to deny a new pest control chemical while allowing old ones to remain in use (Gianessi). Of course, the hazards of the old technologies may be "irreversible" and "involuntarily borne" by some segment of the population. In effect it is not possible to separate hazards from use of technology, and, as such, all technologies have the potential to impose harms that will be uncompensated.

A second criticism of the involuntary risk argument is that to deny new technology is to deny potential gains to those who might be made better off. These lost opportunities for improved health are a cost that must be considered. If human well-being is the goal, then to disallow a technology that can increase food production or lower food prices is to reduce nutritional levels and increase health risk in the population at large (Brosten and Simmonds). There is a greater risk from poor nutrition than there is from residual chemicals on the foods themselves or from the biotechnology. In this regard the very concept of the pareto test and involuntary risk is questioned. Consider a technology that radically increases food production and health in a poor nation but might result in occasional deaths from its use. The pareto rule strictly applied would not permit the use of that technology, yet the failure to use it imposes involuntary harms on a large segment of the population. Charles Lindbloom argues that

> Economists often blunder into the conclusion that policymakers should choose pareto efficient solutions because they help some persons and hurt no others. Not so. If, as is typically the case—and perhaps is always the case—there are still other solutions that bring substantial advantages to large numbers of persons and these advantages are worth seeking even at loss to other persons—for example, protecting civil liberties of minorities even if doing so is greatly irritating and obstructive to others—then there remains a conflict as to what is to be done. The pareto efficient solution is not necessarily the best choice.

The strict attention to compensation for risk bearing discourages technological change. Many authors recognize the trade off between certain and full compensation for individual harms and technological changes that benefit the larger group. The proper trade off is not definable, but institutional reforms to permit weak risk aversion in allowing new technologies can be made (Abraham and Merrill; Abraham). Of course, what individual economists believe about the appropriate trade off between the individual compensation and "progress" in the society at large is not derivable from the rules within the discipline.

IS PROGRESS A MEANINGFUL CONCEPT?

To suggest that harms are irreversible carries unstated premises, including: new technology may not be progressive, technology is the enemy of the natural world, and preferences for the natural world are unchanging. To reject the idea of irreversibility, arguing that we can be resilient, is to assert faith in technological progress and to see the natural world as a human creation. Technological advance has shaped the culture of the 20th century, and as we approach the next century the historians of technology are noting radically increased societal expectations of what technology can achieve. This expectation runs the gamut from biological technology to information technology and the integration of the two. In this process of change, nature will be modified by human technology, but will the natural world collapse? Will nature be different or deadly? Ecologist Renée Dubos says,

> It is not true that nature knows best... By using reason and knowledge, we can manipulate the raw stuff of nature and shape it into ecosystems that have qualities not found in wilderness. Many potentialities become manifest only when they have been brought out by human imagination and toil (p. 461).

Such technological optimism is not without skeptics. They ask if today's technology is different in kind from the past (Costanza). For them, the past is not prologue, since we have the capacity to modify large populations and ecosystems on an interconnected world scale. On this basis some economists might argue that using chemicals or biotechnology in agriculture risks causing unacceptable and irreversible harms. However, neither technological optimism nor pessimism is derivable from economic inquiry but rather must be based on accepting "scientific" judgments made outside the discipline.

However, there is more to the skepticism about technological "progress." Advocates of resiliency and weak risk aversion are willing to experiment in the natural world because the natural world has a different meaning to them than to the strongly risk averse. To the strongly risk averse, tampering with the "natural order" is simply wrong. In his article "The End of Nature," McKibben argues that "an idea can become extinct, just like an animal or plant. The idea in this case is nature—the wild province apart from man, under whose rules he was born and died" (p. 70). What may be at stake is the end of an idea; the idea that humans and nature are separate. McKibben goes on to reflect on the promise of biotechnology to ensure increases in agricultural productivity and concludes,

> The problem is that nature, the independent force that has surrounded us since our earliest days, cannot coexist with our numbers and our habits. We may well be able to create a world that can support our inhabitants but it will be an artificial world—a space station (p. 100).

It is the threat of technological change to the idea of the natural world that often motivates the strongly risk averse. The argument that technology allows us to maintain and increase human welfare over time assumes we can learn what we like based on whatever environment we have, and that troubles some people. Philosopher Mark Sagoff notes that, "Our decisions about the environment will also determine ... what future people are like and what their tastes and preferences will be..." (p. 63). Then, after speculating on a future in which humans totally reshape the natural world—pejoratively a world of plastic trees and barren, but productive, landscapes—he concludes that, "Future generations might not complain; a pack of yahoos will like a junkyard environment. This is the problem. That kind of future is efficient. It may well be equitable. But it is tragic all the same" (p. 63).

Thus technological hazards often are defined as a product of both technology and preferences. To summarize by example, whether DDT was considered a hazard was determined by society's preferences to preserve populations of birds of prey. The fact that DDT may still be used elsewhere in the world is a matter of different preferences, not different effects of the DDT. Damage is a social concept as well as a biological and physical one. Economists' personal views on the meaning of progress must enter their professional arguments.

ECONOMICS IN THE HAZARDS DEBATE: A SUMMARY OF THE ARGUMENT

In considering the application of new agricultural production technologies, the United States of the 1990s is a strongly risk-averse society. We insist on anticipating and regulating all potential harms in advance and have limited confidence that we can recover—be resilient—if harms are realized. Citing arguments such as irreversibility and involuntary risk bearing, this anticipatory policy net catches and holds back emerging agricultural production technologies. Much economic argument from the mainline economic research program, which stresses "market failure," can be enlisted in support of strong risk aversion.

Some reject the anticipatory view and argue for resiliency in our approach to employing new technologies. Advocates of resiliency find the anticipatory approach to be antithetical to the stated goal of increasing "safety"—i.e., human welfare. These people tend to be technological optimists who associate technological change with human progress. They advocate a cautious trial-and-error investigation of new technologies as the path to increased safety in our society. Much of evolutionary economic thinking can be enlisted to support the resiliency argument. Indeed, the market itself can be defended as an effective means to increasing safety.

What an economist argues about managing the hazards of new production technologies depends on that individual's beliefs about the scientific credibility of assessed risk of new technologies, about the meaning of voluntary risk and compensations, and about the meaning of "progress" and "nature." None of these beliefs is derived from the core of the economics discipline. Indeed the economist's arguments often rest not on economic considerations but on these matters of belief that are established outside the discipline.

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