

SESSION III

VALUING RISK REDUCTIONS USING DIFFERENT VALUATION METHODS

Valuing Pathogenic Risk: Methods, Skill, & Rationality

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Introduction

Constrained budgets and increased fiscal accountability prevent a policymaker from reducing all foodborne risk to all individuals. Deciding which risks to reduce and by how much requires evaluation of each new or revised regulation. Comparability of value across all sectors of the economy requires that policymakers rank regulatory alternatives in terms of a common unit. Arguably, the most common denominator is money, or monetary equivalence. Risk valuation systematically evaluates each regulation by estimating the monetary value—both benefits and costs—of a reduction in risk from unsafe food.

Here, we explore some issues in how rational people might value a reduction in risk from foodborne pathogens. 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 often not bought and sold on the auction block. These goods rarely if ever enter a private market, and remain unpriced by collective agency action. Stores and restaurants often do not like to market “safer food” because to do so would suggest that their food might otherwise be “unsafe.”

Valuing risk reductions requires that we value death and illness. These efforts give rise to the loaded term: “the value of life.” The idea of a monetary value of life, or more correctly the value of reduced mortality risk, raises more than a few eyebrows (see Schelling, 1968; Viscusi, 1992). Ethical and moral beliefs often force a person to balk at the idea. But our everyday choices put a value on life, whether we explicitly quantify it or not. Whenever a policy change is enacted or whenever the status quo remains, life and limb are implicitly valued. For example, a North Carolina hospital once refused to spend \$150 per health care worker for an inoculation against

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hepatitis B. Given the workers odds of catching the disease, the hospital had implicitly placed a relatively low value on life. Nothing is lost by explicitly examining the value of reduced statistical risk.

How do we value a reduction in risk? One straightforward answer:

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

Rational risk policy says that a person's value for a risk reduction equals his or her maximum willingness to pay to increase the chances to stay healthy, conditional of his previous private actions to reduce risk. For example, suppose a person was willing to pay \$6 to reduce the risk of death to 1 life in 1,000,000 from 4 lives in 1,000,000—a 3 in 1m risk reduction. The value of life is then \$2,000,000 (= \$6 / [3/1,000,000]). If the person was willing to pay \$0.60, the implied value of life would be \$200,000. This willingness to pay is called the *option price*. The option price is the maximum a person is willing to pay that keeps him indifferent between the gamble and the next best alternative.

What methods exist to actually measure the value of risk reduction? 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. *The human capital 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 often calculated as what the individual contributes to society through the net present value of future earnings and consumption. The human capital approach has an advantage in that it is actuarial, i.e., it uses full age-specific accounting to evaluate risk reductions. A major drawback of the approach is that it assigns lower values to the lives of women and minorities, and zero value to retired individuals. The approach also lacks justification based on traditional economic welfare theory. For this reason, economists have downplayed the human capital method in favor of the willingness-to-pay approach (see, for example, Buzby et al., 1999).

Economists have advocated the *willingness-to-pay approach* since it is based on the theory of welfare economics. 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 he 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. And although far from perfect, economists argue that the willingness-to-pay approach is preferable to the alternative—many believe it is better to have a rough estimate of a well-grounded theory than a precise estimate of a questionable one (see, for instance, Kuchler and Golan, 1999). One can reveal this value indirectly by teasing out the implied willingness-to-pay values from real choices within market settings or one can directly estimate values by asking people what they would be willing to pay for a change in risk. See Freeman (1993) for a good general overview on non-market valuation, and see Caswell (1995) for specific case studies using standard valuation methods for food safety work.

In what follows, we quickly review the key methods used to value risk. We concentrate mainly on two key behavioral underpinnings on the value of food safety—the hidden skill and debatable rationality of the people who confront pathogenic risks. We explore how skill affects the value of reduced risk in indirect methods, and we consider how presumptions of rationality in direct methods compare to and can be modified by exposure to active exchange institutions.

Indirect Methods: Risk and Skill

Valuing risk indirectly is often done in two ways—exploring the wage-risk tradeoffs people make, and exploring the expenditures made on averting behavior, or self-protection. Wage-risk tradeoffs 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. 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 tradeoffs 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 tradeoff is thus determined, other job attributes held constant. A review of the early (1974-1983) empirical results of the hedonic wage-risk model indicates that value of statistical life estimates fall in two ranges—\$450,000-\$720,000 and \$4-\$10 million (in 1990 dollars). Wage-risk studies set the value of a statistical life between \$900,000 and \$6,800,000 (see Viscusi, 1993). 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 only a segment of the population—people with a job; children and seniors are under-represented.

The averting behavior method estimates willingness to pay for risk based on what people actually 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. The current estimates of the value of life range from \$0.46 million to \$0.61 million (in 1986 dollars) (see Fisher et al., 1987; Viscusi, 1993).

The idea that people can use private markets to reduce risk themselves raises an important issue in the value of life and limb. The value of life or limb is usually 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 previously unobserved preferences for risk reduction. But here is the rub. These estimates actually contain more than just unobserved preferences—they capture 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 food supplies but they differ in their ability to access private risk reduction markets. And now say each person is asked to reveal his or her value for a collective program to reduce risk. Each person's value for this collective risk reduction is conditional on his or her private actions (see Ehrlich and Becker, 1972). Following the standard procedures to value life, one might assume that people with a low value for collective risk reduction are willing to tolerate greater risk. But in fact it just might 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 key to estimating the benefit side of rational risk policy is the value of a statistical life (VSL). Of concern is whether the use of the value of statistical life estimate overestimates the actual value of reduced mortality risk. We know that 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 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 million and \$8 million, from the overall range of \$100,000 to \$10 million (Viscusi, 1993). From this range of estimates, the VSL currently used in the Federal Government, first by the Environmental Protection Agency (EPA) and now by other agencies, is \$5.9 million (1997 dollars).

But is this value of reduced mortality risk potentially misleading for foodborne pathogens? In discussing how wage-risk tradeoffs 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. The marginal worker sets the wage differential and hence the inferred value of risk reduction. And if this marginal worker's unobserved risk preference differs from that of other workers, this local tradeoff can be a misleading index of the required wage premium. The same can be said about protection from foodborne pathogens—different people have different skill to avoid risks from food.

Consider now why worker heterogeneity might matter more to the value of statistical life than many people think (Shogren and Crocker, 1991, 1999). Let workers 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 occupations and job activities are identical. Workers select occupations of different inherent risks based on both their skill to protect themselves and their risk preference. This means that the occupation selection is unlikely to reveal perfectly both personal characteristics (Stamland, 1999). When a choice is made based upon two pieces of private information, the choice is unlikely to perfectly reveal either piece although it conveys some information about both. Hence, one would expect workers in a more risky occupation to be more skilled or more tolerant to risk or both. They need not be equally skilled or equally 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.

One can show that the VSL is likely to be systematically biased upward once one accounts for worker heterogeneity in both *skill* and *risk preference* (Shogren and Stamland, 2000a). A worker's unobserved skill to privately reduce his own risk affects the value of risk reduction. The reason for this is now the marginal worker is not randomly selected. Rather he is the person among those in the occupation who demands the highest compensation for *his* 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 one allows workers to self-select between risky and safe occupations.

These results support those who have argued that currently used VSL estimates could overestimate the benefits of new major regulatory decisions. An EPA Science Advisory Board's Advisory Council in its evaluation of the health and ecosystem effects of the Clean Air Act Amendments (CAAA) between 1970 to 1990 worried that the values were biased upward. Additional observers have pointed out that EPA's *best* CAAA benefit estimate of \$22 trillion is nearly the value of total U.S. households and nonprofit organization assets in 1990 (\$22.8 trillion), and actually exceeds the gain in the stock market from 1970 to 1990 (\$1.2 trillion). The idea that skill matters does not contradict the general concern that the operative value of reduced mortality risk used in public policy is suspiciously high.

Consider workers who differ in two respects: they are unequally skilled and they disagree on the value of reduced mortality risk. Different skill levels imply that workers do not face the same probability of a fatal accident in the same job; different risk preferences means that they have different tradeoffs between job wages and the on-the-job risk of a fatal accident. For simplicity, assume there are two types of jobs, safe and dangerous jobs, and two types of workers, highly skilled (*H*) and low skilled (*L*).

In the safe job, both types of workers face a probability $p \geq 0$ of a fatal accident. In the dangerous job, the likelihood of an accident decreases as the worker's skill increases. Assume the low-skilled worker faces a probability $q > p$ of a fatal accident in this job, whereas the high-skilled worker accident probability remains at p . The safe job pays a compensation w_s , and the dangerous job pays w_d . The difference in the wages, $w_d - w_s$, is endogenously given so that the dangerous job is able to attract low-skilled workers, i.e., we are considering an equilibrium in the labor market so that the dangerous job employs workers of different skills. This equilibrium means that the difference in wages, $w_d - w_s$, is just sufficient to make the low-skilled, high-risk worker indifferent between the dangerous and the safe jobs. In general, with two types of jobs, it must be the case in equilibrium that the wage difference is just sufficient to compensate the worker in the dangerous job who requires the highest compensation.

Let $\pi(t)$ denote the fraction of type t workers in the dangerous job. We denote the workers' utility functions by $u(t, P, W)$ where $t \in \{L, H\}$ is the worker's type, $P \in \{p, q\}$ is the worker's fatality

risk in his job, and $W \in \{w_s, w_d\}$ is the worker's wage. For now, assume the worker's utility function takes this simple form:

$$(1) \quad u(t, P, W) = W - P \cdot VOL_t$$

where VOL_t is the monetary equivalent of type t 's opportunity cost associated with premature death in the current period; i.e., VOL_t is type t 's value of life, or more precisely, the value of reduced mortality risk. Allowing VOL_t to depend upon the type allows different types of workers to have different life expectancies and different non-wage utility of life. For instance, the low-skilled workers may be young, inexperienced workers who have longer life expectancies (outside work) than the high-skilled workers.

The wage difference is set so that

$$(2) \quad u(L, q, w_d) = u(L, p, w_s)$$

which, given equation 1, yields the following solution for the wage of the safe job, w_s , in terms of the wage of the dangerous job, w_d :

$$(3) \quad w_d = w_s + (q-p) VOL_L$$

If we do not observe VOL_t directly, we can infer from the wages and the risks that:

$$(4) \quad VOL_L = \frac{w_d - w_s}{q - p},$$

if a type's risk is observable. We shortly consider the case in which it is unobservable. The overall probability that a randomly selected worker will have a fatal accident in the safe job is $P_s \equiv p$ because all types of workers have the same risk, p , in this job. The corresponding probability in the dangerous job is $P_d \equiv p\pi(H) + q\pi(L)$ and, rearranging, we have that

$$(5) \quad P_d = p + (q-p)\pi(L)$$

The true probabilities of an accident, p or q , are likely to be unobservable. If the wages and the statistical probabilities of an accident are used to infer the value of a statistical life, VSL , as follows:

$$(6) \quad VSL = \frac{w_d - w_s}{P_d - P_s}$$

then we have

$$VSL = \frac{w_d - w_s}{P_d - P_s} = \frac{w_d - w_s}{(q - p)\pi(L)}$$

and comparing with equation 4, we have

$$(7) \quad \text{VSL} = \frac{1}{\pi(L)} \text{VOL}_L$$

For example, if we plug $\text{VOL}_L = \$1,000,000$ into equation 7, this yields a VSL of \$4.8 million when $\pi(L)=0.2083$. Currently, many Federal agencies including the EPA use a VSL of \$4.8 million (1990 dollars).

We now present two useful results about the VSL that follow directly from expression 7. To facilitate our discussion, define $\text{VOL}_L < \text{VOL}_H$ as the case in which a low-skilled worker *undervalues* reduced mortality risk relative to the high-skilled worker. First, unless the low-skilled worker undervalues reduced mortality risk, the VSL overestimates the average value of mortality risk reduction. Second, unless the low-skilled worker undervalues reduced mortality risk, the less the proportion of low-skilled workers in the dangerous job, the more VSL overestimates the value of mortality risk reduction.

The third result follows from the observation that high-skill/low-risk workers earn a rent which equals the difference between their wage and their reservation wage, $(q-p)\text{VOL}_L$. The high-skill/low-risk worker earns a skill rent, $(q-p)\text{VOL}_L$, that is higher,

- 1) the larger the difference in skill as measured by the risk difference $q - p$.
- 2) the higher the low-skilled worker's value of reduced mortality risk, VOL_L .

For the VSL to be an unbiased estimator of the average value of reduced mortality risk, we must have:

$$(1 - \pi(L)) \text{VOL}_H + \pi(L) \text{VOL}_L = \text{VSL}$$

which is equivalent to:

$$(8) \quad \text{VOL}_H = \frac{1 - \pi(L)^2}{\pi(L) - \pi(L)^2} \text{VOL}_L \quad (> \text{VOL}_L)$$

These three results hold as long as VOL_H is lower than the critical value identified in expression 8. And on examination one sees that it would be a coincidence if expression 8 holds; it would have to satisfy rather stringent constraints. Noting also that VOL_H may be higher than the critical value given by expression 8, we obtain the fourth result: *VSL is an unbiased estimator of the value of mortality risk reduction in certain cases, but this occurs on a null set. VSL may underestimate the value of reduced mortality risk if the high-skilled workers value mortality risk reduction much more highly than the low-skilled workers.*

These four results suggest that value of lives saved is likely to be systematically biased upward once we account for worker heterogeneity in both *skill* and *risk preference*. The reason for this systematic bias is that the marginal worker is the person who demands the highest compensation for *his* risk in the job. That means that this marginal person faces relatively higher risk because of less skill or has lower tolerance to risk or both relative to other workers. And if his wage differential is divided by the statistical risk in the occupation, which measures the average risk of all the workers, the estimate of the workers' value of reduced mortality risk is biased upward

because the highest required wage differential among the workers is divided by their average risk. Our results are robust as one allows for more than two types and more general utility functions (see Shogren and Stamland, 2000a).

We now take this perspective on skill and valuation and apply it directly to the question of food safety and the VOL (Shogren and Stamland, 2000b). Consider a consumer who chooses a consumption vector of N available goods and services, some of which reduce health risk and some of which are foods. Consumers may derive different levels of enjoyment and different levels of health and fatality risk from the same food. Risks differ for physiological reasons such as allergies and pre-existing health issues whereas enjoyment levels differ due to taste. Let x_t denote individual t's consumption vector. This vector may include - in addition to the consumption all possible foods, all possible ways of dining, etc. - also all other consumption goods and services. But for our purposes, we focus on the consumption of food and other goods or services that impact health risks caused by food.

Let β_t be a N-vector and A_t a positive definite (and, without loss of generality, symmetric) NxN matrix so that $\beta_t'x - x'A_t x$ denotes the enjoyment that individual t derives from the consumption vector x . The first term denotes the utility gain from small levels of consumption and the second term captures satiation effects in the consumption of single foods and the interaction effect between the consumption of different foods. Both β_t and A_t depend upon the consumer, t, due to differences in taste, nutritional needs, etc. We have not included any threshold consumption necessary for survival because we assume that at any optimal choice the individual might make, this 'survival constraint' is non-binding. But the food consumption may involve other health issues such as the possibility for food poisoning and the potential consumption of types of food or quantities of food that engender health risk. The level of risk induced by the food consumption depends upon the individual due to individual risk characteristics such as age, health, etc. We represent this risk induced by the consumption vector by the scalar product $\rho_t'x$ where ρ_t is the vector of the individual's risks per unit of consumption. Finally, we assume there is an (opportunity) cost induced by increased health risk, VOL_t , that also depends upon the individual so that the consumer's utility function can be represented as

$$(9) \quad u(t, x) = \beta_t'x - x'A_t x - \rho_t'x VOL_t$$

We denote the consumer's wealth by W_t and the vector of food prices by P so that the consumer seeks to maximize $u(t, x)$ subject to $P'x = W_t$. We assume that the budget constraint is binding, meaning that the individual would change the consumption choice if he or she became wealthier.

The first-order conditions for the maximization of $u(t, x)$ with respect to x subject to the budget constraint form a set of linear equations. The first N first-order conditions (equating to zero the partials, with respect to x , of individual t's Lagrangian, $L(t, x, \lambda_t) \equiv u(t, x) - \lambda_t (P'x - W_t)$) yield the following solution for x , in terms of the budget constraint's shadow price, λ_t :

$$(10) \quad x^* = A_t^{-1} \alpha_t$$

where

$$(11) \quad \alpha_t = \frac{1}{2}(\beta_t - VOL_t \rho_t - \lambda_t P)$$

The second-order conditions hold because A_t is positive definite so the Hessian is negative definite. When this is plugged into the budget constraint, we obtain the following solution for λ_t :

$$(12) \quad \lambda_t = \frac{P' A_t^{-1} \gamma_t - 2W_t}{P' A_t^{-1} P}$$

where

$$(13) \quad \gamma_t = \beta_t - VOL_t \rho_t.$$

From the first-order conditions for food i and j , we obtain the following result: *assuming there are no interaction effects in food consumption, the individual's opportunity cost of health risk satisfies the following relationship:*

$$(14) \quad VOL_t = \frac{P_j(\beta_{ii} - 2a_{iii}x_i) - P_i(\beta_{jj} - 2a_{jjj}x_j)}{P_j\rho_{ii} - P_i\rho_{jj}}$$

To prove this note that when there are no interaction effects A_t is a diagonal matrix so that the first-order condition obtained by taking the i th partial of the Lagrangian is as follows:

$$(15) \quad \beta_{ii} - 2a_{iii}x_i - VOL_t \rho_{ii} - \lambda_t P_i = 0$$

where β_{ii} is the i th element of β_t , a_{iii} is the i th element along the diagonal of A_t , and so forth. By solving this equation for λ_t , plugging the result into the j th first-order condition, and rearranging, we obtain equation 14.

Researchers have identified some pitfalls in estimating the opportunity cost of health or fatality risk by using variables that are determined by the equilibrium behavior of a group of heterogeneous individuals. The problem is that an estimator based upon this group behavior may be biased by a sorting effect. This sorting determines the equilibrium's marginal individual who winds up determining the equilibrium numbers that enter into the estimator. Since this marginal individual was not randomly selected, but rather according to a particular sorting of the individuals, this individual is almost never representative of the whole group. Thus arises the bias.

Here we take a completely different approach. Rather than looking at the equilibrium behavior of a group of people, we look at the utility-maximizing choices made by each individual. The estimator we obtain in equation 14 is therefore the estimator of one particular person's opportunity cost of health and fatality risks. This therefore explicitly accounts for the heterogeneity among the individuals. Furthermore, equation 14 defines not one but rather $N(N-1)/2$ estimators of VOL_t per person where N is the number of health risk relevant consumption choices that are sampled. With the expansion of the model in the next subsection, we obtain an additional N estimates for a total of $N(N+1)/2$ estimates per person. If there were no noise in the estimation process, all these estimates would of course be the same. But in the presence of noise, such collections of many estimates of VOL_t for each of many persons in a sample may provide

the possibility of bringing the estimation of the opportunity cost of health risks to a new level of accuracy.

If we want to use equation 14 to estimate VOL_t correctly, we need to know the relevant six terms from β_t , A_t , and ρ_t , as well as the chosen quantities, x_i and x_j , and the prevailing prices, P_i and P_j . Most likely, these parameters need themselves to be estimated so that the resulting VOL_t estimates are noisy. In the next subsection we look at an expanded and more complex model that, far from yielding a more complicated estimator for VOL_t , actually yields estimators that require fewer consumer specific variables to be estimated. The present model therefore provides a menu of estimators between which one may select.

Now let's expand the model. Define the indirect utility function $u^*(t, \rho_t)$ as the maximum of $u(t, x)$ over x subject to the budget constraint. This indirect utility is, as denoted, a function of the risk levels, ρ_t , that the individual faces from the food consumption vector, x . Given the above, we have that:

$$(16) \quad u^*(t, \rho_t) = (\alpha_t + \lambda_t P)' A_t^{-1} \alpha_t$$

We assume that as well as having wealth that can be spent in markets to buy goods and services, some of which reduce health risks, the individual may exert effort in order to reduce the health risk engendered by consumption, ρ_t . One example of such an effort would be physical exercise. The benefits obtained from exercise are not necessarily (or only) obtained through the purchase of a service in a market, but is perhaps primarily a service one does oneself at a personal opportunity cost. Other similar "personal" services include choice of leisure activities, lifestyle, etc. To capture this, we assume that the individual chooses his or her optimal risk reduction efforts by maximizing the indirect utility function less opportunity costs that, in net, takes the following form:

$$(17) \quad U(t, \rho_t) = u^*(t, \rho_t) + \sum_{i=1}^N c_i \ln(\rho_{ii} - \underline{\rho}_{ii})$$

where $\underline{\rho}_{ii}$ might be thought of as a physiologically defined minimum risk, which very well could be zero (or even negative if the good or service in question is a risk reduction activity), from a given consumption good.

We have then the following implicit solution to the first-order condition for maximizing $U(t, \rho_t)$ with respect to ρ_{ii} :¹

$$(18) \quad \rho_{ii} = \underline{\rho}_{ii} + \frac{c_i}{-u_{\rho_{ii}}^*}$$

where

$$(19) \quad u_{\rho_{ii}}^* \equiv \frac{\partial u^*(t, \rho_{ii})}{\partial \rho_{ii}} = -VOL_t I_i' A_t^{-1} \alpha_t$$

and I_i is a N-vector with 1 in its i th element and zeroes elsewhere.

¹ The second-order conditions for this maximization problem are checked in each instance in the numerical analysis below because we cannot determine whether they are satisfied in general.

One issue, which we return to in the connection with numerical examples below, is that we are unable to verify that the second order conditions for the implicit solution in equation 18 do hold. Numerical examples verify that the second order conditions do not hold always since we are in some cases unable to generate a solution using equation 18 iteratively. However, we encountered no difficulties in finding instances where iterations of equation 18 converge and in most of these instances the second-order conditions do hold.

Plugging equation 11 into equation 19, we obtain

$$(20) \quad u_{ip_i}^* \equiv -VOL_t x_i^*$$

and so we can rewrite equation 18 as

$$(21) \quad \rho_{ii}^* = \underline{\rho_{ii}} + \frac{c_i}{VOL_t x_i^*}.$$

Solving equation 21 for VOL_t , we obtain the following result: *assuming the individual spends effort to reduce health risks and the second-order conditions hold, the individual's opportunity cost of health risk satisfies the following relationship:*

$$(22) \quad VOL_t = \frac{c_{ii}}{(\rho_{ii}^* - \underline{\rho_{ii}})x_i^*}.$$

Thus we obtain an additional estimator of VOL_t for each health risk relevant consumption choice. Furthermore, the estimator in equation 22 is simpler than that in equation 14 since it relies on estimating only three variables for each consumption choice, it does not require price information, and it does not require comparisons across consumption goods. It may be difficult to obtain good estimates of some of the parameters in equation 22, perhaps especially c_{ii} . Accounting for the heterogeneity between individuals necessarily makes it more complicated to infer these individuals' opportunity costs of health risk. We hope that this model, by providing a potentially large number of estimates for each individual, takes a step toward resolving these complications. Clearly, to assess the usefulness of the estimators we propose, one must employ them empirically and assess the resulting insights.

An additional benefit our model may provide is the fundament for a deeper statistical analysis of the uncertainty with which we estimate the opportunity cost of health risks. Our framework holds the possibility that one may obtain many estimates of this health risk for each single person in a sample. This may provide an opportunity to analyze the errors we make in estimating the opportunity cost of health risk. Are the different estimates for a single person's opportunity cost typically narrowly, or widely, spread around the mean estimate? The answer to this question should be of considerable interest.

Direct Methods: Risk and Rationality

Direct methods to estimate the value of reduced risk can be grouped into two categories—stated preferences and experimental auction methods. Among others, key differences between the two is whether the choice is actually binding when made, and the context of information that can be provided.

Stated preferences methods (e.g., contingent valuation) directly ask people, through a survey or interview, how much they would be willing to pay to reduce risk. 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 markets realistic and relevant to people. The judgmental best estimate of the value of a statistical life was approximately \$0.1-\$15.0 million for both studies (in 1990 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 carefully designed survey can add information on tradeoffs between safety and income, the method has its critics. A major complaint is that people are asked to answer a hypothetical valuation question that neither puts their money on the line nor enforces a budget constraint.

Experimental auction markets are a relatively recent approach to directly value reductions in risk. Experimental auctions use the laboratory to sell real goods to real people within a stylized setting. 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 a well-defined incentive structure that allows a person to learn that honest revelation of his or her true preferences is his or her best strategy. With demand-revealing auctions (e.g., the second-price, sealed-bid auction mechanism), subjects participate in an auction market that allows for learning as participants realize the actual monetary consequences of their bidding. The non-hypothetical auctions with repeated market experience can improve the precision of risk valuation.

Hayes et al. designed a set of experimental auctions to explore the ex ante willingness to pay for safer food. This question. They constructed an experimental auction to elicit both the option price and compensation measures of value for five different foodborne pathogens. They also used additional treatments to evaluate how subjects respond to changes in the risk of illness for a given pathogen, *Salmonella*, and to explore if pathogen-specific values act as surrogate measures of general food safety preferences. All experiments used real money, real food, repeated opportunities to participate in the auction market, and full information on the probability and severity of the food-borne pathogen. The design also used a Vickrey second-price auction to provide incentive to reveal preferences for risk reduction truthfully.

Four results emerge from their experiments. First, people underestimated the objective risk of foodborne pathogens. Second, values across foodborne pathogens were not robust to changes in the relative probabilities and severity, suggesting that people place more weight on their own prior perceptions than on new information on the odds of illness. Third, marginal willingness to pay an option price decreases as risk increases, again suggesting that the people weighed their prior beliefs more than new information. Fourth, they found support that values for specific pathogens might act as surrogates for general food safety preferences.

Overall, the results suggest that the average subject in our experimental environment was willing to pay approximately \$0.70 per meal for safer food. The *Salmonella* treatments under alternative risk levels indicate that the average person would pay about \$0.30 per meal to reduce risk of

foodborne pathogens by a fraction of 10. If one could transfer these values to the U.S. population, the value of food safety could be at least three times the largest previously available estimates.

Use of the lab to elicit value raises several questions of method. Consider three. First, does the unique lab environment inflate values? The observed premium paid in the Hayes et al. experiment exceeded some expectations of what people would pay in a real retail market. One explanation might be the novelty of the experimental experience. These auctions are usually a one-time experience, and the concern is that people might experiment with their bids, bidding high because the costs of doing so are low. Theory suggests an alternative explanation for the high price premia—the novelty of the good. Many bidders have never experienced the goods up for auction, e.g., irradiated meat. In this case, theory says that a bid will reflect two elements of value—the consumption value of the good and the information value of learning how the good fits into his or her preference set. *Preference learning* would exist if people bid large amounts for a good because they wanted to learn about an unfamiliar good they had not previously consumed, because it was unique, or because it was unavailable in local stores. Shogren et al. (2000a) tested these competing explanations by auctioning off three goods that varied in familiarity—candy bars, mangos, and irradiated pork, in four consecutive experimental auctions over two weeks. Their results suggest that preference learning seems to explain the high price premia. No statistical change in bids was measured for candy bars and mangos, whereas the price premia for irradiated pork dropped by 50 percent over the four sessions. These findings suggest that people benefit from the information they gain about how an unfamiliar good fits into their preference ordering.

Second, how do posted prices affect bidding behavior? Lab valuation exercises use multiple trials with posted market prices to provide experience to bidders who walk into these auctions cold. The information sent by a posted market price helps bidders learn about the market mechanism and the upper support of the valuation distribution. Concern exists that market experience will contaminate bids as posted prices turn independent private values into *affiliated* private values, especially if people are unfamiliar with the good up for sale (Harrison et al., 1995).² List and Shogren (1998) explore this possibility by examining panel data from over 40 second-price auctions with repeated trials. Three results emerge. First, the market price affects bidding behavior for unfamiliar products, as implied by affiliated private values. Second, the price effect dissipates when bidders receive non-price information about the good or are familiar with the product before entering the lab. Third, evidence of strategic behavior independent of any price signal still exists; buyers start bidding low and sellers start offers high, and then bids quickly stabilize after one or two trials. These results suggest posted prices can influence bidding behavior for unfamiliar products, but the effect dissipates when people have non-price information about the good or are familiar with the good.³

² Affiliation exists when one bidder who values the good highly increases the chance that other bidders will also put a high value on the good.

³ The results have two pragmatic implications for lab valuation research. First, the affiliation of private values can be reduced, if not removed, by providing product information prior to bidding. Second, a few trials help people learn about the market mechanism. Some people might need the experience since it appears that they did not fully comprehend the strategic implications of the second-price auctions.

Third, how does direct lab valuation for food safety within the lab and using surveys match up with an actual retail market behavior? Lab experiments introduce new price and non-price information and then observe the subsequent changes in bidding behavior. People still know that they are being monitored, however, and the range of alternative purchases is more limited than in a retail setting. Valuation surveys usually use hypothetical questions, and no guarantee exists that hypothetical answers would match those that occur under more realistic circumstances. Respondents know they are not accountable for their choices. Since these institutional differences send unique information flows to consumers, it is possible that distinct decision processes are involved that may cause a person to respond differently to the same choice. Shogren, Fox, and Hayes (1999) explore the similarity of these choices for risk reduction via irradiation, and how they match up with actual choices in a retail setting. All subjects came from the same small college town, and made choices between typical chicken breasts versus chicken breasts irradiated to reduce the risk of foodborne pathogens. Figure 1 shows that the results from both the survey and experimental market suggested significantly higher levels of acceptability of irradiated chicken than were shown in the retail trial at an equal or discounted price for irradiation. Consumer choices were more similar across market settings at a price premium for irradiation.

But all this work rests on the idea that the foundation of the economic theory of choice lies in the expression of values through repeated give and take with others in an exchange institution. The institution defines incentives and articulates knowledge and beliefs about relevant laws of nature and of humans. It relates a person's choice to the choices of others and to the consequences these aggregated choices produce. Moreover, it conserves resources and goods by redistributing them in accord with desires. The exchange institution is therefore a collective habit. When it is absent, a person must draw more intensely upon his or her personal resources.

But since exchange institutions often, even usually, do not exist for environmental assets, a person can act as if his value expressions will go uncontested; he is asocial, and need not be accountable to others. Unless one presumes he is a complete image of a nonstrategic, anonymous, competitive market that is broad in scope, the person may lack the incentives to act in accordance with the utility maximization paradigm and the economic theory of choice that follows from it. Economic and psychological evidence is abundant that, absent the disciplines and the protections of exchange institutions, people often depart from the axiomatic foundation of the economic theory of choice. When no exchange institution provides the gravity to hold his rationality together, the unsocialized person commonly engages in anomalous behaviors (naïve expectations or sucker behaviors) inconsistent with the paradigm. Unsocialized individuals fail to exploit existing gains from trade *and* often engage in behaviors that allow others to exploit these gains. Thaler (1992) presents a lengthy catalogue of these violations, including endowment effects, framing effects, and preference reversal effects.

Because exchange institutions—especially markets—are thin or nonexistent for environmental commodities, individual irrationalities plausibly exercise great influence over the allocation of these commodities and thus the values derived from their presence and use. Delivery of a means to allocate these commodities rationally might be viewed as a major purpose of benefit-cost

analysis, the kit of tools that economists use to infer the values people would attach to these commodities if market discipline were in place. The delivery may be less than the acme of perfection however, if only because applications of the kit usually require the introduction of strong auxiliary conditions linking a person to the market. The auxiliary conditions can be used to make what appears to be an ill-structured problem even to the researcher appear as a well-structured problem to that same researcher (Simon, 1973).

But risks from foodborne pathogens can conjure up images of either a secure chain of food inspections that guarantee our food arrives in sanitized, air-tight receptacles, or a risky adventure every time one goes out to eat. The two images induce vividly different perceptions of risk to public health. Yet such a range of public risk perceptions can exist simultaneously in a community, causing considerable disagreement as to whether a risk is acceptable or not. 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 commonly used in policymaking on environmental risk.

This value of reduced risk depends in part on the rationality we are willing to presume when people confront risk. People deathly 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 consistently value risk reduction the most.

Economists who work with risk most often use the expected utility framework, which presumes people have well-defined preferences for risk and can logically 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 thus economics, is able to judge the overall economic efficiency of some policy decision. Without well-grounded preferences and perceptions, there is a crack in the foundation of the rational theory of choice on which the economist's risk-benefit analysis rests.

But cracks exist. Psychologists and some economists have documented numerous exceptions to the idea of a rational theory of choice (see Machina, 1987; Camerer, 1995). These behavioral researchers have shown how people use rules of thumb, or heuristics, to simplify their reasoning about risk. Using these rules, people often 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 systematic aspects of behavior under risk regularly 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 who make judgments about risk use heuristics, or rules of thumb, that the popular expected utility

framework fails to capture. There is a long list of behavioral anomalies and paradoxes uncovered by cognitive researchers.

In the case of food safety, one key 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 slightly flatter line intersecting the 45° line from above reflects the evidence from different experiments and surveys examining how people actually rank 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 tend to 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 person's perceptions can lead to rejection of potentially beneficial technologies, e.g., commercial nuclear power.

Such irrational reactions can affect the values collected with stated preference methods. The isolated individual, in response to a researcher request to do so, is presumed to be able to imagine an exchange institution, visualize the details of his and others' participation in it, and then to state his one-time value for a nonmarketed environmental commodity. Though contingent valuation employs a data gathering tool that psychologists and sociologists apply to study the cognitive processes that generate a person's choice, its economist practitioners do not often address the general reluctance of these other disciplines to use the utility maximization paradigm to explain the isolated behaviors of individuals. These non-economic disciplines prefer to downplay the quantitative features of a decision process to focus on the framing of the problem, learning about it, clarifying options, etc. These are the functions an effective exchange institution performs on a person. And though the verdict is still out, enough empirical evidence exists to fuel skeptics who wonder whether asking an isolated person to visualize active participation in a repeated give and take situation is sufficient to cause him to behave for one time in accordance with the utility maximization paradigm. A polite request to visualize a nonexistent market does not obviously cause the rationality of the real market to rub off on him.

We posit that a Coasean corollary exists for nonmarket valuation—if information processing costs are zero, the researcher will have enough understanding to provide identically perceived information such that the beliefs of respondents will be complete, and, consequently, elicited values would be identical to the market price, if it existed. But if information costs really are zero, respondents will endogenously generate their own information frames that will be identical to the exogenously provided information frames, i.e., elaborate information packages in survey research would be redundant as respondents would select the same frame endogenously. Information costs are not zero, obviously, thereby implying that the rules and exchange institutions implied by a researcher's exogenous frame impact a respondent's elicited value. Therefore, artificially restricting the range of rules and exchange institutions will result in revealed values that underestimate the true value of the resource. Allowing for the endogenous choice of exchange institution in nonmarket valuation is needed to permit incomplete beliefs to become more complete such that the respondent has the opportunity to participate in the selection of both *what* goods will

be produced and *how* they will be provided. Additionally, some form of arbitrage, albeit possibly mock, should be used to make beliefs even more complete.

Maximum extraction of potential surplus is performed at the level of the exchange institution rather than at the level of the individual (Becker, 1962; Smith, 1991; Grether, 1994; Plott, 1996). Consider the odds that you will suffer a dreaded environmental disease by a given date. You will be able to specify a lower probability value such that odds less than this value are incredibly low and another, higher value such that odds greater than this value are incredibly high. You will insist or try to placate someone who insists that you pick a single, unique value. de Finetti (1974) shows how the selected lower value, upper value, and single-value odds can be interpreted as your greatest buying price, your lowest selling price, and your no-arbitrage price. Your beliefs are complete at the no-arbitrage price (Nau and McCardle, 1991).

If a person has incomplete beliefs, they can be made more complete if he chooses to participate in one or more exchange institutions. It is exchange institutions that pressure the individual to behave in accordance with the utility maximization paradigm (see for example Chu and Chu, 1991; Gode and Sunder, 1993). However the manner in which these pressures induce the individual to submit his beliefs and preferences may differ considerably across institutions and a person may well have preferences over the manner of submission. For example, a person may prefer the anonymity of the nonstrategic, competitive market over a public good club that compels him to divulge more than he would like in interminable meetings for which he does not care. The incompleteness of his beliefs about and thus the value he attaches to a lottery for the environmental commodity will therefore differ with the exchange institutions in which he chooses to participate and with the intensity of his participation.

As we stated, experimental evidence suggests that an isolated person often acts outside the ropes of economic theory. We discussed how he commonly reverses his preferences, makes different bids and offers for the same good, and puts too much weight on his initial endowments. But people usually return to the ring when they interact with other intelligent 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. As such, economists often question the importance of isolated anomalous behavior to explain behavior in thick, well-functioning markets and economic systems.

But markets for several 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 for these goods. The typical survey asks the unsocialized person to imagine an exchange institution, visualize the details of his and others' participation in it, and then to state his one-time value for a non-marketed environmental good. While these surveys generate numbers, the hypothetical institutions are perilously thin and provide the undisciplined and uncontested values that raise fears that irrational behavior is the rule 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, non-market valuation surveys might be improved by a explicit connection to an active market with arbitrage. Cherry et al. (2000) provide experimental evidence of such rationality spillovers—induced rationality in an arbitrated market can spill over to a second non-arbitrated market that would otherwise consist of irrational behavior in the case of preference reversals. Only arbitrage and socialization appear to stop the phenomena (Chu and Chu, 1990). But will the rationality induced in a market with arbitrage spill over to a second market without arbitrage?

Here we extend the account of induced rationality in Crocker et al. (1998) to rationality spillovers. To reduce notational clutter, we consider one representative agent who makes his choices in one time period and takes the state of nature as fixed. A lottery is sequentially available to the agent in two settings, first an arbitrage, market-like setting, MK, and then an isolated, nonmarket setting, NM. Let θ^{NM} be the agent's effort to overcome any irrationalities that his cognitive and computational limitations cause him to have in the isolated setting. Represent the agent's irrationalities by $\Delta^k, k = MK, NM$, the inconsistency between his choice and the fair price for a lottery ticket. Any such gap, Δ^k , invites efforts to close it – like a gap in potential that, when sufficiently great, is crossed by electric energy as a spark. But this need not mean that the agent's shock is great enough to elicit enough effort to close the gap and thus maximize extracted surplus.

The gap Δ^{MK} affects the agent's rationality in the isolated setting parametrically. Assume this effect is independent of the agent's wealth. With a result, Δ^{MK} , the agent's surplus extraction problem in the isolated setting is to choose effort to maximize

$$(23) \quad \text{Max}_{\theta^{NM}} W^{NM} = [Z^{NM} - (1 - \theta^{NM})\Delta^{NM}(\theta^{NM}, \Delta^{MK}) - C^{NM}(\theta^{NM}, \Delta^{MK})],$$

where Z^{NM} is the maximum surplus the agent could extract if he were fully rational in the isolated state. This surplus corresponds to that which would be generated in a world of non-strategic, anonymous, competitive markets for a lottery ticket. Let θ^{NM} be continuous. It can be characterized as lying in the unit interval $[0,1]$, in which the upper bound implies that the agent expends enough effort to override his endowed cognitive and computational limitations completely and the lower bound implies no overriding whatsoever. Getting more education or a new set of eyeglasses might be examples of effort expenditures. Expenditures like these are costly in terms of time and resources. Expression 23 makes both the agent's residual irrationality or unextracted surplus, Δ^{NM} , and his costs of extracting surplus, C^{NM} , in the isolated setting functions of his irrationality, Δ^{MK} , in the arbitrage setting and his effort expenditures, θ^{NM} , in the isolated setting. His irrationality in the isolated setting is determined by what he learned in the arbitrage setting and his willingness to apply that learning in the isolated setting.

Assume

$$\frac{\partial \Delta^{NM}}{\partial \theta^{NM}} \leq 0; \quad \frac{\partial \Delta^{NM}}{\partial \Delta^{MK}} = 0; \quad \frac{\partial C^{NM}}{\partial \theta^{NM}} > 0; \quad \frac{\partial C^{NM}}{\partial \Delta^{MK}} \geq 0,$$

and

$$\frac{\partial^2 \Delta^{NM}}{(\partial \theta^{NM})^2} < 0; \quad \frac{\partial^2 C^{NM}}{(\partial \theta^{NM})^2} > 0; \quad \frac{\partial^2 C^{NM}}{(\partial \Delta^{MK})^2} > 0; \quad \frac{\partial^2 C^{NM}}{\partial \theta^{NM} \partial \Delta^{MK}} > 0.$$

We discuss the sign of $\frac{\partial^2 \Delta^{NM}}{\partial \theta^{NM} \partial \Delta^{MK}}$ subsequently. Assume $\frac{\partial \Delta^{NM}}{\partial \Delta^{MK}}$ equals zero because, by

definition, the isolated agent can be more rational only by trying to be so, i.e., by drawing upon his internal resources to make lessons from his prior arbitrage experiences.

In the isolated setting, the agent's optimal residual irrationality is

$$(24) \quad \Delta^{NM} : \frac{\partial W^{NM}}{\partial \theta^{NM}} = -(1 - \theta^{NM}) \frac{\partial \Delta^{NM}}{\partial \theta^{NM}} + \Delta^{NM} - \frac{\partial C^{NM}}{\partial \theta^{NM}} = 0$$

$$(25) \quad (\Delta^{NM})^2 : \frac{\partial^2 W^{NM}}{(\partial \theta^{NM})^2} = -(1 - \theta^{NM}) \frac{\partial^2 \Delta^{NM}}{(\partial \theta^{NM})^2} + \frac{\partial \Delta^{NM}}{\partial \theta^{NM}} - \frac{\partial^2 C^{NM}}{(\partial \theta^{NM})^2} < 0$$

Analogous conditions exist in the arbitrage setting which produced Δ^{MK} if the extraction of surplus in that setting involves agent efforts to grasp the implications of and to implement transactions, coordination, and negotiation.

Now differentiate the first-order equilibrium conditions for the arbitrage and the isolated settings with respect to a parametric shift in the agent's residual irrationality in the arbitrage setting. Better arbitrageurs than the agent previously had to face might cause this shift. They force the agent to get smarter. This differentiation yields

$$(26) \quad \frac{d\Delta^{NM}}{d\Delta^{MK}} = -\frac{\Delta^{NM} \Delta^{MK}}{(\Delta^{NM})^2},$$

where Δ^{MK} is the agent's optimal residual irrationality in the arbitrage setting alone. The

$\Delta^{NM} \Delta^{MK}$ term on the right-hand-side of expression 26 is

$$(27) \quad \Delta^{NM} \Delta^{MK} : -(1 - \theta^{NM}) \frac{\partial^2 \Delta^{NM}}{\partial \theta^{NM} \partial \Delta^{MK}} + \frac{\partial \Delta^{NM}}{\partial \Delta^{MK}} - \frac{\partial^2 C^{NM}}{\partial \theta^{NM} \partial \Delta^{MK}}.$$

If the agent does not carry over his residual irrationality in the arbitrage setting to the isolated setting, then expression 27 will be zero, implying from expression 26 that the agent does not choose to use whatever he learned in the arbitrage setting to improve the quality of his decisions in the isolated setting. For expression 26 to be positive such that a rationality spillover occurs, isolated effort and reductions in arbitrage irrationality must be complements. Reductions in

arbitrage irrationality must increase the marginal product, $\left(\frac{\partial^2 \Delta^{NM}}{\partial \theta^{NM} \partial \Delta^{MK}} \right) < 0$, and reduce the marginal costs, $\left(\frac{\partial^2 C^{NM}}{\partial \theta^{NM} \partial \Delta^{MK}} \right) > 0$, of the agent's efforts in the isolated setting. Our null

hypothesis is that the net effect of these two cross-partial causes expression 26 to be zero or negative in sign, which means respectively that arbitrage experiences do not impact the quality of the agent's unarbitrated decisions or that these experiences are dysfunctional for these decisions.⁴ The alternative hypothesis is that expression 26 will be positive. To state our hypotheses in the text formally, first consider arbitrage and rationality spillovers.

For a person in the k^{th} institution, ($k = \text{MK}, \text{NM}$) let w^k denote his initial wealth level; A^k, B^k , and ψ^k indicate his holding of lottery A, lottery B and no lottery; and $\text{WTP}(A)^k$ and $\text{WTP}(B)^k$ is his maximum willingness to pay for lotteries A and B. Preference and indifference are indicated by (\succ) and (\sim) . By definition of $\text{WTP}(A)^k$, and $\text{WTP}(B)^k$, the following holds for the k^{th} institution:

$$[w^k + \text{WTP}(A)^k, \psi^k] \sim [w^k, A^k] \text{ and } [w^k + \text{WTP}(B)^k, \psi^k] \sim [w^k, B^k].$$

Preference for lottery A over lottery B implies $[w^k, A^k] \succ [w^k, B^k]$ and by transitivity

$$[w^k + \text{WTP}(A)^k, \psi^k] \succ [w^k + \text{WTP}(B)^k, \psi^k].$$

Given wealth provides positive utility, $\text{WTP}(A)^k > \text{WTP}(B)^k$ follows from the initial preference of lottery A over lottery B. Rational behavior leaves no arbitrage opportunities, i.e., surplus on the table available for others to capture.

In reality, isolated people often contradict this theoretical result. They reverse their preferences by either indicating

$$[w^k, A^k] \succ [w^k, B^k] \text{ and } [\text{WTP}(A)^k] < [\text{WTP}(B)^k].$$

or

$$[w^k, A^k] < [w^k, B^k] \text{ and } [\text{WTP}(A)^k] > [\text{WTP}(B)^k].$$

These inconsistent preferences create opportunities for others to extract gains through exchange.

Surplus left on the table from inconsistent preferences may arise from errors in judging preferences or valuations or both. Errors may be reduced or eliminated when the surplus is captured through the arbitrage provided within an exchange institution. Let the preference of lottery A over lottery B be denoted as

$$[A^k + \varepsilon(A)^k] \succ [B^k + \varepsilon(B)^k],$$

⁴ By treating arbitrage rationality levels tomorrow as positive functions of isolate rationality levels today, this framework could readily be adapted to a multiperiod, sequential process in which irrationality declines with each passing period. This learning-by-doing process need not presume dynamic elemental rationality in the sense that the agent weighs the value of behaving today in terms of what such behavior will do for the temporal conjunction of his irrationalities in all tomorrows. Unintentional rationality spillovers can, in principle, occur over time, events, states, institutional settings, or any other economic dimension.

where $\varepsilon(\cdot)^k$ is the error in judgement for lottery \cdot in institution k ($\cdot = A, B$ and $k = MK, NM$). Summing judgment errors yields the total error in preference ordering for institution k , $E^k = \varepsilon(A)^k + \varepsilon(B)^k$. The valuations for lotteries A and B for the preference-reversing individual are given by

$$[WTP(B)^k + \varphi(A)^k] > [WTP(A)^k + \varphi(B)^k]$$

where $\varphi(\cdot)^k$ is the error in valuing lottery \cdot in institution k ($\cdot = A, B$ and $k = MK, NM$). Total error in valuation for institution k is given by $\vartheta^k = \varphi(A)^k + \varphi(B)^k$. The total error in institution k is the sum of the error in preference ordering and valuation, $\Delta^k = E^k + \vartheta^k$.

Let total error within the k th institution with and without arbitrage be $\Delta^{k(1)}$ and $\Delta^{k(0)}$, in which $k(1)$ and $k(0)$ represent arbitrage and no arbitrage. Direct rationality effects from arbitrage imply that total error is reduced or eliminated in the presence of arbitrage such that $\Delta^{k(1)} < \Delta^{k(0)}$. Accordingly the direct rationality hypothesis refers to the rationality effects of arbitrage within a single institution,

$$H_o : \Delta^{k(1)} = \Delta^{k(0)}; H_a : \Delta^{k(1)} < \Delta^{k(0)}. \quad k = MK, NM$$

Plentiful theoretical and experimental evidence supports direct rationality effects from arbitrage.

Now consider the indirect or rationality spillover effects of arbitrage in the j th institution, $j \neq k$. “Rationality spillover” simply assumes that the individual’s total error in the k th institution is reduced after he is subjected to arbitrage in the j th institution. The rationality spillover hypothesis is thus

$$H_o : \Delta_{j(1)}^{k(0)} = \Delta_{j(0)}^{k(0)}; H_a : \Delta_{j(1)}^{k(0)} < \Delta_{j(0)}^{k(0)} \quad j \neq k = MK, NM$$

where $\Delta_{j(1)}^{k(0)}$ is the individual’s total error in the k th institution subsequent to his participation in arbitrage in the j th institution.

For a given institution, do his preference orderings or do his valuations register the effect that arbitrage has on the person’s rationality? Arbitrage may induce him to correct errors in his preference ordering alone such that $dE^{k(1)} < 0$ and $d\vartheta^{k(1)} = 0$, in his valuations alone $dE^{k(1)} = 0$ and $d\vartheta^{k(1)} < 0$, or both $dE^{k(1)} < 0$ and $d\vartheta^{k(1)} < 0$. Further, rationality effects may occur in only a single lottery type as in $dE(\cdot)^{k(1)} < 0$ and $d\vartheta(\cdot)^{k(1)} < 0$ or pairs as in $dE(\cdot)^{k(1)} < 0$, $d\vartheta(\cdot)^{k(1)} < 0$, $\cdot = A, B$, $k = MK, NM$. Three hypotheses follow:

- Preference adjustment hypothesis – *total errors are reduced by correcting preference orderings alone*, $H_o : E(\cdot)_{j(1)}^{k(0)} = E(\cdot)_{j(0)}^{k(0)}; H_a : E(\cdot)_{j(1)}^{k(0)} < E(\cdot)_{j(0)}^{k(0)}$
- Valuation adjustment hypothesis for low-risk lotteries – *total errors are reduced by adjusting valuations of lottery A*, $H_o : \vartheta(A)_{j(1)}^{k(0)} = \vartheta(A)_{j(0)}^{k(0)}; H_a : \vartheta(A)_{j(1)}^{k(0)} < \vartheta(A)_{j(0)}^{k(0)}$
- Valuation adjustment hypothesis for high-risk lotteries – *total errors are reduced by adjusting valuations of lottery B*, $H_o : \vartheta(B)_{j(1)}^{k(0)} = \vartheta(B)_{j(0)}^{k(0)}; H_a : \vartheta(B)_{j(1)}^{k(0)} < \vartheta(B)_{j(0)}^{k(0)}$

Cherry et al. (2000) designed an experiment to address this question using a computer program to simulate two choices—market and non-market. Treatment 1 was the no-arbitrage baseline—

both choices had real money lotteries and no arbitrage. In treatments 2, 3, and 4, the market choice was held constant—real money lotteries with arbitrage (after round 5). The non-market choice 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.

In an arbitrated 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-arbitrated treatment, reversals were left unchecked for all rounds.

Figures 2-4 summarize the key results. First, the results suggest that arbitrage directly impacts individual rationality. The non-arbitrated reversal rate is about 33 percent and persists over the 15 rounds. Second, rationality spillovers exist. Once arbitrage is introduced in the market, the rate of reversals in the non-market choice decreased too. Reversal rates were about 20 percent after 11 trials, and 10 percent after 15 trials. Rationality spillovers were also strong in the hypothetical treatment, and weaker in the environmental treatment. Third, and of key importance, people adjusted valuations rather than preferences, which indicates the potential for rationality spillovers to improve non-market valuation. Although isolated individuals often fail to behave in accordance with the classic economic paradigm of utility maximization, these results suggest a case in which such irrationality can be overcome if people receive information and discipline from an active exchange institution.

Concluding Remarks

Valuing food safety from collective action is complicated by the fact that people have private information on both their risk preferences and their skill to avoid risk privately. They also make many decisions on low-odds risks in non-market situations in which their rationality can be called into question. Herein we explore how hidden skill and shaky rationality can affect both the theory and methods used to define and estimate value of reduced pathogenic risk. The results suggest that both skill and rationality matter, and as such both factors are worthy of attention in future research efforts.

Pathogen risk to children is one factor we have not discussed in this paper, but it deserves more attention. Children can face disproportionately greater risk from foodborne pathogens because they are kids—smaller bodies, faster metabolisms, shorter attention spans, less knowledge, and fewer resources. Food safety programs that reduce risks to children produce benefits to society that should be adequately represented so policymakers have more information to help them decide which policies are the most worthwhile relative to their costs. The open question is just how exactly to value these reductions in risks to children, which can either arise from a direct effect on their health or an indirect effect on their life chances due to illness in other family members or the degradation of the environment. Do standard benefits estimation adequately

capture the indirect effects on healthy children? In some cases, risks to children might be accounted for in revealed and stated values, and estimating these effects could imply double counting of benefits. But if policymakers fear that caregivers face choice without complete information or experience, the benefits of reduced risks to children might be understated. It also seems constructive to devote resources to explore the link between adults, children, and the value of safer food.

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Figure 1 — Ratio of consumers who prefer irradiated meat, given relative price

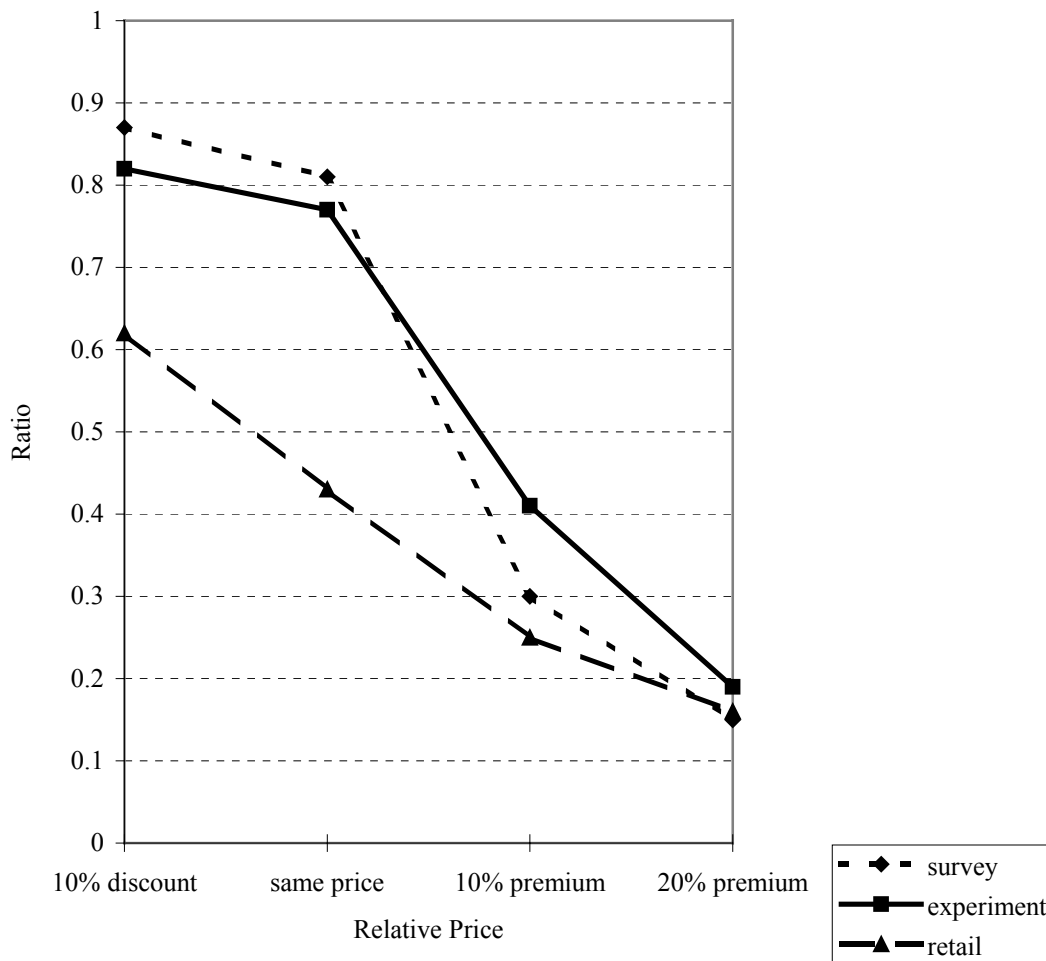


Figure 2 – Preference reversal rates in the market setting

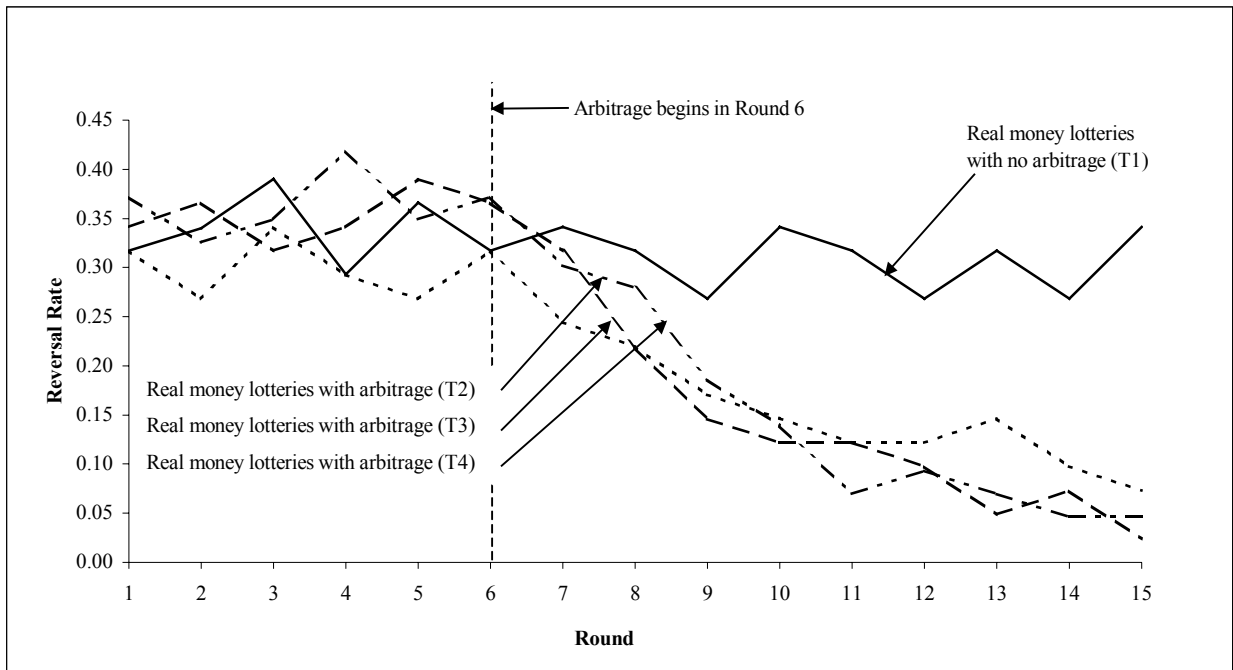


Figure 3 – Preference reversal rates in the nonmarket setting

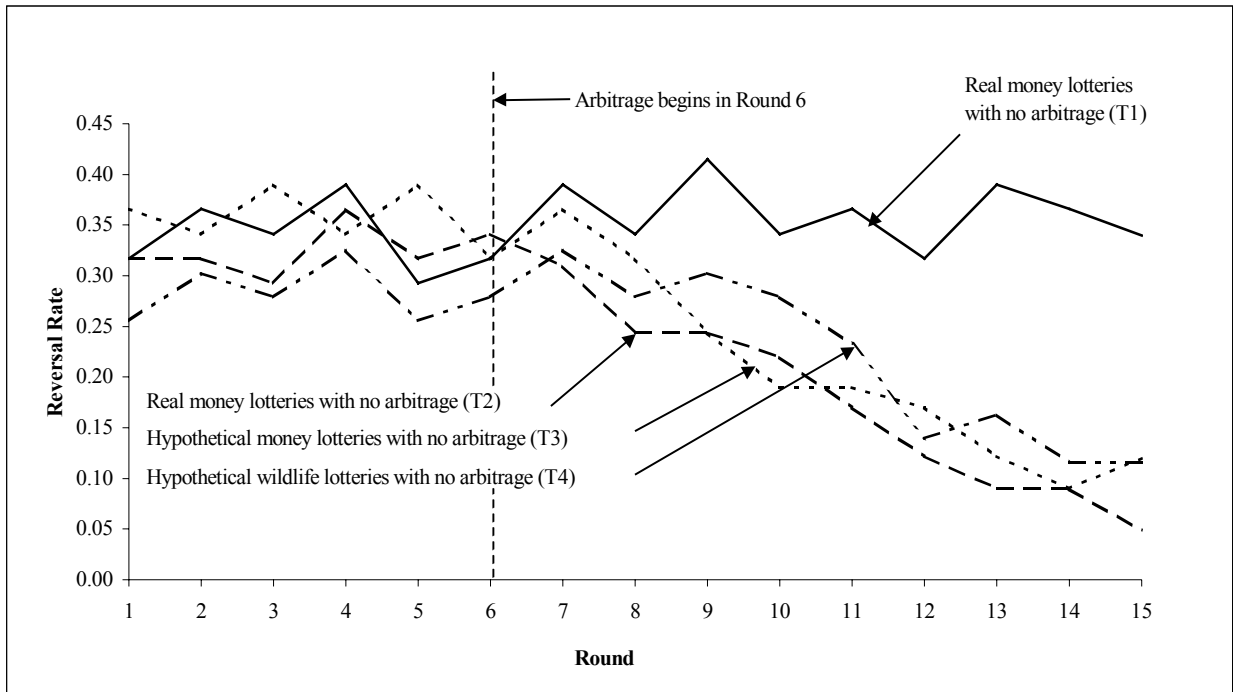


Figure 4 – Mean values for high-risk lotteries: Real versus hypothetical

