Invited Presentation

Experimental Markets and Environmental Policy

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Experimental markets can be a useful tool to guide and evaluate environmental policy. This paper reviews four experiments to illustrate. Two institutional experiments are considered—Coasian bargaining with positive transaction costs, and a gaming experiment of dynamic choice in a conflict. Two valuation experiments are also discussed—the impact of sequential reduction mechanisms on the value of risk, and experimental auction markets to elicit the value of safer food.

1. Introduction

If economists can have heroes, Peter Bohm, Charles Plott, and Vernon Smith are three of mine.[1] Throughout the 70s and 80s, they blazed a trail safe enough that greenhorns like myself no longer needed to justify and defend experiments as a viable research method in economics. Scores of economists now employ laboratory experiments to isolate, control and test alternative theories of choice.[2] As a result, the lab plays a vital role in economics.[3]

Nevertheless, experimental economists can still identify with econometricians from fifty years ago. At that time an econometrician needed a scheme to run a regression or linear program. Limited capacity, time, and money constrained the number of runs to a handful. Once the runs were complete—that was it—one either lived with the results or went through the time-consuming process of collecting more funds for more runs. But every curse has its blessing—in this case, an imposed discipline to identify and test the most interesting questions. Experimental economics forces the same discipline today. One asks the question, develops hypotheses, designs an experiment, runs the treatments, pays the subjects, and either savors the results or searches for new funds to try again. Experiments become habitual, rationally disciplining one's thinking about economics.

Let us advance this discipline one more step and consider how experimental markets can be used to guide environmental policy. Experiments motivated by the questions of policy makers can provide insight into how a proposed change in incentives or benefits will affect behavior. By supplying information on the behavioral link between incentives, values and choice, experimental markets can influence how environmental policy is made and evaluated. Since the lab environment differs from the natural environment by necessity, experiments should be viewed as a dress rehearsal and not the play itself. Experimental markets do not generally dictate policy, rather they are used to improve our understanding of the underlying assumptions and incentives that drive behavioral responses to policy.

In the following sections I rely on four different examples to illustrate the application of experimental markets to environmental policy—Coasian bargaining, environmental conflict, risk reduction mechanisms, and the value of food safety. Based on Smith's (1982) triad of experimental economics—institution, preference, and actual behavior, these examples are classified as either institutional or valuation experiments. Institutional experiments explore the efficiency of alternative incentive design and auction mechanisms to correct market failure given preferences are held constant (e.g.,

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[1] See Bohm (1984), Plott (1987, 1989), and Smith (1982) as a sampler of experimental economics.

[2] See for example the recent experimental economics textbook by Davis and Holt (1993).

[3] Shogren and Nowell discuss the role of theory and experiments in economics relative to the role in ecology. In contrast to economics, experiments have long played a major role in biology (also see Mayr, p. 30). The usefulness of experiments versus theory goes to the core of the debate over the existence of an external world and the acquisition of knowledge. Philosophers such as Bishop George Berkeley and John Stuart Mill believed that ". . . nothing beyond experimental knowledge is either possible or necessary" (Kline, p. 19). Obviously, others disagree.

Franciosi et al.).[4] Coasian bargaining and environmental conflict are examples of institutional experiments. Valuation experiments reverse this and elicit preferences for nonmarket goods such as risk reduction or food safety, given the institutional structure is held constant (e.g., Brookshire and Coursey, Coursey, and Shogren et al.).

2. Coasian Bargaining

No idea has triggered more debate in environmental policy reform than the Coase theorem (Coase 1960), especially the role of transaction costs. The theorem states that two disputing parties will bargain until a private and socially optimal agreement is reached, regardless of which party is assigned the unilateral property right. Third-party intervention is relegated to assigning unambiguous property rights. Although experimental evidence supports highly efficient bargains,[5] the basic complaint is that the Coase theorem is a tautology—the assumptions guarantee the outcome. The zero transaction cost assumption guarantees there is no incentive to terminate bargaining until the efficient resource allocation is achieved. But Coase argues he has been misunderstood; he is not the champion of a zero-transactions-costs world. Rather he maintained that a legal system is immaterial to economics only when transaction costs are zero, and since this world is nonexistent, the law matters. Coase (1988, p. 15) states that "[w]hat my argument does suggest is the need to introduce positive transaction costs explicitly into economic analysis so that we can study the world that does exist."

Herriges and Shogren explore the implications of Coasian bargaining with transaction costs. We construct an experimental design where two parties bargain over a fixed reward given both discrete and continuous real-time transaction costs. The objective is to examine how transaction costs impact efficiency, the distribution of wealth, and temporal dimension of bargaining. Testing the robustness of the Coase theorem under alternative assumptions is essential to understand which complications restrict the efficacy of bargaining and negotiated environmental settlements. By identifying key institutional arrangements that increase effective and efficient agreements, experiments are a helpful tool for effective policy reform.

The experimental design employs a bilateral bargaining framework. Alternating pairs of subjects bargain over the chance of winning a monetary reward as specified by a binary lottery.[6] Six unique transaction cost sessions were examined. Each session involved bargaining over two contracts—the number contract and the transfer contract. The number contract specifies the initial chances of winning the reward, requiring the pair to select one number out of six from a "Lottery Schedule". For example, Table 1 shows that if number 3 is selected, subject A owns 50 out of 100 lottery tickets implying a 50% chance of victory, subject B has 30 tickets implying a 30% chance, while the house has a 20% chance to keep the reward. The transfer contract specifies how the subjects distribute the lottery tickets. Given number 3 is chosen, if subject B agrees to give subject A 25 tickets, A's chance of victory increases to 75%, while B's chance falls to 5%.

Table 1. Example Lottery Schedule

Subject's Chance to Win	Number					
	1*	2	3	4@	5	6**
A	80%	65%	50%	40%	20%	0
B	0	20%	30%	60%	70%	80%
Joint Chance	80%	85%	80%	100%	90%	80%

*Subject A's outside option.
**Subject B's outside option.
@Efficient number—100% chance of victory for A and B.

Opportunity costs are determined by the allocation of property rights. Prior to each session for each pairing, we designate the "controller"—the subject given the unilateral property right over the Lottery Schedule. The controller has the right to unilaterally select a number—the outside option—from the Schedule and inform the monitor, who will then end the session. The outside option or opportunity cost equals 80% for each player in Table 1. No agreement contract needs to be signed. The other subject attempts to influence the controller to reach a mutually acceptable agreement by offering to give some of his or her lottery tickets to the controller.

An agreement is *efficient* if joint expected returns are maximized, and *rational* if both subjects receive at least their potential opportunity cost. Using the values from Table 1, Figure 1 illustrates the efficient bargaining frontier where subject A is the controller. The six asterisks represent the six num-

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[4] These mechanisms include tradable emission permits or common pool allocation schemes.

[5] See Hoffman and Spitzer, for example.

[6] A binary lottery controls for risk preferences since expected utility can be normalized. The value of a large reward is set at unity, while the value of a small reward is set at zero, thereby implying that expected utility equals the chance of winning the large prize.

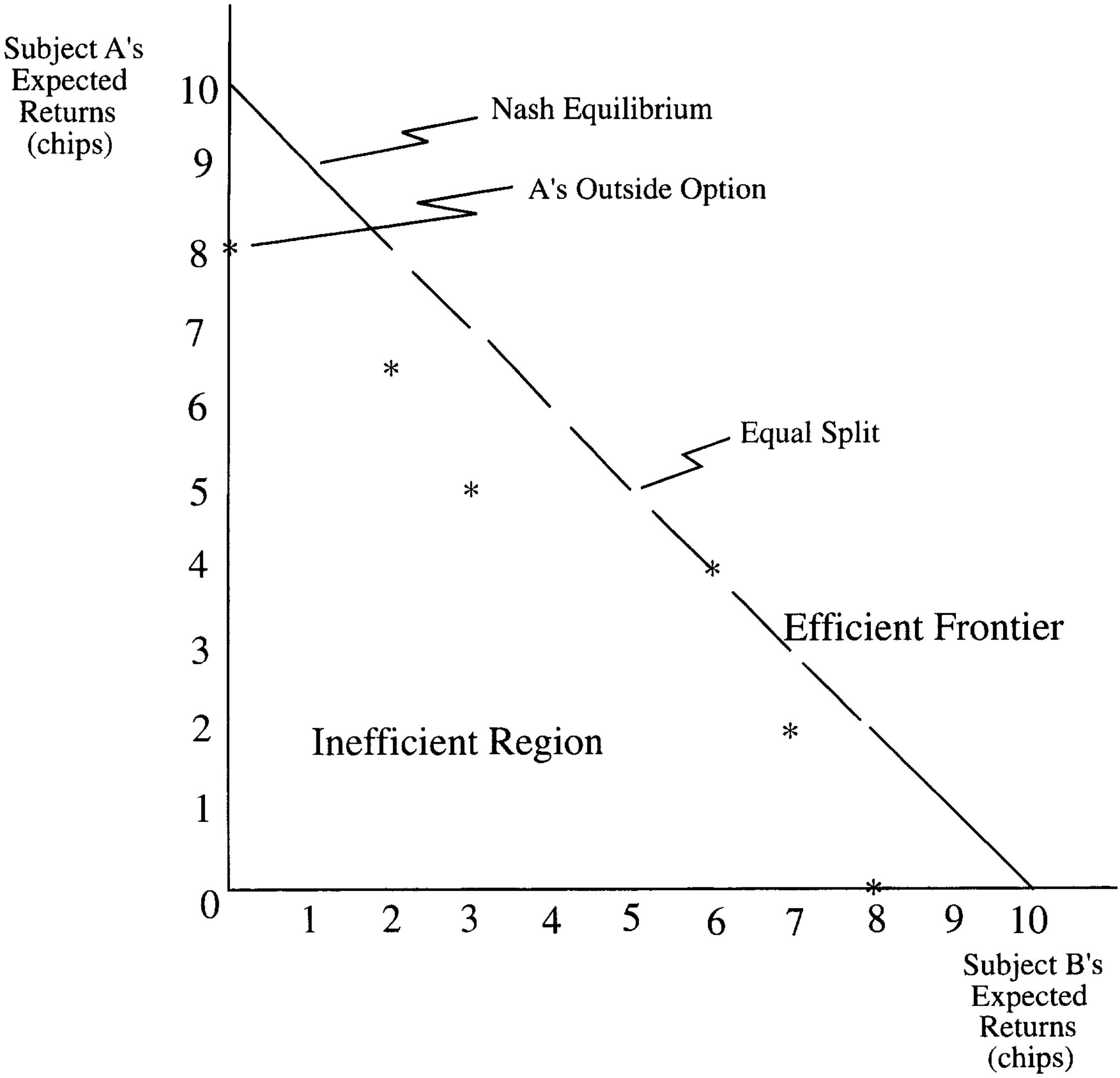

Figure 1. Efficient Bargaining Frontier

ber contracts from Table 1. All points below the diagonal line are inefficient—a joint maximum is not achieved. Given A's 80% outside option, the Nash equilibrium requires A and B to split the remaining 20% chance equally such that A has a 90% chance to win and B has 10% chance. Note that a commonly observed focal point is the equal split where both have a 50% chance to win.[7]

For each bargaining session the reward is 10 chips worth fifty cents each. The 10 chip reward was amassed by requiring a contribution of 5 chips from the controller, 1 chip from the other subject, and 4 chips from the house. Given the potential for uncontrolled nonmonetary motivation as reflected by the equal split focal point, we require a larger contribution from the controller to provide more incentive for rational bargaining.

Each bargain has a 5 minute time limit with the maximum 10 chip reward decreasing over time to reflect real-time transaction costs. Figure 2a illustrates the three discrete transaction costs sessions—rewards decrease by 10 chips after 5 minutes, 5 chips every 2.5 minutes, and 2 chips every minute. Figure 2b shows the three continuous ses-

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[7] A focal point is any outcome that attracts bargainers (see Schelling). In this case, the equal split acts as a focal point for players who follow social cues to divide the chances equally. Thus, the players are argued to act more like fairpersons than the rational gamespersons that theory predicts. See Roth (1987) for a discussion of fairness and gamespersonship in bargaining experiments. But note that fairness may result from uncontrolled loyalty to the bargaining opponent. Shogren (1992) observed that if loyalties are explicitly controlled, then fairness no longer remains an issue—bargainers are extremely competitive.

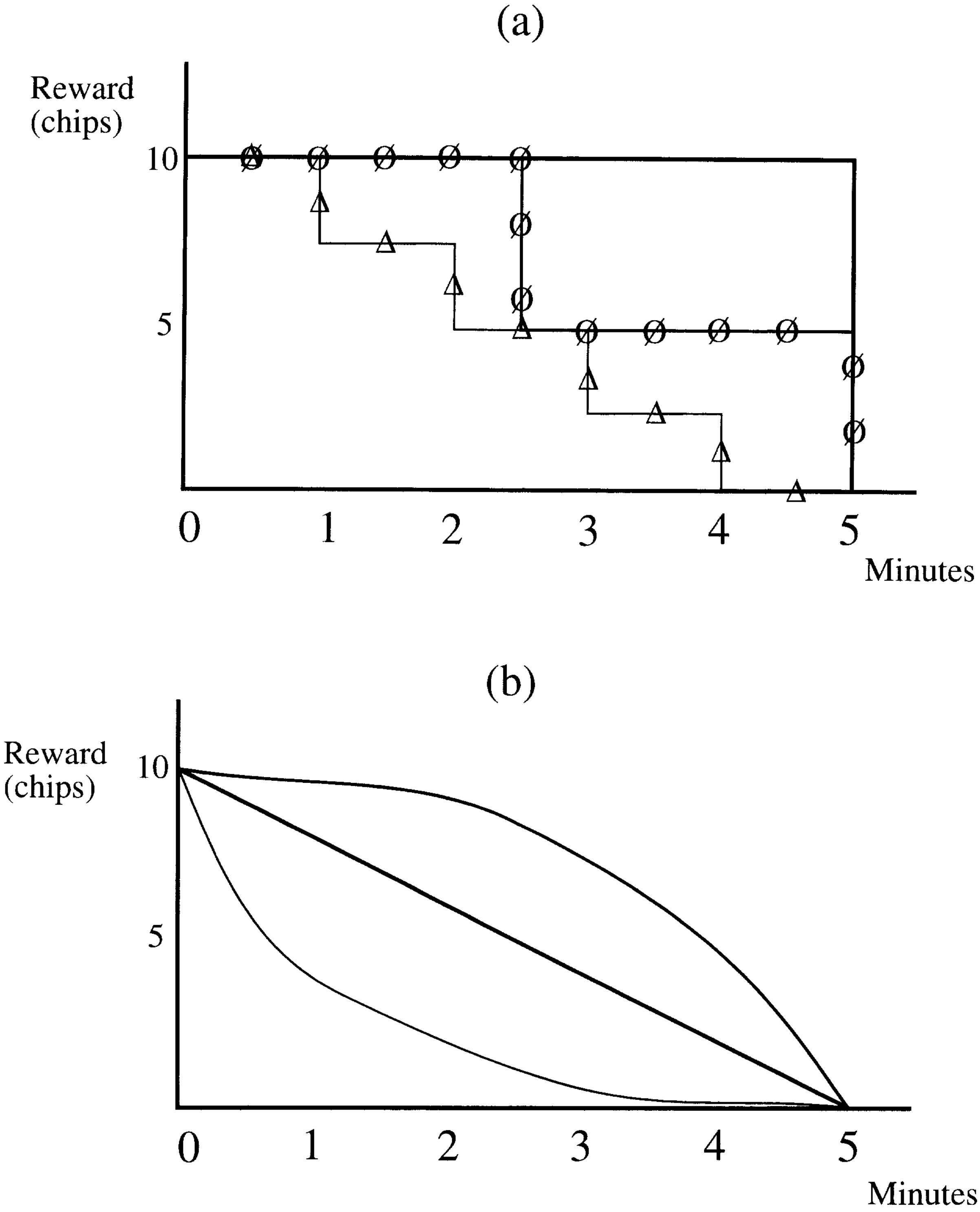

Figure 2. Transaction Costs

sions—rewards decrease at a constant, increasing, or a decreasing rate. For example, in the linear session the 10 chip reward decreases immediately such that if the pairing takes 1 minute to reach an agreement, the final reward is 8 chips. If the session lasts 3.5 minutes, the reward is 3 chips. The clock stops either after both parties sign the agreement form, or if the controller unilaterally ends the session. Each subject participated in all six sessions, each with a unique pairing. All bargains used a personal computer that illustrate transaction costs by a shrinking bar graph. All bargains were face-to-face. No physical threats are allowed. In addition to winnings from the bargaining sessions, subjects received a $4 hourly payment.

Three observations emerge from the bargaining experiments. First, transaction costs significantly reduce the efficiency of the bargaining sessions. Specifically, nearly 75% of the potential gains from bargaining are lost. Although a portion of this loss is due to the transaction costs themselves, considerable dead-weight loss persists. Second, the bargaining agreements cluster around equitable splits, rather than the outside option or Nash equilibrium, supporting earlier studies. But the propensity for equitable splits decreases as a bargainer's wealth diminishes, and is significantly affected by the genders of the bargaining pair.[8] Third, a "deadline effect" is not observed across all treatments—bargainers do not wait until the last moment before agreeing on a contract. We attribute this result to both the transaction costs and the ability of the owner of the property rights to unilaterally end the bargain.

Environmental policy reform through dispute resolution and negotiated settlements must identify the relationship between transaction costs, institutional structures, and relevant indicators of success (e.g., economic efficiency, distribution of wealth). The lessons learned in the lab provide insight into how transaction costs affect the potential efficacy of environmental negotiation. Key issues that can be considered in the lab include how bargaining is affected by uncertain contract enforcement, multiparty bargains, bargains with principal-agent relationships, managed and unmanaged negotiation, the impact of a third-party negotiator, and alternative preferences.

3. Environmental Conflict

Environmental conflict comes in all shapes and forms. People exposed to industrial waste discharge or intensive agri-chemical use devote substantial resources to protect themselves from the risk. Individuals construct filtering systems, firms do likewise. The United States and Canada debate over acid deposition, as do Sweden and Great Britain. North Carolina and Tennessee have conflicting views over the potential for dioxin contamination of the Pigeon river. As pressure mounts to use scarce natural resources wisely, the intensity of environmental conflict will undoubtedly increase.

Environmental policy encourages conflict by promoting technological solutions that simply transfer risk through time or space. Obvious examples include taller stacks for air emissions and storage facilities for nuclear waste. Taller stacks transfer the risk to other geographic regions, while storage sites transfer risk to future generations. These conflicts evolve from unilateral, noncooperative action of one individual, firm, state, or country transferring risk to others. The end result is too many resources devoted to reduce environmental risk—this is somewhat unexpected since economists have traditionally argued that too few resources are employed in pollution control. Technology that transfers risk creates conflict, and a well-intended policy prescription results in inefficient resource allocation.[9]

Game theory and gaming experiments are well-suited to study the economic implications of environmental conflict. A rich variety of strategic behavior can be explored to better understand how noncooperative behavior in pollution control and misallocate scarce resources. A measure of inefficiency in a conflict—rent dissipation—reflects the consequence of a wide range of strategic behavior. The trade-off between the social cost of pollution and rent dissipation can be evaluated in the lab.

To illustrate, consider a conflict where two identical risk neutral players, 1 and 2, compete to win a reward G. Let x_1 and x_2 represent the irreversible effort expended by players 1 and 2 to win the conflict. The probability that player 1 or 2 wins is represented by $p_1 = p_1(x_1,x_2)$ and $p_2 = p_2(x_1,x_2)$. Assume $p_i' \equiv \partial p_i/\partial x_i > 0$, $p_i'' \equiv \partial^2 p_i/\partial x_i^2 < 0$, $\partial p_i/\partial x_j < 0$, and $\partial p_i'/\partial x_j < 0$ for $j \neq i$. The first two terms reflect the standard assumption of diminishing returns to effort, while the third and fourth terms imply that player j's effort decreases both the total and marginal productivity of effort of player i.

Player i selects x_i to maximize his or her expected payoffs

$$\text{Max } [p_i(x_1,x_2)\,G - C_i(x_i)],$$

yielding the following first- and second-order conditions for an interior maximum

$$\begin{aligned} p_i'G - C_i' &= 0 \\ p_i''G - C_i'' &< 0, \end{aligned}$$

where $C_i(x_i)$ is the cost function for effort expended in the contest. Assume $C_i' > 0$ and $C_i'' < 0$.

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[8] Women were more likely to bargain to equal splits with men than with other women.

[9] See Crocker and Shogren for further discussion on transferable risk.

		FAVORITE				
		C1	C2	C3	C4	C5
UNDERDOG	R1	400,400	400, 1660	400, 1570	400, 1520	400, 1120*
	R2	1660, 400	700, 1180	580, 1210**	536, 1204	380, 960
	R3	1570, 400	747, 1043	610, 1090	557, 1093	357, 893
	R4	1520, 400	758, 982	616, 1034	560, 1040*	342, 858
	R5	1120, 400	640, 700	503, 747	442, 758	160, 640

Figure 3. 5 × 5 Expected Payoff Table

Given specific probability-of-winning functions (e.g., logit), Baik and Shogren demonstrate that if one player has more ability—the favorite—such that his or her chances of victory exceed one-half at the Nash equilibrium, both players will prefer the weaker player—the underdog—to commit to expend effort first. Both players' expected payoffs are the greatest if the underdog leads and the favorite follows given subgame perfection is used as the equilibrium concept.[10] This reduces social cost by reducing rent dissipation. The Canadian-US acid rain debate is an example of the underdog moving first to enact environmental policy before the favorite (Forster).

Holt et al. test the robustness of the favorite-underdog hypothesis by constructing a two-stage gaming experiment. In Stage 1 the favorite and the underdog independently decide to whether lead or follow. In Stage 2 the players select a level of effort in the order determined in Stage 1. Within this design there are three potential subgames—simultaneous-move subgame,[11] favorite-leads subgame, and the underdog-leads subgame. Figure 3 illustrates a 5 × 5 expected payoff matrix, where each cell lists payoffs in tokens worth $0.01 each. For example, if the underdog selects row R2 and the favorite selects column C3, the underdog's expected payoff is 580 tokens—$5.80, while the favorite expects to earn 1210 tokens—$12.10. Twenty trials are run, each player faces a different opponent for each trial, and there is no time limit. One trial is selected at random to determine take-home pay.[12]

There are three potential equilibria in Table 1. First, the equilibrium in the simultaneous-move subgame is (R4, C4) = (560, 1040)—neither player has an unilateral incentive to deviate from his or her strategy, given the supposed strategy of the other player. Second, the equilibrium in the favorite-leads subgame is (R1, C5) = (400, 1120). Third, the equilibrium in the underdog-

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[10] In a multi-stage game, a subgame perfect equilibrium exists if every subgame has a Nash equilibrium—no player has an incentive to deviate from his or her choice of effort at any stage of the game. The criteria for a Nash equilibrium is that each player maximizes his or her own expected payoffs, given the likely actions of the other player. See Fudenberg and Tirole (pp. 69–100) for a detailed discussion of subgame perfection.

[11] Note that if both players decide to lead or if both decide to follow, then effort will be selected simultaneously in Stage 2.

[12] The use of a random-trial-payoff scheme will not affect behavior if the independence axiom supporting expected utility theory holds, i.e., if expected utility is linear in probabilities.

leads subgame is (R2, C3) = (580, 1210). Since both players' expected payoffs in the underdog-leads subgame exceed those in the other two subgames (favorite—1210 > 1120 > 1040; underdog—580 > 560 > 400), the subgame perfect equilibrium is for the underdog to move first and select R2 and for the favorite to follow and select C3.

Overall, the results do not support the theory. Instead, the results suggest that the underdogs do not always prefer to lead (35–58% in all trials) and favorites do not always follow (55–77%). Underdogs who lead overinvest in effort, while favorites underinvest. Total dissipation of the reward is also greater than predicted—a result more consistent with the argument that number 2 tries harder. This breakdown of subgame perfection is supported by the seemingly irrational behavior observed in McKelvey and Palfrey's centipede gaming experiment. The failure to support subgame perfection, even in our relatively straigtforward game, suggests that we should remain cautious in predicting environmental policy reform based on gaming behavior until we better understand the limits of strategic behavior and dynamic choice in games with complete information.[13]

Another important, but relatively unexplored, area of environmental conflict is the private enforcement of environment regulation. The regulator sets incentives through symmetric, asymmetric, or no reimbursement than can influence the level of investment in legal resources, thereby changing the social cost of the conflict. A regulator's choice of legal fee reimbursement and its efficiency effects can be explored in the lab. In addition, a private enforcer has a choice of whom to sue—either the polluting firm or the federal or state agency responsible for the enforcement of the regulation. The choice reveals the private enforcer's preferences both for outcomes and for the lotteries that define the probabilities of achieving these outcomes. Depending on relative costs and benefits, the enforcer will sue the agent most likely to produce the desired objective. Finally, lab work can explore the link between Coasian bargaining and conflict rules where zero rent dissipation can be maintained as a Nash equilibrium, thereby allowing settlement of the suit prior to trial.

4. Risk Reduction Mechanisms

Psychologists have observed that an individual's valuation of a good can be influenced by alternative ways of representing the good (e.g., Tversky and Kahneman). In the case of environmental risk, this evidence suggests that *how* the risk is reduced may affect the value an individual assigns to the protection of life and limb. Since individuals can reduce the expected damages of an environmental risk by employing self-protection or self-insurance, either privately or collectively, understanding how the risk reduction mechanism affects value is important for public policy (Shogren and Crocker 1991). Self-protection reduces the probability of the loss, while self-insurance reduces its severity (Ehrlich and Becker).

In a classic two-state world, if self-protection guarantees a 0% probability of a loss and a 100% probability of a gain, an individual's value for self-protection is his or her certainty equivalent, x, such that

$$U(M + G - x) = pU(M - L) + (1\text{-}p)U(M + G) \qquad (1)$$

where p and 1-p ($0 \leq p \leq 1$) are mutually exclusive and jointly exhaustive probabilities of a monetary loss, \$L, and a monetary gain, \$G. Let U represent the thrice differentiable, continuous, increasing von Neumann-Morganstern expected utility function, and M be endowed monetary wealth. In contrast, self-insurance reduces the loss, L, to zero, while maintaining the original odds for a gain

$$pU(M - z) + (1\text{-}p)U(M + G - z) = pU(M - L) + (1\text{-}p)U(M + G) \qquad (2)$$

where z is the individual's value of self-insurance risk reduction.

Although a person can access combinations of these risk reduction mechanisms, little is known about how these substitution opportunities affect rational choice under risk. To better understand rationality given multiple opportunities to reduce a risk, Shogren and Crocker (1993) designed a set of experimental risk reduction auctions of sequential substitution between private and collective self-protection or self-insurance. The increased opportunity set can reveal implicit preferences for alternative risk reduction mechanisms.

We test rational behavior by examining two hypotheses—whether the sequencing of the private and collective mechanisms affects valuation, and whether individuals prefer self-protection to self-insurance. First, Shogren (1990) observed that in the single mechanism markets, private risk reduction was preferred to collective reduction. The disparity in private and collective values probably reflected the perceived impact of the two auction mechanisms. Individuals may perceive the private auction as more effective than the collective auction where they had less control and the incentive to report low bids. This incentive should remain in the multiple mechanism markets regardless of the sequence of the private or collective auction. If the

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[13] Also see Roth (1991), Smith (1992), and Stone and Schaffner (ch. 9).

sequence matters it is critical that future attempts to value risk using contingent valuation should incorporate various feasible combinations of the alternative risk reduction mechanisms.

Second, theory and evidence both suggest that self-protection should be preferred to self-insurance. Examining equations (1) and (2), the value of self-protection exceeds the value for self-insurance for the risk neutral or risk averse expected utility maximizing individual, $x > z$. For a risk neutral individual, $x = p(L + G)$ and $z = pL$, implying $x > z$. For a risk averse individual, $x = M + G - U^{-1}(EU)$ and $z = M + G - U^{-1}(EU + p[U(M + G - z) - U(M - L)])$, again implying $x > z$. The single market experiments supported this result. Multiple opportunities should not change this incentive—self-protection should be preferred to self-insurance. We test this hypothesis by comparing the final experienced bids for self-protection and self-insurance for both private and collective auctions. Further evidence of a difference supports the argument that both probability and severity reduction must be considered in risk valuation.

The experiment constructs private and collective risk reduction mechanisms by combining two auctions for self-protection and self-insurance. The private auction is a Vickrey sealed bid, second price auction where the highest bidder secures the 100% risk reduction and pays the highest losing bid. The Vickrey auction has been promoted as a possible elicitation device for contingent valuation because of its well-known preference revealing properties.[14] The collective auction was a modified Smith (1980) sealed bid auction, where the cost to reduce risk equaled the sum of the subjects' expected consumer surplus. Costs were not public information. If the sum of collective bids exceed the costs of provision, the mean collective bid was posted as the reigning price. Unanimity was required such that any one could veto collective risk reduction. Collective reduction was also rejected if the summed bids were less than costs.

The auction environment is defined as follows. Let $M^i(t) = (m_1^i(t), m_2^i(t))$ represent the set of messages sent by subject i in trial t, where $m_1^i(t)$ and $m_2^i(t)$ are the messages sent in auction 1 and 2 by subject i. The set of all messages sent in auctions 1 and 2 at trial t are represented by $m_1(t) = (m_1^1(t), m_1^2(t), \ldots, m_1^n(t))$ and $m_2(t) = (m_2^1(t), m_2^2(t), \ldots, m_2^n(t))$. The commodity to be auctioned, $h_1(t)$ or $h_2(t)$, is a private or collective risk reduction from a binary lottery, $\vartheta = [p, +\$G; (1\text{-}p), -\$L]$. The parameters for the four binary lottery treatments were $p = 1\%, 10\%, 20\%, 40\%$, $L = \$4$, $G = \$1$, and $M = \$10$. Let $h_1(t) = (h_1^1(t), h_1^2(t), \ldots, h_1^n(t))$ and $h_2(t) = (h_2^1(t), h_2^2(t), \ldots, h_2^n(t))$ reflect the allocation rules in the auctions. The cost rules for the auction are written as $C_1(t) = (C_1^1(t), C_1^2(t), \ldots, C_1^n(t))$ and $C_2(t) = (C_2^1(t), C_2^2(t), \ldots, C_2^n(t))$, were $C_1^i(t)$ and $C_2^i(t)$ are the costs to the agent i in auctions 1 and 2.

Given these definitions, the institutional structure, I, of our private-collective auctions is

$$I = \begin{cases} \Big[h_1^1(m_1(t)) = 1, \quad C_1^1(m_1(t)) = b_1^2(t); \quad h_1^i(m_1(t)) = 0, \quad C_1^i(m_1(t)) = 0 \\ \qquad\qquad \text{for } \forall i \neq 1 \Big| \sum_{i=1}^{n} b_2^i(t) < E[CS] \text{ or } V \geq 1 \Big] \\ \Big[h_2^i(m_2(t)) = 1, \quad C_2^i(m_2(t)) = \sum_{i=1}^{n} b_2^i(t)/n\forall i \Big| \sum_{i=1}^{n} b_2^i(t) \geq E[CS] \text{ and } V = 0 \Big] \end{cases}$$

where all messages are in the form of bids—$m_1^i(t) \equiv b_1^i(t)$ and $m_2^i(t) \equiv b_2^i(t)$. Let bids be ordered from highest to lowest such that $b_1^1(t) > b_1^2(t) > \ldots > b_1^n(t)$ and $b_2^1(t) > b_2^2(t) > \ldots > b_2^n(t)$. Also $V = 0$ reflects unanimity in collective voting for risk reduction, and $V \geq 1$ implies at least one veto vote in the collective. Expected consumer surplus, E[CS], is the cost to supply the collective risk reduction.

Four markets were created—(a) Private, then Collective self-protection; (b) Collective, then Pri-

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[14] The intuition behind the Vickrey auction is straightforward. If a player bids higher than her true value, she increases the probability of winning the prize, but she also increases the likelihood that the highest losing bid will exceed her true value, thereby resulting in a negative surplus. Alternatively, bidding lower than her true value decreases the likelihood of winning the prize. The dominant strategy is for the player to bid her true value.

vate self-protection; (c) Private, then Collective self-protection; and (d) Collective, then Private self-insurance. The Private, then Collective Markets first gave the subjects an opportunity to reduce risk via the Vickrey auction. After the highest bidder was announced, the subjects had the opportunity to collectively reduce risk. All subjects, including the highest bidder in the private auction, reported a bid for collective provision. If the collective provision was rejected, only the highest bidder in the private auction secured a 100% risk reduction. The Collective, then Private Markets operated identically with one noted exception—if collective provision was accepted, the private market did not operate. Otherwise, the private auction was held.

The subject's rational behavior is defined as $M^i(t) \equiv \beta(u^i, n > 1 \mid I)$, where u^i is the value of risk reduction for subject i. Our results suggest the risk reduction mechanism still matters, but not as much. We reject the hypothesis that the order of the multiple markets does not influence the value of risk reduction. Table 2 displays the statistics for a Wilcoxon rank sum test to compare the private and collective bids in each market. For each lottery in each market, statistically significant differences between private and collective bids always occurred in the Private, then Collective markets (5% confidence level). But in the Collective, then Private markets, the frequency of significant differences between private and collective bids was only 12.5%. In one case the collective bid actually exceed the private bid (10% lottery—Collective, then Private self-protection). This result points out the importance of understanding the relationship between collective and private actions.

Table 2. Order of Multiple Markets and the Value of Risk Reduction: Wilcoxon Rank Sum Tests between Average Private and Collective Bids for Combined Markets

Market	Loss Probability	Test Statistic	Observed Significance Level
Self-protection, then collective protection	1%	−2.403	.02*
	10%	−3.347	.00*
	20%	−3.347	.00*
	40%	−3.643	.00*
Collective protection, then self-protection	1%	−1.935	.05*
	10%	−1.678	.09
	20%	−1.676	.09
	40%	−0.714	.48
Self-insurance, then collective insurance	1%	−3.095	.00*
	10%	−2.664	.01*
	20%	−2.664	.01*
	40%	−2.896	.00*
Collective insurance, then self-insurance	1%	−1.416	.16
	10%	−1.038	.30
	20%	−1.038	.30
	40%	−0.669	.50

*Significant at 95% level or better that bids were not derived from the same paretal distribution.

We also reject the hypothesis that self-protection is valued more highly than self-insurance. Table 3 presents the Wilcoxon matched sample sign test where in only 2 of 16 cases did the self-protection and self-insurance bids exhibit statistically significant differences. This result challenges Shogren's (1990) earlier support of the hypothesis, and violates the first-order stochastic dominance property of expected utility theory. This is somewhat discouraging in that the additional complexity of sequential risk reduction opportunities is a mere fraction of the complexity in the world. Future attempts to value reductions in risk need to consider how alternative risk reduction mechanism affects the revealed value of life and limb.

5. Food Safety

Policy makers need information on the benefits and costs of food safety to enact effective national policy. Current estimates of the costs of food-borne illness range from $4.8 billion to $23 billion. But it is posited that these cost-of-illness measures underestimate the true cost of unsafe food because individuals presumably would be willing to pay more than the actual costs incurred—Roberts argues that the true cost is underestimated by at least an order of magnitude. This implies that we need to develop valuation techniques to estimate the demand for safer food. Survey methods such as the contingent valuation method allow one to directly obtain value estimates. But regardless of how well these surveys are designed and executed, people still know they are valuing a hypothetical scenario. The absence of real market discipline creates an environment conducive to inaccurate and unreliable responses.

The lab offers an alternative approach to elicit values for safer food. Following the pioneering work of Bohm (1972) and Coursey et al., Hayes et al. construct an experimental auction market to elicit the value of safer food. The experimental markets elicit the option price measures of value for five food-borne pathogens—Campylobacters, Salmonella, Staphylococcus aureus, Trichinella spiralis, and Clostridium perfringens. In addition, we constructed six additional experiments to evaluate how subjects respond to changes in the risk of illness for a given pathogen—Salmonella, and to determine if there is a pattern of surrogate bidding in the elicited values. All experiments use real

Table 3. Self-Protection versus Self-Insurance: Wilcoxon Matched Sample Sign Tests for Valuation Difference between Protection and Insurance

		Private Bid		Collective Bid	
Matched Markets	Loss Probability	Test Statistic	Observed Significance Level	Test Statistic	Observed Significance Level
Self-protection, then	1%	0.49	.63	0.73	.46
collective protection *and*	10%	0.33	.74	−0.15	.88
self-insurance, then	20%	1.66	.10	1.94	.05*
collective insurance	40%	0.99	.32	0.63	.53
Collective protection, then	1%	−1.43	.15	−0.82	.41
self-protection *and*	10%	−2.61	.01*	−0.92	.36
collective insurance,	20%	−0.04	.97	1.78	.08
then self-insurance	40%	1.61	.11	0.83	.41

*Significant at 95% level that bids were not derived from the same parental distribution.

money, real food, repeated opportunities to participate in the auction market, and full information on the probability and severity of the food borne pathogen.

Performed at the Iowa State University meat-testing lab with modern kitchen facilities, the general experimental design follows a two stage procedure—first, after subjects fill out a questionnaire on general knowledge of food safety and personal food consumption patterns, a five trial pre-test using a candy bar is used to acquaint the subjects with the Vickrey auction. Second, two types of food items are introduced and described to the subjects. One item is a test product purchased from a local source with the typical odds of being contaminated with a food borne pathogen. The second item was the same product stringently screened for pathogens with a low probability (1 in 100 million) of illness. Ten trials of the Vickrey auction are used to elicit "naive" bids to upgrade to the stringently controlled item from the test item. The bids are naive in that the monitor does not provide information on the objective odds of illness; only the individual's subjective perception and the second highest bid are available to guide bidding. After trial ten, the monitor provides information about the objective chance and severity of the pathogen. Ten more trials are run to elicit "informed" bids. The objective chance was calculated for the likelihood that a typical U.S. consumer would become ill from the relevant pathogen for one meat-related meal.

Our results suggest four patterns of behavior. First, we examined whether our data fit the oft-observed empirical phenomena that people tend to overestimate low probability risks. If so, this would violate the linearity-in-probabilities condition in the independence axiom underlying expected utility theory (Machina). We elicited each subject's subjective probability of food borne risk by asking him or her to estimate the number of people out of 1 million who will become ill from the pathogen given that one consumes an average American diet. The results that the subjects actually underestimate the annual probability of becoming ill from a food-borne pathogen, a result inconsistent with earlier observations (see Viscusi and Magat).

Second, we measured the ex ante economic value to reduce the risk from each of the five pathogens. Figure 4 shows the average bids per trial with and without outliers for Campylobacter. For each participant, we elicited either the option price to decrease the objective risk of a given pathogen to a 1 in 100 million chance, or the compensation demanded for an increase in risk from the 1 in 100 million odds to the objective risk level. The robustness of the observed measures of value is explored given repeated market participation with and without full information of the objective probability and severity of the given pathogen. We expect the value measures to reflect the wide range of objective risks (1 in 125,000 to 1 in 25 million). Our results suggest that the value measure is not particularly robust to changes in the relative risk levels of the five pathogens. Value is fairly constant across pathogens, even given the wide range of risks.

Third, given this pattern of constant bidding, we next elicited the value for one pathogen, Salmonella, given ten-fold increases in the level of risk ranging between a 1 in 13.7 chance to 1 in 1,370,000 chance. This allows us to examine how people respond to increases in the probability of illness, holding the severity of the illness constant. The results of these treatments suggest that the marginal option price decreases as risk increases, an observation consistent with the hypothesis that

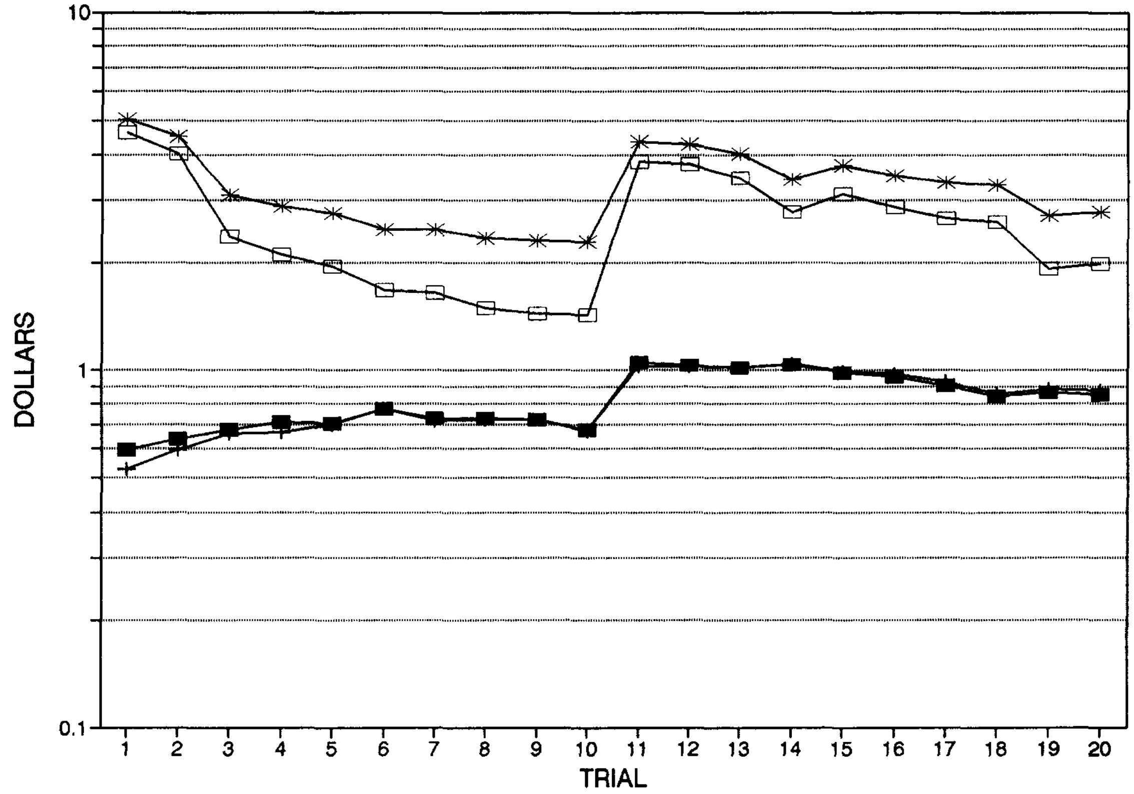

Figure 4. Average Option Price and Compensation Demanded for Campylobacter

people will pay more to eliminate the last bit of a risk than they will pay for an equal decrease that still leaves them facing a substantial risk (see Tversky and Kahneman).

Fourth, we tested for the existence of surrogate bidding. Kahneman argued that surrogate bidding exists if the value measures for a specific pathogens act as ersatz measures for general food safety preferences. If surrogate bidding prevails, then values for specific goods can not be relied on as accurate indicators of preference. Our work provides the first test of surrogate bidding in a lab valuation experiment with real money, a real good, and repeated market participation. We test for surrogate bidding by comparing the value estimates from each pathogen treatment with the value estimate from a treatment that combines all the pathogens. The objective risk of the combined pathogens is a 1 in 46,000 chance of illness per meal from at least one of the pathogens. Our results reveal evidence of surrogate bidding in that the average option price of the five pathogen treatments is not significantly different from the average value for a reduction in the combined risk of all five pathogens. Overall, subjects paid about $0.70 per meal to upgrade to a safer food product; an amount robust to the experimental treatment.

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. The relative ability to isolate and control potential problems such as surrogate bidding reveals experimental markets as a viable alternative to standard nonmarket valuation methods to evaluate the demand for safer food. Other applications of our experimental markets reveal patterns of regional variation in willingness to pay for increased food safety. Subjects in Arkansas and Massachusetts paid approximately twice as much as subjects in Iowa and California for the same reduction in exposure to Salmonella. We have also used the markets to explore consumer reaction to new food products and processes. Results suggest that informed consumers will accept milk from cows and lean pork from animals treated with growth hormones. Preliminary results also suggest a high level of acceptance of pork products treated by irradiation for the control of Trichinella, even among uninformed consumers.

6. Concluding Remarks

Information on how institutional incentives affect efficiency and how individuals value nonmarket goods is needed to guide environmental policy. Complementing field data, lab experiments provide insight to guide the decision maker's best guess as to the likely outcome of a proposed policy. Remaining skeptics may complain that environmental issues are too complex to be adequately captured in the lab. Two retorts—first, a general theory should work in a specific case. If not, it casts doubt on its general validity, allowing one to question the applicability of the theory to the more complicated world. The lab often provides the cleanest possible test of a specific case. Second, as argued by Plott (1989), complexity is not an argument against experiments, but rather an argument for a certain type of research program—one where the complexity of the lab experiment gradually increases to allow one to isolate and control the factors found to decrease the robustness of the model. The best guesses guiding environmental policy can be improved with careful identification of how such complexities as transaction costs, conflicts and strategy, alternative ways to reduce risk, and information affect behavior and value.

One last indulgence. Experiments have been promoted as an ex ante means to strengthen the contingent valuation (CVM) of nonmarket goods (see Coursey and Schulze). The idea is to go into the lab prior to the CVM survey to pretest incentive design. The ex ante research should improve the accuracy of the CVM survey by observing how bidding behavior is affected by alternative incentive compatible auctions and repeated market experience. I agree—but I also believe experiments can be used ex post as well. For lack of a better name, call this proposed ex post procedure CVM-X. There are four steps to CVM-X. First, after testing and revising the questionnaire, run the CVM survey and elicit hypothetical or real bids for the good in question. Second, bring subsamples of the CVM respondents into the lab to determine how their initial CVM bids are affected by a lab environment with real goods, real money, repeated market experience and alternative demand revealing auctions. Third, apply appropriate statistical analysis to predict the final experienced bids (X) based on the initial hypothetical bids and other socio-economic characteristics. Finally, adjust the bids of the CVM respondents who did not participate in the lab experiments for the learning and market experience effects revealed by the subsample. The CVM-X procedure could prove a cost-effective tool to combine the strengths of CVM and the lab—increasing the accuracy of a survey, and broadening the scope of nonmarket valuation in the lab. We are currently designing a CVM-X test on consumer acceptance of food irradiation; other applications would be enlightening.

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