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Private Protection from Collective Environmental Risks

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Abstract

Environmental protection is designed to reduce collective risks to human and environmental health. Since private citizens are free to reduce the risk privately as well, these environmental risks are endogenous to economic and ecological circumstances. Herein we review an economist's perspective on environmental risk reduction policy given this endogenous risk idea. We review the literature on choice under risk, risk valuation and the value of statistical life, risk perceptions, and rational risk regulation.

Key words: *Environmental protection, Endogenous risk, Rationality valuation, Perception, Regulation*

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I. Introduction

Environmental policy aims to protect people and nature. Economics helps to make policy more cost-effective by showing how society can get more protection at less cost. Within an economic context, however, environmental protection should be viewed as a lottery-a set of collective risky choices defined by the probabilities and severities of alternative events. An environmental lottery captures the reality that no policy eliminates risk to human or environmental health; rather policies alter the risk. For example, a nation reduces collective climate risk by curtailing greenhouse gas emissions to lower the likelihood that bad states of nature occur; people also reduce to climate risk by changing production and consumption decisions to reduce the severity of a bad state if it does occur. Mitigation and adaptation together work to reduce but do not eliminate such collective risks.

In addition, private citizens have the liberty to protect and adapt on their own accord. Risk is endogenous to them. A person invests resources to influence the collective environmental risks he or she confronts. Examples 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. A person invests in a water filter, move, buy a membership to a health club, jog, eat food low in fat and high in fiber, or apply sunscreen; each choice altering his risk to health and welfare. How a person increases the likelihood that good things happen and bad things do not depends on both his attitudes toward risk and his technology to reduce risk.

A policy maker must consider these adaptive responses when choosing the optimal degree of public risk reduction. Otherwise, policy actions will be more expensive than need be with no additional reduction in environmental risk. Intuitively, most policymakers and researchers would agree with this logic -adaptation affects the costs and benefits of environmental risk reduction. But this obvious point is neglected in policy making. This occurs because environmental policy is fragmented. The Kyoto protocol for climate change, for example, is almost all mitigation, with limited adaptation. The signatories focus on mitigation targets and timetables without acknowledging how adaptation can affect these emission reduction efforts. But many rational decision-makers keep repeating, at least informally, that a mitigation-only approach like Kyoto limits the options.

Effective environmental protection can benefit from an integrated approach that addresses how economics affects choice under risk, risk valuation, risk perception, and an integrated portfolio of risk reduction strategies. Herein we provide a general discussion of private protection from collective environmental risk rather than technical review of decision theory. Aspects addressed are how private citizens and governments confront the challenge of finding reasonable answers to these questions about rational environmental risk policy-how do people perceive risk, make choices under risk, how they value risk reduction, and how can society manage and regulate risk rationally?

II. Environmental Protection under Risk

Choice under risk has captivated people at least since the time humans "discovered" gambling was fun-ancestral humans waited until the Renaissance before witnessing the development of a systematic theory of probability (Savage, 1954; Knight, 1971). Until that time, people seemed to think we did not create much of their own luck. Fate was the master. Their lives were linked closer to nature, and much more exposed to its whims. Crops failed and children died without seeming reason. People were busy trying to survive nature rather than ponder the systematic nature of risk (see Starr, 1969; USNAS, 1983).

As people learned to use free trade to create value, they had more desire to master risk. More trade meant more wealth and more risk. Trading partners separated by unpredictable oceans had an incentive to understand how to manage and control risk. As trade routes turned into world wars and global stock and bond swaps, the gains from risk assessment and management as practical arts increased. Those who had a sophisticated appreciation of the behavioral underpinnings of risk had a better chance of winning real and metaphorical battles. This holds for environmental risk (Crocker and Shogren, 1999).

To follow the intellectual history of understanding how people make choices under risk, consider three gambles: gamble X is a certain payment of $30-a sure bet; gamble Y is a coin flip in which $100 is won with a heads, and $100 lost with a tails; and gamble Z is a roll of a die in which $2,000 is won if a #1 is rolled, $1,000 is won with a #2, and $500 is won with a #3, while $0 is lost with a #4, $1,000 is lost with a #5, and $2,000 is lost with a #6.

Theorists speculating on how people make choices under risk thought that many people would prefer the gamble with the highest expected value-the probability weighted average of all possible outcomes of the gamble. Gamble Z has the highest expected value, but it is observed that many people shy away from gamble Z and take gamble X instead. The old adage that a bird in the hand is worth two in the bush reflects the prudent strategy to go for the sure thing.

But why does the gamble with the lower expected value attract some many people? In the eighteenth century, Nicholas Bernoulli devised the St. Petersburg paradox to illustrate how this works. Suppose the following proposition is offered. A gamble can be bought into on a fair coin toss. If a head comes up on the first flip, $2 is earned; if it takes two flips to uncover a head, $4 is earned; if it takes three flips, $8 is earned; if it takes four flips, $16 is earned; five, $32; six, $64; seven, $128; and so on. What is the maximum someone should be willing to pay to buy into this gamble? Most people will pay less than infinity even though infinity is the expected value of this gamble: Expected value = [1/2] chance of $2 + [1/4] chance of $4 + [1/8] chance of $8 +…= $1 + $1 +$1 + $1 + $1 +…= infinity. Most people are suspicious of the gamble because the variance of the gamble is also infinite. Variance reflects the potential volatility of the outcome. More variance implies more chance that bad states will be realized.

Daniel Bernoulli offered a reason why people will pay much less than infinity for a gamble with infinite variance: a gain of $2,000 is not worth twice as much as $1,000. People have diminishing marginal returns to wealth. This means people get less value out of the last dollar earned than the first dollar earned. Bernoulli's insight is that a person's satisfaction arising from more wealth is inversely proportionate to the quantity of the goods previously possessed.

Increased wealth increases total utility at a decreasing rate, which is why the utility function is curved. Gambles with high variance are less attractive-the gain from an extra dollar added to wealth is smaller than the loss from an extra dollar taken away. One example of a useful utility function with this property is: $u(w) = (w)^{1/2}$, where u = utility, and w = wealth. For instance, wealth of $10,000 creates a utility level of 100, while wealth of $1,000,000 creates a utility level of 1,000. A 100-fold increase in wealth increases a person's utility by 10-fold. When a person acts this way they are said to be risk averse. A risk averse person will take a certain payoff over a fair bet—a gamble in which the expected value is zero, e.g., 50:50 odds to win or lose $1,000. A risk loving person prefers a fair bet to a certain payoff equaling the expected value of the gamble. A risk neutral person is indifferent to the choice between a gamble and certain payoff equaling the expected value of the gamble.

Bernoulli's insight was formalized into Expected Utility theory (EU) by von Neumann and the economist Morgenstern (1944) and Savage (1954). EU theory has been the most successful model of how people make decisions under risk. The formal theory of expected utility reflects the idea that people make choices about risk based their beliefs about the probability that good and bad events will be realized, the consequences of good and bad events, and the utility or satisfaction a person gets from the consequence that is realized. Despite limits to the EU model, researchers use the model because it is intuitive and tractable.

The key step in the development of the expected utility model for environmental policy is the idea of endogenous risk. Endogenous risk accounts for a person's ability to influence the risk confronted, either privately and collectively through market insurance, self-protection and self-insurance (or or mitigation and adaptation). A person is not helpless against the risk (Ehrlich and Becker, 1972; Shogren and Crocker, 1991, 1999). Market insurance can be purchased against illness. Investment can be made in different risk reduction strategies to change the odds of suffering from some illness caused by air pollution-an air filter can be bought for the person's home, or the person can at better and exercise more. Actions taken can reduce the likelihood that the bad state will occur, or reduce the severity of the state if realized or do both. Actions to reduce the likelihood of illness are referred to as self-protection; actions to reduce the severity are self-insurance.

The economic problem is now more complicated. If a person selects the level of self-protection and self-insurance that balances the extra gains obtained from lower odds of illness and less severity with the costs of protection and personal insurance,

$$EU = \pi(z)u(w - z - x) + (1 - \pi(z))u(w - D(x) - z - x),$$

where $= \pi(z)$ is the probability of the good state which depends on the level of self-protection, z, and $D(x)$ is the severity of illness which depends on the level of self-insurance, x. Including the private ability to reduce risk is helpful in understanding choice under environmental risk, because these actions link risk assessment with risk management. Account must be taken of these actions to measure risk accurately and to manage risk effectively (see Kane and Shogren, 2000).

Although risk assessment has amassed a useful record of estimating potential threats to humans and nature, one problem permeates the risk assessment literature-the under-emphasis on how people adapt to the risk they face or have created. Over the last decade of the twentieth century scientists have acknowledged that environmental risk is endogenous. People can influence many of the risks they confront.

Cases exist in which people have little time to react to protect themselves, such as in the Chernobyl situation. Some people have argued that the problem can be redefined so that risk is independent of human action. This position is self-defeating. Consider a situation in which bacterial groundwater contamination threatens a household's drinking water. The probability of illness among household members can be altered if the water is boiled. An analyst could define the situation as independent of the household's actions by focusing on groundwater contamination, over which the household is likely to have no control. But this definition is economically irrelevant if the question is the household's response to the risks from groundwater contamination. The household is concerned about the likelihood of illness and the realized severity, and it is able to exercise some control over those events. The household's risk is endogenous because people spend valuable resources to reduce the probability and severity of a risk (Crocker and Shogren, 1999).

People substitute private actions for collectively supplied safety programs. They use: stronger building materials to reduce the damage from tornadoes, storms, and earthquakes; more thorough weeding and crop storage in response to the prospect of drought; sandbagging and evacuation in anticipation of floods; and improved nutrition and exercise regimens to cope with health threats. At the policy level, these private risk reduction choices can affect the success of collective regulations that promote safety. Use of automobile 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 when drivers observe them. At work, rules promoting personal protective equipment (e.g., hard hats) have the same problem-they protect those workers who wear them. In each case, decisions influence both the probability and the magnitude of harm.

Endogenous risk implies that observed risks are functions of both natural science parameters and an person's self-protection decisions. Given the relative marginal effectiveness of alternative self-protection efforts, how people make decisions about risk differs across people and situations, even though the natural phenomena that trigger these efforts apply equally to everyone. Assessing risk levels in terms of natural science can be misleading. Relative prices, incomes, and other economic and social parameters that influence any person's self-protection decisions affect risk. Just as good public policy-based economics requires an understanding of the physical and natural phenomena that underpin choices, good public policy-based natural science requires an understanding of the economic phenomena that affects risk. Accounting for private decisions to adapt can increase the precision of risk assessment. Failure to address endogenous environmental risk will result in excessive economic expenditure at no gain in environmental quality.

III. Valuing Risks to Life and Limb

We now consider how rational people value a reduction in risk, for both private and collective strategies. Constrained budgets and increased fiscal accountability prevent a policymaker from reducing all risk to all people. Deciding how to reduce risk requires evaluation of each new or revised regulation (see for example Crouch and Wilson, 1982; Viscusi, 1992; Sunstein, 2002). Comparability of value across all sectors of the economy requires that policymakers rank regulatory alternatives in terms of a common unit. A common denominator is money, or monetary equivalence. Risk valuation evaluates each regulation by estimating the monetary value–both benefits and costs–of a reduction in risk.

Valuing the costs and benefits of reduced risk is formidable and controversial. While measuring the cost to control risk is more straightforward, the benefits are a challenge to quantify. Problems arise because goods associated with reduced risk-death and injury-are not bought and sold on the auction block. These goods rarely, if ever, enter a private market, and remain un-priced by collective agency action. Valuing risk reductions requires that a value is placed on death and illness. In theory, economists value a reduction in risk as how much people are willing to pay:

$$\text{The value of risk reduction} = \frac{\text{Willingness to pay for risk reduction}}{\text{Change in risk}}$$

Rational risk policy says that a person's value for a risk reduction equals their maximum willingness to pay to increase the chances to stay healthy, conditional of previous private actions to reduce risk. For example, suppose a person will pay $6 to reduce the risk of death to 1 in 1 million from 4 in 1 million; a 3 in 1 million risk reduction. The value of life is then $2 million (= $6 /[3/1,000,000]). If the person was willing to pay $0.60, the implied value of life is $200,000. How can the value of risk reduction be measured? The literature on rational risk valuation has developed two general approaches to measuring the economic benefits of reduced risk: the human capital and willingness-to-pay approaches.

Human capital approach. This approach values risk reductions by examining a person's lifetime earnings and activities. The value of a risk reduction is the gain in future earning and consumption. The value of saving a life is calculated as what the person contributes to society through the net present value of future earnings and consumption. The human capital approach has an advantage since it uses full age-specific accounting to evaluate risk reductions. A major drawback is it lacks justification based on traditional economic welfare theory; the method also assigns lower values to the lives of women and minorities, and zero value to retired people. For this reason, economists have downplayed the human capital method in favor of the willingness-to-pay approach.

Willingness-to-pay approach. Economists have advocated the willingness-to-pay approach since it is based on the theory of welfare economics (see Hanley et al., 2007). Welfare economics lays the foundation for estimating the value of risk reduction. People value risk reduction if it leads to a greater level of utility or welfare. The welfare change is measured by the maximum that the average person would be willing to pay to reduce risk or the minimum compensation that person would be willing to accept for an increase in risk. Economists then use this willingness to pay or accept to estimate the implied value of life and limb. Although far from perfect, economists argue that the willingness-to-pay approach is preferable to the alternative-it is better to have a rough estimate of a well-grounded theory than a precise estimate of a flighty one. Four empirical approaches are used to determine the willingness to pay for risk reduction: the wage-risk trade-off, stated preferences, experimental auctions, and averting behavior.

Wage-risk trade-offs. Wage-risk trade-offs are based on the theory of hedonic prices. Hedonic price theory captures the idea that a person's wage rate depends on skill, education, occupation, location, environment of work, and job safety or risk (See Viscusi, 1992). A worker will accept a higher wage for more risk, holding all other job attributes constant. More risk, higher wages-and a worker selects his job to equate the incremental willingness-to-pay for each attribute to the incremental contribution of each attribute to the wage rate. The value of risk reduction is the incremental willingness-to-pay for the attribute "job safety." Workers then compare their risk-wage trade-offs to the rate that the market is willing to trade risk for wages. The market equilibrium between workers and employers then determines the risk premium-the extra compensation for risky jobs. The wage-risk trade-off is determined, other job attributes held constant. A review of the early (1974-1983) empirical results of the hedonic wage-risk model indicates that the value of statistical life estimates fall into two ranges-$450,000 to $720,000 and $4,000,000 to $10,000,000 (in 2000 dollars). Wage-risk studies set the value of a statistical life between $900,000 and $6 800,000. But note that these values can be challenged. Critics question the presumptions that workers know all the risks in the job, and can change jobs costlessly. Also, they point out the weak correlation between job safety and environmental hazards. They also stress that hedonic models consider a segment of the population-people with a job; children and seniors are underrepresented.

Stated preferences. Stated preferences methods (e.g., contingent valuation) ask people how much they would be willing to pay to reduce risk through a survey or interview (Hanley et al., 2007). The approach constructs a hypothetical market, in which a person buys or sells safety. The method attempts to reveal a person's willingness to pay for a risk reduction. The challenge is to make these hypothetical market realistic and relevant to people. The judgmental best estimate of the value of a statistical life was about $0.1-15.0 million for both studies (in 2007 dollars). The range of values is consistent with the high range estimates of the hedonic wage-risk model, thereby dampening the complaints of its critics. Although a survey can add information on tradeoffs between safety and income, the method has its critics. A major complaint is that people asked to answer a hypothetical valuation question that does neither puts their money on the line nor enforces a budget constraint.

Experimental auctions. Experimental auctions are a recent approach to value reductions in risk. Experimental auctions use the laboratory to sell real goods to real people within a stylized setting (see for instance Lusk and Shogren, 2007). Laboratory experiments can isolate and control how different auctions and market settings affect values in a setting of replication and repetition. Experiments with repeated market experience provide an incentive structure that allows a person to learn that honest revelation of their true preferences is their best strategy. Using demand revealing auctions (e.g., the second-price, sealed-bid auction mechanism), subjects will participate in an auction market that allows for learning as participants realize the actual monetary consequences of their bidding. The non-hypothetical auctions with market experience can improve the precision of risk valuation. For example, work in experimental markets to elicit the ex ante willingness to pay for safer food. These experiments used real money, real food, repeated opportunities to participate in the auction market, and full information on the probability and severity of disease resulting from food-borne pathogens.

Averting behavior. The averting behavior method estimates willingness-to-pay for risk based on what people pay to protect their families and themselves. People reveal their preferences for lower risk through the market for self-protection-such as smoke detectors, seat belts, medicine, bottled water, and water filters. Averting behavior methods, however, can be unreliable predictors of economic value depending on market prices and market organization (Hanley et al., 2007).

The idea people use private markets to reduce risk raises an important issue in the value of life and limb. The value of life or limb is defined as the cost of an unidentified single death or injury weighted by a probability of death or injury that is uniform across people. The willingness-to-pay approach captures this cost by revealing the unobserved preferences for risk reduction. But here is the rub. The estimates contain more than just unobserved preferences-they captures preferences for risk reduction conditional on each person's unobserved ability to reduce risk privately.

Consider an example. Suppose people have identical preferences for risk reduction from contaminated drinking water, but they differ in their ability to access private risk reduction markets. Now say each person is asked to reveal their perceived value for a collective program to reduce risk. Each person's value for this collective risk reduction is conditional on that person's private actions. Following the standard procedures to value life, it might be assumed that people with a low value for collective risk reduction are willing to tolerate greater risk. But in fact it might just be that they have access to effective private risk reduction and have reduced the risk themselves.

But why does this matter? This matters because the statistical value of life used in benefit-cost estimates is most likely upwardly biased, because it has not addressed these private actions. To see this, consider the value of life used by the US Environmental Protection Agency (EPA). The Agency's value of life, about $7 million per life (2007 dollars), is the mid-point estimate of different valuation exercises. The value is conditional on the private ability to reduce risk in the study it was taken from. To apply this fixed value to other risk reduction policies is to assume implicitly that any other study has the identical private risk reduction opportunities. That this is always the case is not obvious. Why should the market for the private reduction of water risk be identical to the market for toxic air risk? By focusing on collective risk reduction, the statistical life approach can bias the value of risk reduction, which can lead to inefficient levels of environmental degradation. Allowing a people to reveal whether they would prefer to reduce risk privately or collectively or both will elicit a more exact measure of the value of risk reduction.

The key to estimating the benefit side of rational risk policy is the Value of a Statistical Life (VSL). The concern is that the use of the VSL estimate is likely to overestimate the actual value of reduced mortality risk. Health, safety, and environmental concerns drive most new regulations promoted in Washington DC. By far, the most critical category of benefits that economists can quantify and monetize is the reduction in mortality risk, or the VSL. The greater the value for reduced mortality risk, the greater the odds the benefits of any given regulation will justify the extra costs. Recent reviews suggest that the VSL is somewhere between $2 to $8 million, from the overall range of $100K to $10 million (Viscusi and Aldy, 2003).

But is this value of reduced mortality risk misleading? In discussing how wage-risk trade-offs are estimated by the wage differential between jobs with different risks, researchers have suggested that worker heterogeneity can affect the value of reduced mortality risk. Viscusi (1992) notes the marginal worker sets the wage differential, and the inferred value of risk reduction. If this marginal worker's unobserved risk preference differs from that of the other workers, this local trade-off can be a misleading index of the required wage premium.

Consider now why worker heterogeneity might matter more to the value of statistical life than many people think. Let workers to be heterogeneous in two respects: they have unique risk preferences (i.e., they put different values on life and health), and they have unique skill to protect themselves so that they encounter different risks even if their occupation and job activities are identical. Workers select occupations of different inherent risks based on both their skill to protect and their risk preference. This means that the occupation selection is unlikely to reveal perfectly both personal characteristics. When a choice is made based upon two pieces of private information, the choice is unlikely to reveal perfectly either piece of information, although it conveys some information about both. Workers in a more risky occupation should be more skilled or more tolerant to risk or both. They need not be equally skilled or tolerant to risk due to self-protection, self-insurance, job stickiness, switching costs, irreversibility, imperfect mobility across occupations, life cycle in skills, experience, education, and safety.

The VSL is biased upward once worker heterogeneity is accounted for in both skill and risk preference (Shogren and Stamland, 2000). A worker's unobserved skill to reduce his own risk privately affects the value of risk reduction. The reason for this is that now the marginal worker is not randomly selected. Rather this worker is the person among those in the occupation who demands the highest compensation for personal risk in the job. Relative to other workers, the marginal person has either higher risk or lower tolerance to risk or both. This implies that when the marginal worker's wage differential is divided by the statistical risk in the occupation, which measures the average risk of all the workers in the occupation, the resulting VSL estimate is biased. The VSL estimate is most likely upwardly biased because the highest required wage differential among the workers is divided by their average risk. The result holds even if workers are allowed to self-select between risky and safe occupations.

These results support those who argue VSL estimates overestimate the benefits of new major regulatory decisions. An EPA Science Advisory Board's Advisory Council, for instance, worries that the estimates used in the US government to monetize the health and ecosystem effects of clean air policy are weak surrogates for the real values. Some observers have taken this a step further. They point out that EPA's "best" CAAA benefit estimate of $22 trillion is the value of total US households and nonprofit organization assets in 1990 ($22.8 trillion), and exceeds the gain in the stock market from 1970 to 1990 ($1.2 trillion). The model does not contradict their general concern that the operative value of reduced mortality risk used in public policy is high.

The value of life is inferred through real world wage-risk tradeoffs made across different occupations. Market data is used to draw out preferences for risk that are otherwise private information. The problem is that workers' choices are not just driven by risk preferences. Workers can invest effort to protect themselves from risk, and their skill to do so is private information. Workers select occupations of different inherent risks based on both their risk preference and their skill to reduce risk—and when a choice under risk is made based on two pieces of private information, the choice is unlikely to reveal perfectly either piece of information. This suggests inferences made from market or survey data might lead to biased signals about the value of reduced mortality risk, if it does not account for private information about a worker's skill to reduce risk, and to value risk reduction.

IV. Risk Perception

Determining whether the risk needs to be regulated depends on how people are willing to trade-off risks for the benefits they can generate to society. Their willingness to surrender benefits for reduced risk represents the value they place on risk reduction. Estimating this value for risk reduction is a critical component of risk-benefit analysis, now used in policymaking on environmental risk. This value of reduced risk depends in part on people's perceptions of and preference for risk (Slovic et al., 1982). People afraid of the risks they see around every corner are likely to value risk reduction more than those who live to take risks. This statement seems straightforward enough, and the logic behind it guides most economists who address environmental risk. Those at most risk who are most afraid of risk and who have the most income should value risk reduction the most.

Economists who work with risk use the expected utility framework which presumes people have well-defined preferences for risk and can form rational perceptions of risk. The working presumption is that people have a solid foundation that drives their choices, such that when they confront a risk, new or old, they are able to evaluate the odds and consequences in a systematic and predictable way. A person's stated value for risk reduction is based on a logical foundation of choice-welfare economics, and economics judges the overall economic efficiency of some policy decision. Without well-grounded preferences and perceptions, rational choice theory is weak. But psychologists and behavioral economists have documented numerous exceptions to the idea of a rational theory of choice (see Tversky and Kahneman, 1981; Arrow, 1987; Baron, 1994; Starmer, 2000). These behavioral researchers have shown how people use rules of thumb, or heuristics, to simplify their reasoning about risk. Using these rules, people react to risk in broader patterns than predicted by expected utility theory. This suggests that the standard model used to guide risk-benefit decisions is "too thin"-the model does not predict the systematic aspects of behavior under risk observed in many situations. In fact, the evidence suggests that risk preference and perceptions seem to be systematically influenced by the context of choice.

People are complicated. People use heuristics, or rules of thumb when making judgments about risk that the popular expected utility framework fails to capture. A long list of behavioral anomalies and paradoxes exist (Baron, 1994). One bias in judgment is when people overestimate low probability risks and underestimate high probability risks. Imagine a 45° line that represents the case in which the general public's subjective risk equals objective risk as defined by expert opinion. Now imagine a flatter line intersecting people's actual rank of the threats posed by different risks. People seem to inflate low risks that they have little to no control over (e.g., nuclear power) and deflate high risks that they can control to some degree (e.g., driving to work). They worry more about how and where a risk arises than its magnitude, e.g., synthetic versus natural carcinogens. This poor calibration between experts' objective opinions and the lay persons' perceptions can lead to rejection of beneficial technologies, e.g., commercial nuclear power.

Another example of a breakdown in EU theory is the classic Allais paradox (Allais, 1953). The paradox constructs a counter-example to the independence axiom that gives EU theory its empirical content-linearity in probabilities. The most common method involves obtaining a person's response to a pair of choices designed to give inconsistent answers. Allais provided the first counter-example with the following two pairs of choices:

A:	100% chance of $1 m	vs.	B:	10% chance of $5 m 89% chance of $1 m 1% chance of $0 m

and

C:	10% chance of $5 m 90% chance of $0 m	vs.	D:	11% chance of $1 m 89% chance of $0 m

If the person maximizes expected utility, then they must either prefer the pair (A,D) or the pair (B,C). Allais, and numerous other variations have demonstrated many people prefer (A,C). This suggests that expected utility theory is too thin a theory of choice under risk-people are making systematic choices that are not captured by the theory.

Some risks are more acceptable than others are. People who accept the risk of smoking or driving without seat belts may not accept the risk associated with nearby treatment, storage, and disposal of hazardous material. Voluntary risks people think they can control are more acceptable than involuntary risks they believe are outside their control. Technologies that inhibits the sense that this risk is "voluntary" are less acceptable-e.g., nuclear power. Recent research has refined this argument with the idea that space, time, familiarity, dread, anxiety, regret, time horizons, and perceived controllability drive the idea of voluntary.

The perception gap raises a potential dilemma for the regulation. Suppose experts argue that the risks from a certain product are unacceptable, while many people perceive the opposite. Does the policymaker ban the product or allow people to use their own discretion? The beef-on-the-bone ban in the UK is a good example of not leaving the decision to people. The policymaker's dilemma is to balance the tradeoff between preserving freedom of choice, and maintaining public safety. The policymaker may be tempted to step in and regulate the risk in the best interest of society. Such paternalistic action creates conflict with societies committed to consumer sovereignty-the person is best able to judge what is or is not in that person's best self-interest.

Risk perception examines lay persons' perceptions of risky technologies, and the determinants of their relative acceptability. Using risk-benefit analysis, researchers attempt to measure the welfare benefits of risky technologies. The majority of risk acceptance research has been in the area of public perception of low-probability/high-consequence technology such as nuclear power. Lay persons will not accept risk if the hazard is perceived as uncontrollable, regardless of expert opinion. For example, in the 1980s, lay persons perceived nuclear power as the number one risk to public safety, while experts ranked it twentieth¯below the risk of a household accident (see Waller and Covello, 1984). Regardless of expert opinion, during the late 1970s and 1980s, Swedish citizens perceived nuclear power risk as so unacceptable that policymakers agreed to phase out the entire industry over the next quarter century.

Another risk perception effect is when people judge a risk by its familiarity with other risks they have confronted. They base their decisions on how well what they know represents the new event. This tendency to stick with personal prejudices can cause people to ignore risks that have characteristics that they have not confronted before. A person might tend to underestimate the risk of radon because it is odorless and colorless, and nothing exists against which it can be compared. Other occasions exist when people fear the worst when given good and bad information because they seem to recall bad events. People frequently have alarmist reactions to well-publicized risks to health or the environment (Sunstein, 2002).

People also seem to place more weight on small losses than huge opportunities. They dislike losses more intensely than they like the equivalent gains. This "loss aversion" idea suggests that people treat perceived gains and losses differently in two ways. People seem to seek out risk when gambles involve loss; but to avoid risk for the equivalent gambles that involve gains. This evidence suggests that rather than thinking about overall wealth, people seem instead to judge the value of gains and losses from a status quo-a reference point. They judge risk by what they have experienced and how it affects their current standing. The context in this case is the status quo. A person's value for risk reduction then will depend on the reference point and the nature of the gains and losses of the lottery.

Loss aversion has been used to explain the unpredicted gap between the Willingness-To-Pay (WTP) and Willingness-To-Accept (WTA) measures of economic value. Under rational choice theory given small income effects and many available substitutes, the WTP and WTA for a good should be equal and near the market price. But evidence suggests that a significant gap exists between WTP and WTA, maybe up to a tenfold difference. Critics of rational choice point to this gap as evidence that standard economic theory has failed, and that people instead are motivated by loss aversion, or a fundamental endowment effect-people are less willing to surrender a good they are endowed with relative to their eagerness to acquire the same good.

In addition, how the risk is "framed" affects choice in ways unpredicted by expected utility. If a person has well-formed preferences and values, a choice between two options should be independent of how these options are represented or described. But again, psychologists show how choice and values can be influenced by different ways of framing an identical problem (see Tversky and Kahneman, 1981). A famous example illustrates the importance of framing effects. Answer the following three questions:

Q.1: Which of the following options do you prefer?
A. A 100% chance to win $30
B. An 80% chance to win $45

Q.2: This is a two stage game. In the first stage, there is a 75% chance the game will end with no prize and a 25% chance to move to the second stage. If you reach the second stage you have a choice between:
C. A 100% chance to win $30
D. An 80% chance to win $45

Q.3: Which of the following options do you prefer?

E. A 25% chance to win $30

F. A 20% chance to win $45

The choice must be made before the game starts. Please indicate the option you prefer.

Q. 2 and 3 are identical in odds and rewards, and should produce identical choices from a person. But instead, people treat Q.1 and Q.2 as the same, and not Q.2 and Q.3. People prefer option C in Q.2 and option A in Q.1, while they prefer option E in Q.3. This is the so-called "certainty effect"-an option framed as a "sure-thing" appears as attractive as a certain option. All this suggests that framing matters to risk policy. Studies confirm that regulators should pay as much attention to how they provide the information as to what information they provide. People also place varying levels of trust in information on environmental risk according to the source.

People also do not deal well with ambiguity in risk. Ambiguity implies that the probabilities of bad events are uncertain—the odds of a bad event might range between 1% and 10%. Ambiguous risks dominate most decisions people must make, e.g., investments, health care, exercise, and food. Also, while the expected utility model assumes that people handle ambiguous risk, consider the following example. Suppose there was the choice between choosing a ball from an urn with a known number of colored balls and an urn with an unknown number of colored balls in a payoff situation. Most people prefer drawing from the urn with the known distribution. This is the Ellsberg paradox (Ellsberg, 1961). Even in experiments using professionals who deal with risk on a daily basis, actuaries, business executives, life insurance executives, and MBA students, were averse to ambiguous risk (Fox and Tversky, 1995).

Finally, people also reverse their preferences. A person is said to reverse preferences when that person's ranking of two gambles is different from the selling prices the person assigned to each gamble. A person prefers lottery A to B, but he puts a greater monetary value on B than A. The preference reversal phenomenon has been duplicated in numerous settings, including with real gamblers in Las Vegas, and by skeptical economists doubtful of the earlier work by psychologists. (see Lichenstein and Slovic, 1971; Grether and Plott, 1979).

Below is a classic example of the lotteries leading to a preference reversal:

Q.4 Which gamble do you prefer, A or B?

Gamble A: 35/36 chances to win $4
1/36 chance to lose $1

Gamble B: 11/36 chances to win $16
25/36 chances to lose $1.50

Q.5 Suppose you own both gambles. What is your selling price for:

Gamble A: $________
Gamble B: $________

Expected utility theory requires one to be consistent across preference rankings and monetary values. If you preferred lottery A to B, and assigned a higher $ value to B than A, you have reversed your preferences.

The logical inconsistency is this: suppose you preferred A to B, and valued A at $2 and B at $8. Now if your statements are a true indication of your preferences, you can be turned into a "money pump" in three easy steps: (1) you can be sold B for $8, (2) you can be asked to switch B for A because after all you preferred A to B, and then (3) A can be bought back from you for $2. Now you have neither gamble, and you lost $6 (–$6 = $2 – $8). Efforts to eliminate preference reversals have been successful when stakes are large and when people are made aware they can be a money pump (Chu and Chu, 1990). Since these circumstances are less likely to be observed for environmental goods, preference reversals have led some researchers to conclude that standard environmental valuation exercises and surveys are unreliable, and a poor guide for rational risk regulation.

Risk perceptions matter to environmental risk policy. If a person's stated values for risk reduction are inconsistent with their underlying preferences, society has less information to use to judge the relative net benefits of one environmental policy over another. If values are context specific so that they change with the policy, then two policies with risk-benefit analysis cannot be compared because it would be like comparing apples and oranges. Economists maybe cannot rely on standard risk-benefit analysis to guide policy if values always depend on the context.

Failure of EU theory can affect other aspects of strategic risk policy as well. For example, the equilibrium solution called subgame perfection and backward induction gives the key concepts to many environmental contests that involve risk. Subgame perfection rules out incredible threats on-and off-the equilibrium path by requiring each player (1) to look forward and think about every possible subgame that could be reach in the game tree of the contest, (2) to guess what players would do in each subgame, and (3) to work backwards, using those guesses, to decide what to do at the start (see for instance Camerer, 1997). Each player looks ahead and reasons backward to reduce the number of likely equilibria in the contest. The subgame perfect equilibrium is a set of strategies, one for each player, such that in any subgame the strategies form a Nash equilibrium. Equilibria that are not subgame perfect are argued to be less likely to occur, and should be ruled out as possible outcomes.

A poor correspondence between predicted and observed behavior in gaming experiments motivated researchers like Camerer (1997) to argue for a new "behavioral game theory." Game theorists would benefit by taking a middle-of-the-road perspective between over-rational equilibrium analysis and under-rational adaptive analysis driven by pattern recognition from empirical data. This approach has three steps: begin with a situation in which game theory has a prediction; if actual behavior differs, think of explanations of the unpredicted behavior, and then extend the theory to incorporate these explanations. Three methods are suggested to extend game theory-non-expected utility theory (e.g., prospect theory), learning (e.g., updating beliefs), and pregame theory (e.g., mental models of what people are thinking about). A maintained belief in behavioral game theory would suggest that the endogenous timing model might need to be overhauled with new behavioral restrictions that will serve to close the potential gap between theory and observation.

Camerer (1997) considers three areas in which violations are present-social allocations, choice and judgments, and strategic situations. Social allocation issues occur because the basic assumption of self-interest fails under many experimental settings. Most efforts sidestep the issue by assuming that one's utility function can include the utility of others. Choice and judgment issues arise when people do not perceive the game consistently. Two violations are at issue-behavior changes when the description of the game changes even though outcomes do not change, and overconfidence about one's own relative skill. Strategic situations issues emerge because the strategic reasoning principles used in game theory may be irrelevant to the average person-e.g., irrelevance of labels and timing, iterated dominance, and backward induction.

A different perspective exists on how to close the potential gap between theory and observation in rational risk policy—lack of institutional context to reward competition over trivial differences in measurable performance. Economic models presume absolute payoffs motivate behavior-even if a trivial difference exists between measurable performance and the associated payoffs from optimal and suboptimal behavior. A person is presumed to be purposeful as that person finds it worthwhile to capture the extra unit of satisfaction, however small. But evidence from the laboratory suggests that people are not so exact in their ability or willingness to discern and react to trivial differences in payoffs. A person is more likely to misbehave the smaller the gap between optimal and suboptimal payoffs. Trivial payoff differences do not punish deviations from optimal behavior, regardless of whether utility is assumed ordinal or cardinal. A researcher must choose either to reformulate the model to include behavioral extras in the utility function (e.g., altruism, envy, spite, errors), or to impose an institutional context that provides high rewards for trivial differences in measurable performance such that self-interest is rewarded, even encouraged.

Other researchers have taken the second path. They consider whether tournament incentives can close the gap between predicted and actual behavior in a game. In the wilds, tournaments have emerged as the exchange institution that pushes high-ability people to exert the extra effort needed to win when the difference between winning and losing is measured in fractions of seconds or points or parts per billion. Tournaments with nonlinear payoffs that increase at an increasing rate are designed to reward a trivial numerical deviation between optimal and suboptimal behavior by a substantial difference in payoffs (see for example Ehrenberg and Bognanno, 1990; Frank and Cook, 1996). Many sports like track-and-field, tennis, or golf, use a nonlinearly increasing reward system in which the winner's payoff is twice that of the runner-up; performance pay in top management positions uses a similar reward structure. A tournament incentive scheme with nonlinearly increasing payoffs mimics a hierarchy of exchange institutions that reward rational self-interest by providing a reason to bother looking ahead and reasoning back despite the human predilection to ignore unlikely events.

The gaming tournament examines how three key design features affect behavior-nonlinear payoffs, structure to the decision frame, and more time to think about strategy. The results suggest that tournament-style incentives can improve the correspondence between theory and behavior, but that more time-to-think is the driving force that closes the gap. This result contrasts findings in two prior gaming tournaments, in which rational self-interested behavior dominated even though time was limited.

Experimental evidence suggests an isolated person acts outside the ropes of economic theory. It has been discussed how such a person reverses preferences, makes different bids and offers for the same good, and puts too much weight on initial endowments. But people interact with other self-interested people in an active exchange institution. These institutions arbitrage the irrational decisions of people by rewarding those acting rationally or learning to act rationally. Economists question the importance of isolated anomalistic behavior to explain behavior in thick, well-functioning markets and economic systems.

But markets for key goods and services are thin or non-existent; they lack sufficient arbitrage opportunities that can induce rational economic behavior. Most environmental assets, for instance, lack well-defined exchange institutions, and as a consequence, behavior in the allocation and valuation of environmental goods is more likely to be irrational. This observation calls into question the reliability of nonmarket valuation surveys that have emerged to understand behavior relating to these goods. The typical survey asks the unsocialized person to imagine an exchange institution, visualize the details of both that person's participation and that of others in it, and then state the resulting one-time value for a nonmarketed environmental good. While these surveys generate numbers, the hypothetical institutions are thin, and provide the undisciplined and uncontested values that raise fears that irrational behavior is the rule and not the exception. But most people participate in both thick and thin markets simultaneously. The key question is whether the rationality induced from arbitrage in a thick market could spill over to behavior in a thin market. If so, nonmarket valuation surveys might be improved by an explicit connection to an active market with arbitrage. Cherry et al. (2003) provides some experimental evidence of such rationality spillovers-induced rationality in an arbitraged market can spill over to a second non-arbitraged market that would otherwise consist of irrational behavior.

Preference reversal provides the motivating example to illustrate the potential for rationality spillovers from arbitrage. Economic theory presumes that a person's preference orderings and expressed valuations are consistent, but laboratory evidence suggests otherwise. Isolated people reverse their preferences despite inducements such as greater rewards, different presentations, training, and record keeping. Arbitrage and the socialization created appear to stop the phenomenon. But will the rationality induced in a market with arbitrage spillover to a second market without arbitrage?

An experimental design that addressed this question used a computer program to simulate two independent markets (#1 and #2) that were simultaneously open, in which one market arbitraged preference reversals and the other did not. Four treatments were considered. Treatment 1 was the no-arbitrage baseline—both markets #1 and #2 had real money lotteries and no arbitrage. In treatments 2, 3, and 4, market #1 was held constant-a real money lotteries with arbitrage (after round 5). Market #2 varied across the treatments: (a) real money lotteries without arbitrage in treatment 2; (b) hypothetical money lotteries without arbitrage in treatment 3; and (c) hypothetical environmental lotteries without arbitrage in treatment 4. At least 41 people participated in each treatment for a total of 160 subjects.

All treatments had 15 trials. For each trial, subjects were asked to make decisions in the two markets #1 and #2. Each market had two states of the world-a high probability/low payoff lottery and a low probability/high payoff lottery. Preferences over lotteries were obtained, and buying and selling prices elicited, using a variation of the random draw pricing procedure.

In the market with real money lotteries, each subject was endowed with a money balance and lotteries were bought, sold, and played. If the indicated value exceeded a randomly determined reservation value, the subject bought a lottery, and the outcome was determined by a random draw with the money balance adjusting by the winnings or losses. If a subject did not purchase a lottery, the money balance remained unchanged. If the situation was hypothetical, subjects were not endowed with a money balance, did not face a budget constraint when indicating values, and lotteries were not exchanged or played.

In an arbitraged treatment, all possible rents from subjects reversing their preferences were extracted in three steps. The market (1) sells the least preferred and most valued lottery to the subject; (2) trades the least preferred lottery for the most preferred lottery; and (3) buys the most preferred and least valued lottery from the subject. The subject is left with no lotteries and a monetary loss equaling the difference between the indicated values of the lotteries. Note that the arbitrage mechanism was not active until after the fifth round. Under a non-arbitraged treatment reversals were left unchecked for all rounds.

Compare the reversal rates in market #1 to the non-arbitrage baseline. Compare the reversal rates in market #2 to the baseline to see evidence of rationality spillovers. The robustness of rationality spillovers is examined by varying the lotteries in market #2. The results show that arbitrage impacts rationality. The non-arbitraged reversal rate is about 33% and persists over the 15 rounds. Treatments 2, 3 and 4 introduce arbitrage after trial 5. Prior to arbitrage, the reversal rates coincide to the baseline at 34%. Rates decrease once arbitrage is introduced, falling below 20% after three rounds, below 12% after six trials of arbitrage, and to about 5% in the final trial. Arbitrage induced more rational behavior.

Rationality spillovers do exist. In treatments 2, 3 and 4, the initial five rounds mimic the baseline results-reversal rates being about 33% for the money treatments (2 and 3), and 27% in the environmental treatment (4). Once arbitrage is introduced in market #1, reversals in market #2 decrease. Reversal rates were about 20% after 11 trials, and 10% after 15 trials. Rationality spillovers were strong in the hypothetical treatment, and weaker in the environmental treatment. Subjects adjusted valuations rather than preferences, which indicates the potential for rationality spillovers to improve nonmarket valuation. The results from market #2 suggest that rationality induced by arbitrage can spillover to non-arbitraged situations, and that such spillovers occur whether the non-arbitraged situation is real, hypothetical, or environmental.

Isolated people fail to behave in accordance with the classic economic paradigm of utility maximization. Such irrationality can be overcome if people receive information and discipline from an active exchange institution. Herein evidence has been presented on how an active exchange institution can generate rational behavior spills over to a thin or hypothetical market. Rates of preference reversals in both markets declined as a result of arbitrage in one market. Rationality spillovers existed whether the non-arbitraged market used real, hypothetical, or environmental lotteries. This result suggests that the rationality spillover phenomenon can be used to improve nonmarket valuation techniques by moving beyond one-shot surveys that fail to contest responses to a simulated exchange institution that provides repetitive market-like feedback. If the effects of market discipline can spillover to a nonmarket valuation setting, the stated values might reflect the landscape and allow for improved allocation decisions regarding environmental assets.

V. Regulating Risk

We have focused defining risk, how people make choices under risk, how they value risk, and how all of this is tempered by risk perception. Managing and regulating risk in society requires regulators to integrate assessment, psychology, economics, and political factors. Risk management policies are complicated by numerous factors: scientific complexity and uncertainty, political and economic pressure from special interest groups, financial abilities to clean-up disposal sites, jurisdictional disputes, unresolved liability, and variations in local, state, and federal policy goals. Successful strategies to manage risk should address which risks are to be confronted now and in the future, how these risks will be controlled in a cost-effective manner, and how who faces what risk is balanced.

Consider several ways to select the risks that are chosen to face. A common first reaction is to want to set a target of zero risk to society. Regulation in the US, such as the Delaney Clause of the Food, Drug, and Cosmetic Act that prohibited the presence of any known carcinogen as a food additive in processed food, is a zero risk regulation. As science becomes better at measuring small amounts of trace chemicals that are potential carcinogens, the zero risk approach is restrictive. If almost everything causes cancer of some form, what can be eliminated? The costs to hit a zero risk target increase at an increasing rate-it becomes prohibitive. Some actions and activities can be so risky that society should ban their use, resulting in zero risk because they are gone from society. But in most cases for goods that are needed and wanted, reasonable people recognize that zero risk is a noble yet unachievable goal.

The next wave is for society to set an acceptable risk target that can be reached using current or new technology. Technology-based standards are a centralized process of setting permissible levels of contamination or building codes. People or firms (companies) who ignore these standards would be punished in civil or criminal court. Examples include uniform limits on total emissions per day or year, emission per ton of input used in a production process, and type of equipment used in production, such that it is the best available control technology. One argument advanced by proponents of technology standards is that technology-based engineering decisions that construct a uniform threshold of acceptable risk have to measured; costs and benefits are left unmeasured. Many people now see this as the major problem with standard-based risk reduction strategies, but uniform standards are likely to be inefficient.

A third wave is to promote cost-effective risk reduction. Dollars now enter into the picture. Costs matter. Cost-effectiveness allows regulators to set a target and then asks that people be allowed to find the most cost-effective path to achieve the target. The idea is to take the public's preferences and perceptions of risk into consideration. This can be accomplished through open meetings in which regulators and the public set health and safety targets. Cost-effectiveness attempts to find the least cost method to achieve the goals. One advantage of cost-effectiveness is that it does not have to measure the benefits of the target. The method maximizes lives saved given a fixed budget in which assumptions on values are built into the model.

If the trade-offs involved in risk management are to be considered but costs or benefits are still not to be measured, regulators can address risk-risk trade-offs, or comparative risk analysis. Risk-risk analysis compares how one risk is traded-off for another. For example, an energy policy that would switch to more nuclear power and less coal power would shift the nature of risk to radiation rather than climate change. A shift to more hydropower would shift the risk toward more endangered species protection. The framework requires estimation of the tradeoff between consumer health risks and substances that offer a direct health benefit. The health benefits of drugs, exercise, and diet, for example, fit into this framework. The benefit of the risk-risk framework is that regulators can convert health outcomes into fatality risk equivalents, which might allow more meaningful comparisons than a risk-dollar tradeoff.

Finally, policymakers can use risk-benefit or cost-benefit analyses. Here dollar measures of both costs and benefits, and a direct comparison of the tradeoff between risk and dollar benefits are required. As discussed, economists have spent considerable effort to determine the value of reduced risk. Cost-Benefit Analysis (CBA) can be used as a tool to measure the economic efficiency of a regulation. CBA attempts to measure the costs associated with the risk regulation and the subsequent welfare benefits from a risk reduction. The costs of differing policy alternatives are then compared with their benefits to determine if and to what extent the risk will be reduced. The goal of cost-benefit is to maximize economic efficiency and make the resulting risk reductions as large as possible.

Controversial aspects exist in CBA (Hanley, Shogren and White, 2007). The value of risks to life should be addressed. The appropriate discount rate remains a nagging question. Exponential discount rates place less weight on the future. Also, equity and distributional questions must be confronted-whose risk will be reduced and who will pay? Equity criterion spreads out the costs and benefits of risk based on some subjective measures to weight which gets what for which price. Risk can be distributed equally among people, or it can be progressively or regressively distributed based on, say wealth.

Environmental risks to children illustrate hard questions over whose risks should be being reduced. Evidence suggests that children face disproportionate health risks from environmental hazards. These unbalanced risks stem from several fundamental differences in the physiologies and activities of children and adults. As children develop, their digestive, nerve, and immune systems are more susceptible to toxic pollutants and other environmental hazards. Children eat, drink, and breathe more for their weight, and spend more time outside exposing themselves to greater amounts of contamination and pollution relative to their weight than adults. Children also face potential exposures over their entire lifetime. They are also less able to recognize and to protect themselves. All this suggests that children require special attention when dealing with environmental risk.

Based this argument, President Clinton unveiled in April 1997 a new executive order to protect children from environmental risks. The Order directs the federal government to safeguard children from environmental threats through more policy, better research coordination, and more federal regulatory analysis. All US federal agencies must now make the protection of children a high priority when implementing their statutory responsibilities and fulfilling their overall missions. Agencies promulgating major regulations that may have a disproportionate impact on children now must evaluate how regulation could affect children's risk, and then explain why the planned regulation is preferable to alternative actions that might have more cost and less risk to children.

This forces agencies to ratchet up their regulatory standards, with a corresponding increase in the costs and burden of regulation. The pressure to raise standards across the board may generate criticism from industry and other groups who assert analysis of impacts on children can lead to bad decisions, i.e., Superfund cleanups based on the exposure of children to toxins, and analytical flaws in the public health data supporting recent Clean Air Act proposals on ozone and particulate matter. The additional burden may further delay the regulatory process, and add resource demands to agencies confronting tight budgetary constraints.

Regulators have many tools at their disposal to reduce risk, either to adults or to children. They can impose mandates, liability rules, pollution taxes and subsidies, create new markets, and use informed consent through risk communication. Taxes and markets have been discussed previously. Risk communication strategies are now considered.

The major benefit of risk communication and informed consent is that people are allowed to make informed choices based on preferences toward risk rather than uniform government bans or regulation. The risk manager must be sure that the information consumers have will result in more accurate private decisions regarding risk. The language of the hazard warnings seems to maximize political interests rather than advancing the primary objective of informing consumers and enabling them to make better decisions. By ignoring fundamental economic and psychological concepts of decision-making under risk, warnings will not convey the information necessary for consumers to make sound choices regarding risks and precautions.

But regulators and the public must also be aware that risks can be regulated by being transformed and transferred elsewhere. Transferable risk implies that people protect themselves by transferring the risk through space to another location, or through time to another generation. Most environmental programs do not reduce environmental risks by cutting the mass of materials used or causing them to accumulate in the economy. People select a technology that transfers a risk which creates conflict and induces strategic behavior. Some nations and states reduce their air pollution by building tall stacks such that the winds carry the emissions to those downwind. Some local governments ban toxin storage within their jurisdictions, thereby shifting the problems elsewhere.

Markets are a critical tool to manage environmental risk. Markets are used by all in everyday life, and by some without them knowing it; others even champion their use. Most people appreciate the choices and opportunities that markets provide to families. Markets are embraced daily-voluntary exchange regulated by competition is a big part of how lives are lived, and almost everyone likes choice.

Markets should be appreciated by all for another reason. Many scientists dedicated to reducing risk believe that markets are the most effective tool humans have "discovered" to organize and coordinate the diffuse sets of information spread throughout society. Markets use prices to communicate both the laws of nature and the laws of humankind. Prices send signals to coordinate decentralized economic decisions efficiently. Markets succeed when prices define the trade-offs faced such that resources are allocated to their highest valued use in society. But markets can fail too. Society confronts unacceptable health and safety risks when a market price fails to communicate social desires and physical constraints. Prices might mis-state the economic value of a reduction in health risk from an environmental threat, or prices might not even exist to signal the value. Left alone, a market might produce too few or too many goods or services. A wedge is driven between what a person wants and what society.

Even when markets are a problem, they can be the cornerstone of the solution. Rather than turning to more government regulation or stakeholder-participation processes, society can adjust existing markets or create new markets to manage risk. A market is a tool whose precision depends on how society defines the rules to regulate its behavior—i.e., property rights, liability, information. People who are unhappy with the prices that a market produces need to see the connection between the signals sent and the underlying rules that are defined. Work can be done together to change these rules, and markets should be viewed as a slave not as a master.

The market as a "third way" to manage risk works to create new rules to address the failings of existing markets. Except in those cases in which government intervention is superior to markets, market-based policy serves as a ready substitute for technocratic or stakeholder processes, which have their own set of successes and failures. For instance, stakeholder processes involve those who are affected—those who are indirectly affected through nonmarket avenues are not represented. The processes do not register the external spillovers resulting from stakeholder gains or losses.

Other kinds of real risks need to be considered-financial risks, for instance-in which people are all much less willing to delegate decision-making authority to government or stakeholders. The fact that people have been creating and using markets to manage risks for the last three centuries should send a signal of their power. In fact, the market has a powerful democratizing effect on risk management decision. The question should be asked-what system of decision-making involves greater public participation than the market?

Also the odds and consequences of uncertainty in financial risks are greater than those of most health and environmental risks. The relative stakes per percentage risk are much larger in financial risks than in environmental risks even though this is not much thought about. The government is not asked to regulate stock prices, although many people ask why is it the government is allowed to manage social security funds given the paltry rate of return on investment. An equivalent percentage reduction in financial risk relative to environmental health risk would yield more return in present value terms even if a statistical life is valued at $5 million. More financial wealth, some of which will be invested in health, might be more cost-effective than a direct reduction in the environmental risk.

Insurance is a prime example of how markets are used to manage certain types of risk. Imagine driving a car without it; imagine allowing a teenage son to drive the car without it. Insurance works from the law of large numbers. These markets pool together many identical and independent risks, and spread the risk around the people in the market. Insurance can separate risks into distinct pools based on a person's lifestyle, and can control how people behave when no one can watch them through deductibles, co-insurance, and exclusions of coverage. Insurance markets allow a person to reallocate some of their wealth from the good days when everything goes right to the bad days when everything goes wrong.

Securities are another example of market risk reduction. Securities allow a person to reduce risk by slicing big risks into small pieces. This allows for diversification-many people can hold a small part of many risks without substantial exposure to any one risk. People can also use securities to hedge their bets. Say for example, a person fearing risk from natural disasters (e.g., hurricanes, earthquakes) can offset the risk by buying shares in companies that benefit from such disasters (e.g., construction companies).

Consider the role of markets, for instance, in how children's health risk is managed-this is a current policy initiative at the US EPA. Suppose society wants to reduce the risks that a child's life chances will suffer because the child's caregiver became ill from exposure to an environmental hazard. The caregiver may value the opportunities that a higher family income can provide for the child. There might be temptation to propose some regulatory action to ensure that income, time, and stress were maintained at pre-sickness levels. But many people have already reduced this risk through the market. They buy disability, health, and life insurance so as to help maintain a child's life chances. While not perfect, these markets reveal in part what caregivers are willing and able to pay to reduce the risk to their children.

Markets also force people to make a distinction between rhetoric and action in the context of risk. Everyone has opinions. Markets help to separate those opinions that people are willing to back up with real resources from those that they are not. The discipline provided by the market forces people to relate their choices to the choices of others and to the consequences the sum of these choices produce. This role is crucial in risk reduction. Ample evidence from laboratory markets suggests that the difference between stated and actual choices can be significant. People overstate their real willingness to cooperate or to contribute to the public good when asked a hypothetical question-and in many contexts, understanding the gap between actions and intentions can make all the difference between whether a risk reduction project passes the benefit-cost test. Markets do not sustain cheap talk backed by either deep or shallow pockets.

Here is an example. Consider the evidence from laboratory markets designed to reveal the stated and actual benefits of using or avoiding irradiation to reduce the health risk from the parasite *Trichinella*. The US Food and Drug Administration approved the irradiation of pork, which has been shown to reduce the viability of *Trichinella* organisms by over 99%. Several experiments have been designed by the authors and their colleagues to judge whether stated willingness-to-pay matches up with what people paid. The evidence suggests that these parameters do not match, and that this gap between intentions and actions might be context-specific. This suggests that the stated benefits to use or to avoid food irradiation are exaggerated in surveys, and that it seems most worthwhile to pay attention to research using actual field trials in retail markets.

Whether markets will flourish as a tool to manage environmental and health risk needs to be considered over decades of time. Markets to trade pollution permits are a case in point. Conceived in the 1960s, tested in the 1970s and 1980s, and implemented in the 1990s, discussions of tradable pollution permits and rights are now commonplace. Emission markets work by assigning property rights to pollute. These rights create value to something that was otherwise a free good, e.g., clean air or water. The most visible example is the acid rain trading program that reduced sulfur dioxide emissions by 50% at one-half to one-third of the cost of a command-and-control approach. Such success stories raise the costs to policymakers who neglect how effective markets can be at managing risk to society.

Even climate change policy has rallied around the "carbo" market-that is the market for carbon emissions, as an integral part of the cost-effective risk reduction strategy. The US has proposed creating an international market to trade carbon emissions. This carbo market would allow buyers the flexibility to find the low-cost carbon emissions from around the world. Estimates suggest that a market would cut the costs of reaching the Kyoto targets by between 50% and 80%. The interesting twist here is the biggest advocates for carbon markets are non-economists. In contrast, economists question whether the property rights regimes could be constructed such that the market would function as predicted.

The carbo market could reduce the costs to reduce risk through mitigation. But people also reduce risk privately through adaptation. Markets help to facilitate these choices. People adapt through the market by investing in actions to reduce the probability that bad events occur, and to reduce the severity of a bad event if it does occur, or both. These private self-protection and self-insurance markets affect how a person perceives the value of a collective project aimed at reducing risk that can be privately addressed. Again, markets matter for managing risk because human behavior and economic parameters help to determine the degree of risk.

A key issue now emerges when one acknowledges that people already use the market to reduce risk. This suggests that economic behavior plays a big role in the technical assessment of risk. If markets affect choice, and choice affects risk, then the traditional risk assessment-risk management bifurcation is open to challenge. This is because even if an environmental hazard applies to everyone, the actual risk might differ across people and situations given their access to private markets. Now, risk assessment is a function of both natural science and behavioral parameters, like relative wealth and prices, and risk assessment that does not incorporate this market information can be biased-it can overestimate the risk to those who can adapt, and underestimate the risks to those who cannot. Market actions and reactions to risk must be addressed head on in risk assessment.

The New York Times reported sometime within the year 2000 that for 5000 years the best humans could do was to increase their life expectancy by 5 years. About 200 years ago something changed-and since then Western culture has witnessed a 30-year increase in life expectancy. How can it be a pure coincidence that it was around the same time that Adam Smith's classic work on the power of the market (*The Wealth of Nations*) was published? For two centuries scientists have noted that the market is one of the best ways to organize diffuse sets of information and to direct motivations in society. Markets avoid the risk that someone someday might decide to use a democratic participation stakeholder argument to wrestle control over the savings and pensions that many people now seek to achieve with respect to health and environmental risk.

The market is a process of discovery. Markets allow the creation of more wealth, that in turn allows the creation of more health, and even when one market fails, a new market can be constructed to manage the risk. Markets can make good risk policy better by allowing for the flexibility to reduce risk cost-effectively. Rejecting market-based solutions to risk requires those critics to uncover a logical difference between financial risk and health and environmental risk-a difference so logical that a politician would be unsuccessful in arousing public support for treating them the same. No system to reduce risk is universally preferred. Markets have a leading role to play in it is chosen to reduce risk and aim for substantiality. But it must be remembered that markets work for people and not the other way around. Identifying when and where potent markets can be created or corrected to reduce risk is a major task for all.

VI. Concluding Remarks

Environmental risk is endogenous. Environmental protection requires understanding the nature of environmental risk, how people perceive and react to this risk, and how collective action can help or hinder private actions. Understanding basic economic behavior under risk can help to make decisions to control risk more effective—reducing more risk for more people. Knowing how to assess risk, whether people make risky choices with reason or at random, what people are willing to pay to reduce risk, and what institutions exist to control risk, can help better decisions to be made on how to save lives and reduce injuries.

Risk is endogenous when private citizens can affect collective risks through costly economic investments. Economics has a responsibility to convince the natural sciences to connect mind to matter by including economic parameters in their core frameworks that address environmental risk. Defining the environmental thresholds of human and ecosystem health that underpin risk reduction policies is critical for more cost-effective action. Human actions and reactions to nature have a role in determining the risks that shape lives, and understanding how people react to and protect themselves from risk can again result in saving more lives at less cost.

Why should natural sciences go through all the trouble to incorporate this economic link? The estimated value of collective environmental protection is biased otherwise, and benefit estimates in CBA are biased. Consider, for instance, sexual behavior and the risk of AIDS. Standard epidemiological practices treat a person's decisions concerning frequency of contact and number of partners to be independent of the prevalence of the disease. If we assume people choose their own risks based on the odds faced and what they can do to reduce these odds, economic circumstances can be identified under which these private actions will affect the spread of AIDS in the population. In another example, the gains from reducing the risk of lead poisoning in US children double when the parents' decisions to reduce exposures and body burdens are accounted for. Environmental health research should address economic influences. A good example is the nine-fold increase in calculated benefits of a well-functioning wetland acre (average) following from the inclusion of the behavioral interactions of economies and ecosystems.

A non-economist can interpret separability as saying that nature sets the pace and that people react and respond, but do not alter its everyday workings. This perspective places economics on the sidelines during the creation of environmental policy. Rather than opting for great tractability and the appearance of specificity, economists will have more opportunities to participate in environmental research and policy if they make the least arbitrary and most coherent set of modeling choices. With but few rather exceptional cases, assuming non-separability represents this set for endogenous risk and the natural environment. The approach may make economists more like ecologists who lack broad generalizations, but they will be less arbitrary and will remain coherent.

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