Ultimatums and Tantrums: A Resource Sharing Experiment

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Abstract

The ultimatum game experiment has a long history in experimental economics. In-vivo ultimatum like strategic settings often involve uncertain rejection and payoff reversals. This paper presents the results of an ultimatum like experiment extended to reflect characteristics of a shared international river, in particular where a downstream nation has the potentially payoff reversing strategy option of a military strike. Subjects implicitly split an endowment between water consuming and security enhancing investments, where relative security investments determine the probability of the payoff reversal, with one subject being able to purchase a gamble to reverse the payoffs. Maximin, folk, and Nash solutions are compared, with results suggesting that behavior is

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responding to folk theorem like incentives. Dynamic analyses support this by showing no significant relationship between the gamble choice and its single period rationality.

JEL: C7,C9,N4,Q2

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1 Introduction

This experiment is motivated by the observation that for a shared river, a downstream nation may be able to use an arms race to divert resources of an upstream nation from water using activities to military accumulation. Using a model where military expenditure serves no productive function, Janmaat and Ruijs (2004) show that the threat of attack by the downstream nation can induce the upstream nation to invest in defense, rather than in water capturing activities. This results in greater volumes of water reaching the downstream nation. They also show that the threat of attack can benefit the downstream nation without an attack ever occurring.

There is considerable concern that pending water scarcity, particularly in the developing world, will lead to violent conflict (Falkenmark, 1990; Gleick, 1993; Orme, 1997). Empirical studies, using measures of population pressures as proxies for resource pressure, suggest that resource constraints may increase the risk of violent conflict both within nations (Hauge and Ellingsen, 1998) and between them (Tir and Diehl, 1998). The results are suggestive, but not all that strong. Case studies (Homer-Dixon, 1994, 1999) have mapped out linkages between resource scarcity and violence, but have been criticized for limited variability of variables important in the highly complex relationships (Gileditsch, 1998).

In this paper we focus on one specific relationship where military expenditure can serve a role in securing resource access, a shared international river. To isolate these incentives from the many other reasons nations may invest in their military, we use an experimental approach modeled on a modified ultimatum game. The experiment implements a version of the model developed in Janmaat and Ruijs (2004), a specialization of an anarchy model (Cothren, 2000; Garfinkel, 1990; Hirshleifer, 1995). We examine three cases, which differ in the attacker's cost. In one case there is a pure strategy Nash equilibrium where war always occurs, while in the others a pure strategy Nash equilibrium is absent. For all cases we compare the Nash outcome for the war always game with a maximin outcome and possible cooperative 'folk theorem' outcomes. Behavior appears to be influenced by the location of strategy combinations that are mutually beneficial.

Another situation with similar characteristics is the relationship between a parent and a young child. The parent is often in the position of choosing between an own preferred option and one preferred by the child. The child can respond to the parent's choice with a tantrum. The outcome of the tantrum is uncertain. The parent may give in or stand firm. Myopically, the subgame perfect solution to this game would involve the parent always giving in, and the child always throwing a tantrum. However, tantrums are costly to the child (banging head against wall hurts!), and myopic behavior is (thankfully) unrealistic in this repeated game. If the parent can invest in defense (perhaps by reading some of the many parenting books available), then the probability of the child winning falls. This, it is promised, will lead to a desirable change in the child's behavior.

The ultimatum game is a specialization of a bargaining game, where one participant in a two participant group, the proposer, chooses how to divide an allocation and the other, the responder, can accept or reject the division (Davis and Holt, 1993). A rejection typically results in both participants earning a default payoff, frequently zero. A special case of the ultimatum game is the dictator game, where the second participant has no choice but to accept the decision made by the first. The Nash equilibrium for the ultimatum game is to offer the smallest possible positive share to the responder, and in the dictator game the dictator should keep the entire allocation. These results are typically not observed, with the proposer offering considerably more than predicted (Güth and Tietz, 1990; Guth, 1995). This result can be explained by 'fairness' concerns or as an effort to maintain reciprocity relations that may be important outside the experimental setting. Alternatively, uncertainty about the responder's propensity to reject can also induce proposers to offer shares much higher than the Nash prediction (Chambers, 1988; Lopomo and Ok, 2001). One fairly effective method of generating near Nash results is to convince participants that they have earned the right to their power position. This has been done by allowing purchase of position in an auction (Güth and Tietz, 1990) or through performance on a pre-game task (Hoffman et al., 1994). List and Cherry (2000)also find evidence suggesting that behavior converges towards Nash more rapidly when the amount being divided is larger. Gantner et al. (2001) conducted an ultimatum experiment with advance joint production. Subjects choose investment levels, and then bargain over the results of the investment. They find that an equity model is a better predictor of behavior than the Nash equilibrium.

The dictator game structure is very similar to the default rights scheme on a river, riparian rights. With riparian rights, each water user along a water course has the right to use whatever quantity of water they want. None need be left for downstream users. Analogously to the dictator game, we expect water users to use water until the marginal product of water is zero. This prediction is strongly supported by behavior observed within developing country irrigation systems, where authorities are unable to control farmer's water use decisions (Chambers, 1988; Saini et al., 1989; Sharma and Acharya, 1989; Deshparde and Supe, 1989). After comparing successful and unsuccessful small scale irrigation systems in Nepal, Lam (1996) argues that technology which undercuts traditional reciprocity relations plays an important role in breaking down successful sharing arrangements, a result consistent with the experimental observations surrounding ultimatum and dictator games.

This paper reports on an experiment which extends the ultimatum game by making rejection a probabilistic event, where the probability that rejection is successful depends on choices of both players. The probabilistic rejection captures the uncertain success of a military strike or a temper tantrum. Both players can influence the probabilities by investing in defensive or offensive capacity, rather than 'accepting' the ultimatum and 'making the most of it.' The paper is organized as follows. The next section describes the model implemented in the experiment, leading to an overview of the experimental design. This is followed by a discussion of the results, which precedes the conclusion.

2 Model

The payoff tables used in this experiment are based on the model of two riparian nations on one river used in Janmaat and Ruijs (2004). In that model, nations have a fixed endowment to divide between productive investment and their military. For the experiment, we define the productive investment as simply 'investment', with the remainder of subject's endowment implicitly purchasing 'defense.'

There are two subject types, labeled A and B, with A representing the upstream nation and B representing the downstream nation. The expected payoff function for the upstream nation is

$$V_A = F_A(I_A) + G_B(1 - \pi(I_A, I_B))\,[F_A(0) - F_A(I_A)]$$

where I_i is the investment by type $i \in \{A, B\}$, G_B is B's choice to purchase a 'payoff reversal lottery,' $F_A(I_A)$ is a monotonically increasing production function for A, and $\pi(I_A, I_B)$ is a 'conflict' function that determines the probability of the event $I_A = 0$, the payoff reversal. Since the residual $\omega_i - I_i$, where ω_i is an endowment, is spent on defense, we require that $\partial\pi/\partial I_A > 0$ and $\partial\pi/\partial I_B < 0$. *Ceteris paribus,* each subject's expect return is decreasing in own investment.

The expected payoff for subject type B is

$$\begin{aligned} V_B &= F_B(I_A, I_B) + (1 - G_B)C_B \\ &+ G_B \pi(I_A, I_B)\left[F_B(0, I_B) - F_B(I_A, I_B)\right] \end{aligned} \quad (1)$$

where $F_B(I_A, I_B)$ is the production function for subject type B, satisfying $\partial F_B/\partial I_A < 0$ while $\partial F_B/\partial I_B > 0$, and C_B is the cost to B of choosing a payoff reversal lottery. In general, if $C_B = 0$, then it is optimal for B to always choose $G_B = 1$, while for large enough C_B, B will always choose $G_B = 0$. This experiment explores intermediate regions, where C_B is such that a one shot pure strategy Nash equilibrium does not exist.

In Janmaat and Ruijs (2004), investments I_A and I_B measure expenditures on water capture (dams, etc.), with an increase in upstream water capture, less is available downstream. The water payoff for each type of subject is

$$\begin{aligned} W_A &= P(1 - e^{-gI_A}) \\ W_B &= (P - W_A)(1 - e^{-gI_B}) \end{aligned}$$

with parameters at $P = 20$ and $g = 1$. This water then enters a constant returns to scale Cobb-Douglas production function

$$\begin{aligned} F_A(I_A, W_A) &= A I_A^{\alpha} W_A^{(1-\alpha)} \\ F_B(I_B, W_B(W_A)) &= A I_B^{\alpha} W_B^{(1-\alpha)} \end{aligned}$$

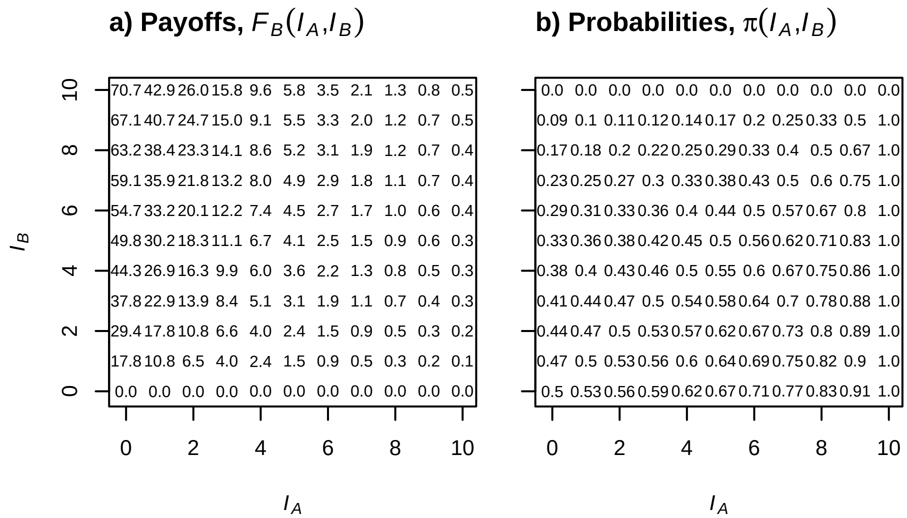

Figure 1: Payoffs and payoff reversal probabilities. Panel (a) reports payoffs, $F_B(I_A, I_B)$, for subject type B, as a function of I_A and I_B. Subject type A's payoffs, $F_A(I_A)$, are shown in the $I_A = 0$ column, with I_A replacing I_B. Panel (b) reports the probability that payoffs will be 'reversed', in the sense that I_A becomes zero, as a function of I_A and I_B.

with parameter values at $A = 5$ and $\alpha = 0.5$. This allows payoffs to be expressed strictly in terms of I_A and I_B. The function used to generate B's success probabilities was

$$\pi(I_A, I_B) = \frac{\omega_B - I_B}{(\omega_A - I_A) + (\omega_B - I_B)}$$

with endowments for each subject at $\omega_i = 10$.

The payoff function $F_B(I_A, I_B)$, evaluated at the choices available to the subjects, is shown in figure 1a. The payoff function $F_A(I_A)$ can be seen in the leftmost payoff column in the figure, with I_A replacing I_B. Figure 1b shows the probability that payoffs will be reversed, in the sense that I_A will be set to zero, should B choose rejection.

The payoffs and probabilities can be combined to determine an expected payoff, should B choose rejection, for each I_A and I_B combination. Since B's rejection choice occurs after I_A and I_B are chosen, and B knows those choices, then the one shot subgame solution is for B to choose $G_B = 1$ whenever expected payoffs exceed payoffs with $G_B = 0$ (assuming risk neutrality). The lottery cost C_B determines how large the expected gain must be before a rational, risk neutral, myopic individual will choose $G_B = 1$.

Figure 2 shows the expected payoffs to both players, assuming that B is maximizing single period expected return. The shaded region of the figure identifies strategy combinations where B will choose $G_B = 1$, and the hashed region marks strategy combinations that are mutually superior relative to the Nash when G_B is fixed at one. Being mutually superior to the Nash, they can be supported by a grim trigger strategy. As the cost of attempting a payoff reversal increases, the region where it is rational to do so shrinks. When $C_B = 10$. A Nash equilibrium exists at $(5, 5)$. When $C_B = 15$, $(5, 5)$ is no longer a Nash equilibrium, although at $(5, 5)$, it remains single period rational for B to choose $G_B = 1$. When $C_B = 35$, it is no longer rational to choose $G_B = 1$ at $(5, 5)$, and there is no pure strategy Nash equilibrium.

A couple of alternative solution concepts may apply when there is no Nash equilibrium. Uncertainty aversion (Chow and Sarin, 2001; Eichberger and Kelsey, 2000; Kelsey and Milne, 1999; Salo and Weber, 1995) suggests that players may adopt a *Maximin* like strategy, maximizing the minimum payoff over a set of possible opponent strategies. Suppose that each player

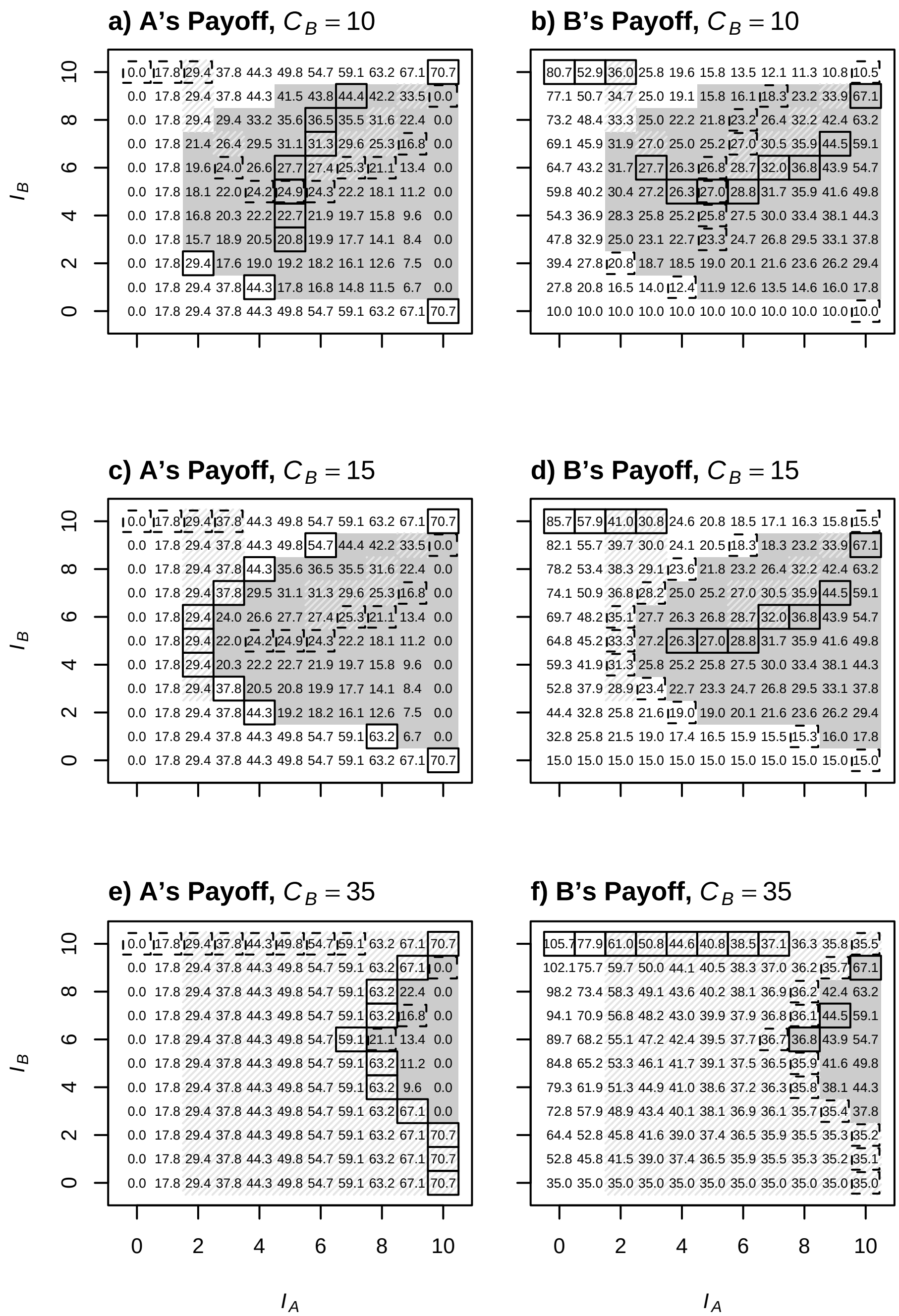

Figure 2: Expected payoffs assuming one shot rationality and subgame perfection. In solid shaded region, expected return for B with $G_B = 1$ exceeds certain return when $G_B = 0$. Hashed region strategies mark strategy combinations which generate mutually beneficial expected payoffs. Best responses are encircled with solid or dashed boxes.

Table 1: Experiment design matrix, with number of pairs in each group. $G_B = 1$ either results in a random or certain payoff reversal. Numbers in parentheses are session numbers. One control was also implemented, with G_B always equal to one.

Reversal	$C_B = 10$	$C_B = 15$	$C_B = 35$
Random	9(2,5)	10(8,9)	8(3,6)
Certain	3(4)	2(7)	-

believes that the other will choose a strategy from among the set of best responses. On this restricted strategy space, when $C_B = 10$, the maximin strategies and the Nash equilibrium coincide. When $C_B = 15$, the maximin occurs at $(2, 5)$, while when $C_B = 35$. With repeated play, Folk theorem solutions also suggest themselves. Mutually beneficial strategy pairs are easy to identify when there is a Nash equilibrium. For play in the absence of a Nash equilibria, Folk theorem points are marked relative to the payoffs at $(5, 5)$, the Nash for low cost games.

3 Experimental Design

The design matrix for this experiment is shown in figure 1. There are five treatments and one control. In three treatments, lottery cost is varied and payoff reversal is determined by drawing a random number. In two treatments the random payoff reversal is replaced by the expected values. Type B's now choose between two payoff tables. In addition to the five treatments outlined in the table, a control treatment (treatment 1) was also conducted, where G_B always equals one. This control had eight subjects in four pairs.

The experiment was implemented using pencil and paper. The instruction sheets and data recording sheets are available from the author on request. Each experimental session involved only one treatment. The experiment was conducted during a 120 minute session. At the beginning of the experiment, an instruction and record sheet package was distributed. The record sheet included space to enter the investment choice, and record the choice of G_B, as well as space to calculate the subject's own payoff and the payoff of the other subject. The instructions were read to all subjects before anyone was designated type A or B. The instructions were followed by two examples and a worked test that emphasized the calculation of expected values. The cases worked through demonstrated one case where it was optimal for B to set $G_B = 1$ and another where it was not. After an interval of about 10 minutes for subjects to work through two examples, the facilitator guided the subjects through the examples in detail.

The experiment was conducted in a partitioned classroom. Instructions were read to the subjects together as one group. The group was then divided in two, with one of the half groups moved to the other side of the partition. Subjects that appeared to know each other were kept in the same subgroup, to minimize non-induced preference problems. After subjects were divided and separated, one subgroup was randomly selected (coin flip) to be type A. Random numbers where then drawn to pair subjects. Pairings were written on cards and given to the facilitators. At the beginning of each round, subjects were asked to choose an investment level and enter it on their record sheets. After all subjects had entered their value, the sheets were collected and values displayed on a blackboard visible only to the other types (see figure 2). Subjects could see all choices by the other subjects, but did not know who they were paired with. Sheets were returned and subjects calculated payoffs and payoff reversal probabilities. Type B subjects now choose whether to purchase the preference reversal lottery. The choice was then revealed to type A subjects by circling the corresponding investment on the type A display. A two digit random number was then drawn by selecting two ping-pong balls from a bucket, each with a single digit on it. This number was then written on the board for each subject. This procedure was repeated, providing all subjects with a visible history of the investment choices for all subjects of the opposing type. Subjects then calculated their own payoff and the payoff of their opposing partner. All information entered on the boards was also recorded by an assistant with a computer at the back of the room, in a position to see both boards. This record was used for calculating the payments. Payments were made in cash at the end of the experiment.

4 Discussion of Results

Six sessions were conducted at Acadia University in March, 2004 and three in November 2004. The specifics are in the design matrix (Table 1). Sessions ran for approximately two hours on three different Saturdays. A total of 72 subjects participated, each earning an average of $13.50 in Canadian currency.

We consider three possible outcomes, two consistent with myopic play, and one allowing for dynamics. The myopic outcomes are the Nash equilibria for the game where a random payoff reversal can always occur, the

Table 2: Reproduction of fields in blackboard display. In this example subjects in the left half were numbered $1, 2, \ldots$ while subjects in the right half were numbered $6, 7, \ldots$. For each round, investment values selected by subjects in the left half of the room were written on the board visible to the right half, next to the number identifying the right half subject. The same pattern was followed for filling out the table visible to the left half subjects. After the investment values were entered, a random number was drawn and written in the appropriate row. The type B subjects' choice of G_B was then made known to type A by circling the investment value.

a) Left Half Room

Round	1	2	3	...
Draw	0.75			
#				
1	6			
2	4			
3	7			
⋮				

b) Right Half Room

Round	1	2	3	...
Draw	0.75			
#				
6	4			
7	5			
8	2			
⋮				

maximin outcome where each player maximizes the minimum payoff over all the rival's best response strategies. Dynamically, the fixed pairing suggests that folk theorem type cooperation may occur. Strategy pairs which generate mutually beneficial payoffs relative to the $G_B = 1$ Nash equilibrium are identified as folk theorem candidates. A number of regressions are also performed to compare between myopic and more dynamic interactions.

Table 3 reports the predicted outcome for Nash and Maximin. All formulations have a number of strategy pairs that Pareto dominate the Nash outcome. These are therefore not reported, but shown on the graphical representations that follow.

Before proceeding to specific hypothesis testing, the different possible groupings are examined. Table 4 reports the results for tests of pooling

Table 3: Nash and Maximin outcomes, with investment levels for each player and G_B choice. When $C_B = 15$, a pure strategy Nash equilibrium does not exist. However, at $(5,5)$, it is still one shot rational to choose $G_B = 1$. When $C_B = 35$, a pure strategy Nash equilibrium does not exist and at $(5,5)$, the rational choice includes $G_B = 0$.

C_B	Nash		Maximin	
	I_A, I_B	G_B	I_A, I_B	G_B
$C_B = 0$	(5,5)	1	(5,5)	1
$C_B = 10$	(5,5)	1	(5,5)	1
$C_B = 15$	*(5,5)*	*1*	(2,5)	0
$C_B = 35$	*(5,5)*	*0*	(7,6)	0

all possible pairs of sessions. P values in the table are adjusted using the method of Holm (1979). The upper right triangle P values are for tests of the form $H_0 : \mu_i^A = \mu_j^A, \mu_i^B = \mu_j^B$ on the regression of investment choices against session dummy variables, where i and j are different sessions. Two groupings suggested by these results are (1,2,4,7,8) and (3,6), with session 5 possibly on its own, and session 9's results fitting weakly in either of the first two groups. The lower triangle of table 4 reports corrected P values for tests of the form $H_0 : \mu_i^A = \mu_j^A, \mu_i^B = \mu_j^B, \mu_i^G = \mu_j^G$ for a dummy variable regression also including the G_B choice. To deal with the heteroscedasticity inherent in the fact that investment values range between 0 and 10 and G_B values are either 0 or 1, the inverse standard deviation for each observation series was used to weight the observations in the regression. Session 1 is not included in these results, as there was no G_B choice. The groupings that stand out how are (2,4,8) and (3,6). Session 5 stands alone, with 7 possibly belonging to the first group, and 9 again weakly fitting with either of the

Table 4: P values for equality restrictions between parameters for experiment sessions. Upper triangle tests equality of mean investment levels without considering G_B. Lower triangle tests equality of mean for all three controlled variables. P values are adjusted using the method of Holm (1979). Bold values are significant at $\alpha = 0.05$.

	2	3	4	5	6	7	8	9
1	0.1239	**0.0005**	0.9617	**0.0007**	**0.0000**	0.2218	0.9539	0.0808
2		**0.0000**	0.2033	0.0509	**0.0000**	**0.0024**	0.2218	**0.0005**
3	**0.0000**		**0.0003**	**0.0000**	0.3168	**0.0440**	**0.0138**	0.2340
4	**0.0277**	**0.0000**		**0.0013**	**0.0000**	0.1733	0.9250	0.0503
5	**0.0309**	**0.0000**	**0.0000**		**0.0000**	**0.0000**	**0.0162**	**0.0000**
6	**0.0000**	0.3151	**0.0000**	**0.0000**		**0.0041**	**0.0003**	**0.0084**
7	**0.0002**	**0.0027**	0.1142	**0.0000**	**0.0000**		0.2926	0.2415
8	0.2057	**0.0042**	0.2601	**0.0057**	**0.0000**	0.1872		0.2744
9	**0.0000**	0.2218	**0.0002**	**0.0000**	**0.0027**	**0.0287**	0.2218	

first two groups. Given these results, and the hypotheses to be tested, six groups are formed, 1, 2+4, 5, 3+6, 7+8 and 9.

A summary of the results is shown in table 5. It is immediately apparent that there is relatively little variation in the mean investment choices made by the subjects. For G_B, sessions 1, 4, and 7 stand out. However, the session one result is an artifact, as G_B was fixed at one. For treatments 4 and 7, subjects of type B chose which payoff matrices to use, after knowing both investment choices. The payoffs when they choose $G_B = 1$ were the expected values for sessions (2,5) and (8,9) respectively. All else equal, if subjects are risk averse, one expects the expected value to be chosen more frequently than having to bear the risk of a gamble. However, if type A can rationally expect a higher frequency for $G_B = 1$, then A would have a stronger incentive to

Table 5: Summary of Experimental Results. Sessions 1, 2, and 3 took place on Saturday the 27th of March, 2004, and sessions 4, 5, and 6 on the 3rd of April, 2004, and sessions 7, 8 and 9 on the 6th of November, 2004. Type indicates whether a random number was drawn (D) or if expected values were offered (E), whether G_B was fixed (F) or could be chosen (C), and the cost C_B of choosing $G_B = 1$. The number of subjects (N) and the number of rounds (T) are also shown.

					I_A			I_B		G_B
Session	Type	N	T	Min	Mean	Max	Min	Mean	Max	Mean
1	D,F, 0	8	25	0	5.07	9	0	5.00	10	1.00
2	D,C,10	10	17	1	4.59	9	1	4.89	10	0.65
3	D,C,35	8	21	1	6.05	9	1	6.26	10	0.52
4	E,C,10	6	30	0	5.26	10	2	5.40	10	0.98
5	D,C,10	8	21	1	4.07	9	1	5.93	9	0.69
6	D,C,35	8	21	0	6.44	10	0	6.40	10	0.54
7	E,C,15	4	30	1	5.92	10	0	5.60	10	0.85
8	D,C,15	8	14	1	5.38	10	2	5.71	10	0.66
9	D,C,15	12	17	1	5.48	10	0	6.01	10	0.54

choose an I_A such that B will not choose $G_B = 1$. However, the average I_A choice is larger than in the sessions where payoff reversal was random. This suggests that A's were 'betting' on B loosing the preference reversal lottery.

Bar graphs showing the choices made, token earnings, and frequency of preference reversal, are shown in figure 3. The graphs are arranged with the three controls on the left, and the sessions ordered from $C_B = 10$ to $C_B = 35$. For I_A and I_B there is a weak upward trend as C_B increases. For both players, earnings (V_A and V_B) are generally increasing in C_B. This is expected, as type B subjects receive C_B extra tokens if they choose $G_B = 0$. As such, the total surplus to divide is increasing in C_B. To correct for this, the relative efficiency is plotted as an overlay in panel (d). For all sessions, the maximum aggregate return is $F_A(10) + F_B(10, 10) + C_B$. However, the inequity of the resulting distribution can only be offset in this experiment by moves that will reduce overall efficiency. The relative efficiency shows very little difference across the treatments. Finally, the frequency with which $G_B = 1$ is chosen is decreasing in C_B. In line with this, the frequency with which the outcome of the draw favors B is weakly increasing in C_B. These results are mildly supportive of the maximin predictions presented in table 3, if one considers the direction of the effects. However, the precise predictions are far from satisfied.

Table 6 reports the results for multivariate tests of the hypotheses that observed average behavior either equals that of the Nash equilibrium for a game without the second stage, or equals the maximin outcome in table 3. When only the investment levels were tested against the different possible outcomes, classical hypothesis tests were used. However, since G_B can only take on one of two values, a bootstrap was used to test the three component nulls. These tests show that one cannot reject the hypothesis that average observed results for groups 1 and 2+4 are equal to the Nash outcome. None of the remaining groups are statistically close to either the Nash outcome or the maximin. Comparing the test statistic values, group 3+6 is closer to the maximin outcome than to the Nash outcome, while groups 7+8 and 9 are closer to the Nash outcome. The group containing session 5, for which the Nash and maximin outcomes coincided, and for which the Nash outcome was an equilibrium, has average choices which are statistically different from the Nash investment levels.

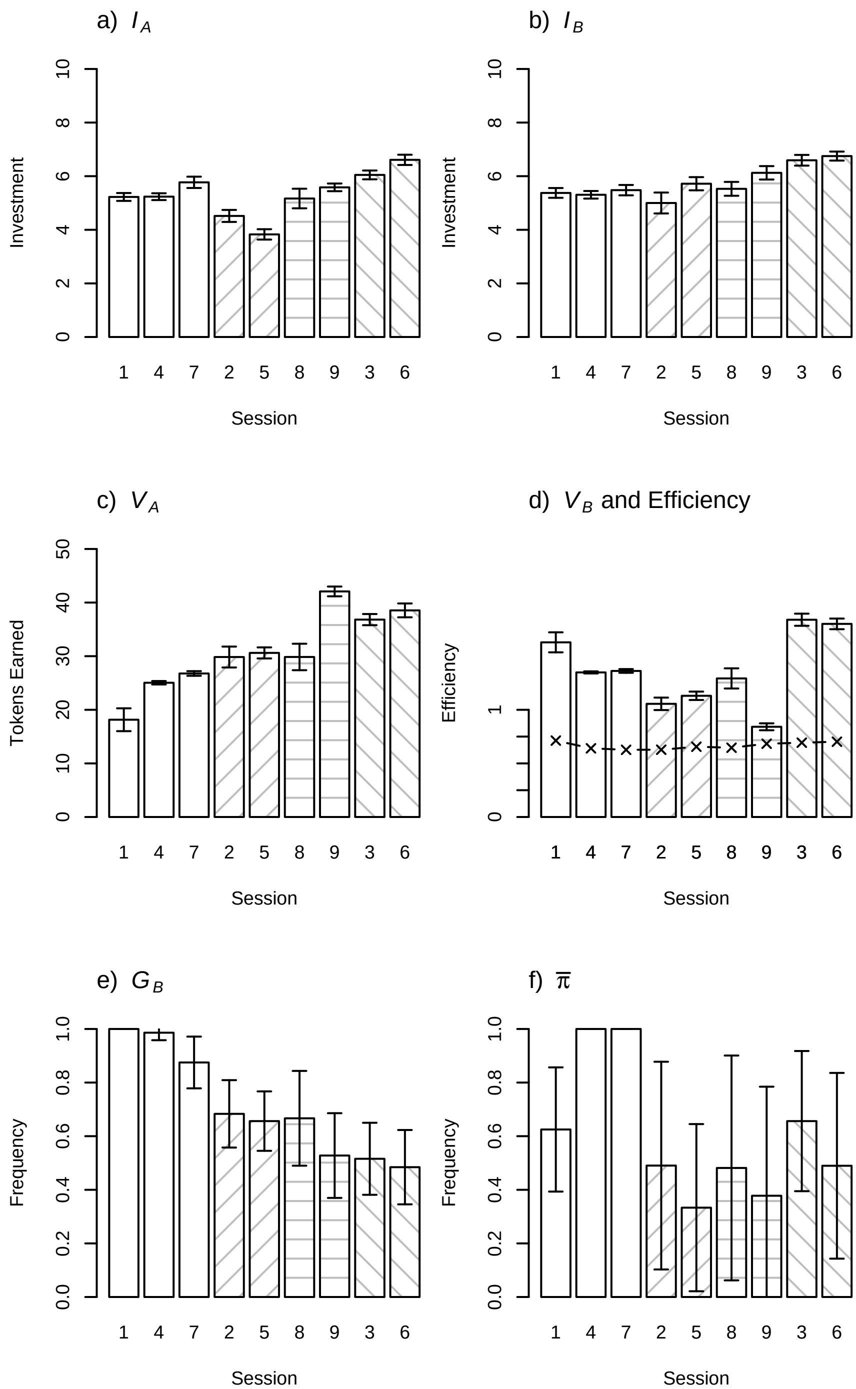

Figure 3: Investment, average tokens earned, frequency with which $G_B = 1$, and frequency at which payoffs were reversed.

Table 6: Multivariate tests of observed strategy combinations against predicted strategy combinations and Nash equilibrium. Classical tests are conducted without considering G_B. Bootstrap P values are calculated for joint hypotheses on I_A, I_B, and G_B. Bootstrap P values are generated using 9999 bootstrap samples.

					vs *Maxmin*		vs *NE*	
Group	I_A	I_B	G_B	H_0	F	P	F	P
Classical P Values, I_A and I_B								
1	5.23	5.38		5,5	-	-	1.13	0.3385
2+4	4.87	5.17		5,5	-	-	0.57	0.6321
3+6	6.33	6.67		7,6	7.41	0.0001	37.42	0.0000
5	3.83	5.72		5,5	-	-	9.51	0.0000
7+8	5.60	5.52		2,5	105.6	0.0000	5.09	0.0021
9	5.58	6.12		2,5	58.8	0.0000	6.70	0.0003
Bootstrap P Values, I_A, I_B and G_B								
2+4	4.87	5.17	0.85	5,5,1	-	-	1.26	0.2896
3+6	6.33	6.67	0.50	7,6,0	13.86	0.0000	57.80	0.0000
5	3.83	5.72	0.66	5,5,1	-	-	14.76	0.0000
7+8	5.60	5.52	0.79	2,5,0	162.2	0.0000	7.97	0.0003
9	5.58	6.12	0.53	2,5,0	88.03	0.0000	11.19	0.0000

The hypothesis tests highlight two results. First, in all the treatments where a pure strategy Nash equilibrium does not exist, treatments 3, 6, 7, 8 and 9, showed average behavior that was statistically different from the Nash outcome. Similarly, in three of the four treatments where a pure strategy Nash equilibrium exists, observed behavior is not statistically different from the Nash outcome. This implies that for this two stage game, the Nash equilibrium is a useful solution concept in those implementations where a pure strategy Nash equilibrium exists.

The second point highlighted by the hypothesis test results is that the maximin outcome provides little predictive power. These maximin solutions are constructed using all rival strategies that are part of the best response. The set of rival strategies which are considered in identifying the maximin can be further restricted, but only extreme restrictions change the predicted outcome. These are therefore not considered. For this game, the maximin does not seem to be an appropriate solution concept for those implementations where a pure strategy Nash equilibrium does not exist.

Another implication of the myopic version of these games is that, if type B players are risk neutral, they should choose $G_B = 1$ whenever its expected return exceeds that for $G_B = 0$, and both risk neutral and risk averse type B players should choose $G_B = 0$ whenever its expected return exceeds that resulting from choosing $G_B = 1$. Figure 4 plots the number of times each strategy pair was chosen, and the number of times that B choose $G_B = 1$. Table 7 reports the number of times that type B chooses $G_B = 1$, and the share of the total number of times the investment pairs fell in the rational and irrational regions for a risk neutral type B player. In all but one case

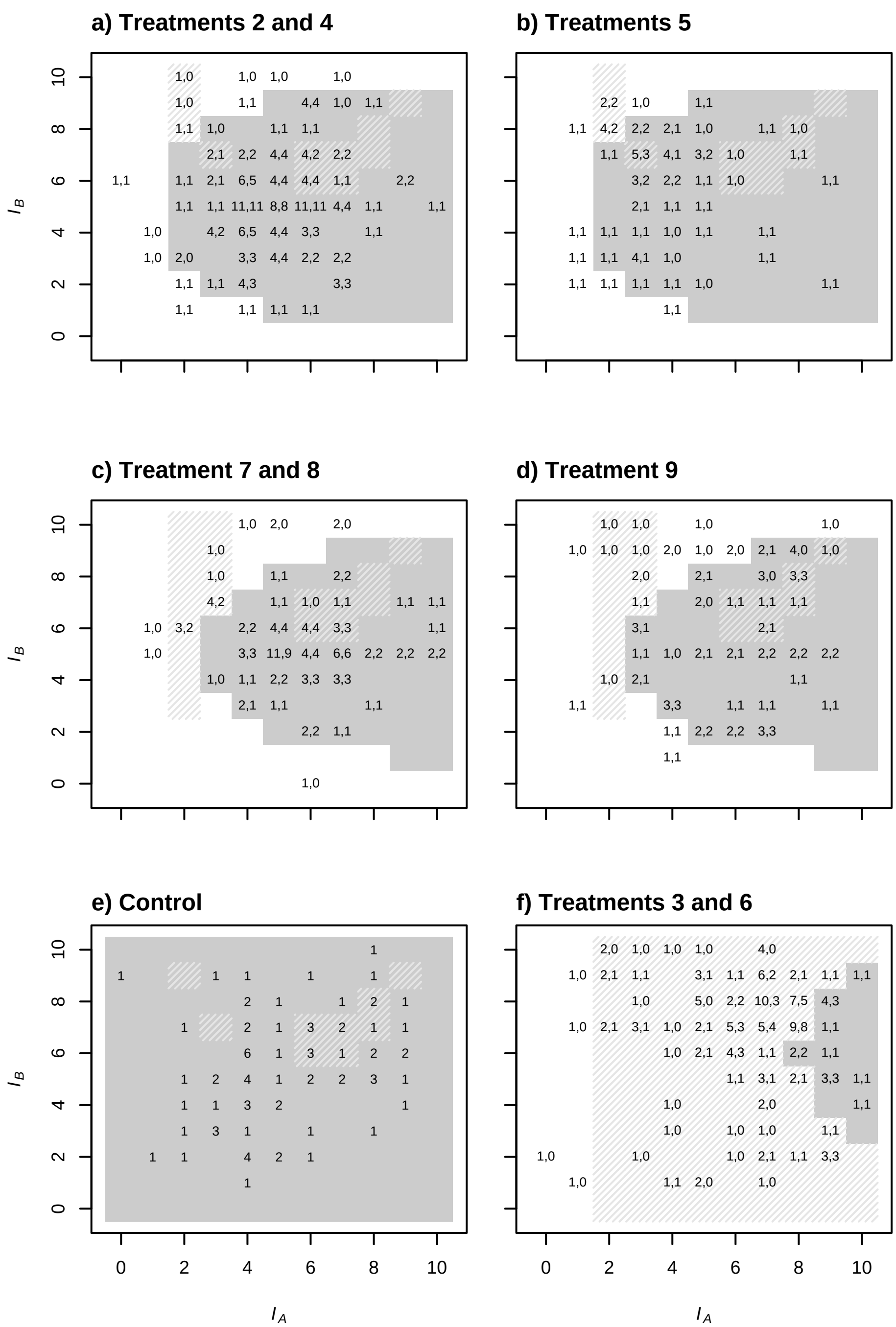

Figure 4: Strategy combinations by treatment group. Grey shaded region identifies investment strategy pairs where setting $G_B = 1$ is single period rational. Hashed cells mark strategy pairs where return to both players is greater than at $G_B = 1$ Nash equilibrium. Cells representing strategy pairs that were chosen at least once contain two numbers (except control). The first number is the number of times that this strategy pair was chosen. The second number is the number of times that with this strategy, $G_B = 1$ was chosen in the second stage.

Table 7: Frequency of $G_B = 1$ choice when this choice is myopically rational and when it is not for a risk neutral type B player.

	Rational			Not Rational		
Group	$G_B = 1$	Total	Ratio	$G_B = 1$	Total	Ratio
1	80	80	1.0	-	-	-
2+4	109	122	0.893	6	13	0.462
3+6	13	14	0.929	51	114	0.447
5	32	51	0.627	10	13	0.769
7+8	64	69	0.928	4	17	0.235
9	34	53	0.641	4	19	0.211

the frequency at which type B chose $G_B = 1$ was greater in the rational region than in the irrational region. This provides some weak support for rationality on the part of the players. However, as reported below, with a logistic regression, within round rationality does not provide any predictive power for the G_B choice.

To examine the results for focal points, cluster analysis was used. Figure 5 plots the centers of each of the clusters when there are six and three clusters remaining, and for the overall average. The clustering method used was the centroid method, where clusters are aggregated based on the distance between their centroids. The radius of the circles in the figure measures the relative number of members in the clusters. For treatment group 2+4, most investment pairs are part of a cluster near the Nash outcome, even when there are still six clusters remaining. This effect is similar, although somewhat less pronounced, for treatment group 7+8. For the control, there are two foci when six clusters remaining, but one dominates when the number of clusters falls to three. For all three, the focus is near the Nash outcome. For treatment 5, the foci look to be towards the boundary, with the larger concentrations in the direction of mutually beneficial points. Treatment 9 also appears to be focused towards mutually beneficial points, but these remain well inside the $G_B = 1$ region. For treatment group 3+6, the foci are in the neighborhood of the maximin point, but in the direction of combinations which are mutually beneficial relative to this outcome as well as relative to the Nash outcome. Since mutually beneficial outcomes can only be sustained through a Folk theorem style argument, will shortly consider a more dynamic analysis.

The rationality can be further analyzed using a logistic regression to predict the probability that $G_B = 1$. A range of regressions were considered, with the 'best' model including $\pi(I_A, I_B)$, the probability that I_A will be set to zero if $G_B = 1$; $\Delta V_B - C_B$, the difference in payoff to B between the case where $I_A = 0$ and I_A takes on the value chosen by A, net C_B; and D_G, the one shot rationality of setting $G_B = 1$, if B is risk neutral. The results for these regressions are shown in table 8. The results are presented both for the pooled model and the individual regressions. The AIC numbers suggest that the individual regressions are superior to the pooled regressions - the sum of the AIC values is lower. This is confirmed with a likelihood ratio test. Regressions were also run using investment levels instead of the probabilities and gains implied by them. Using nested model tests, these models were inferior to the model presented. An arcsine transformation of the probability levels was also used, to stretch the range of the probability variable. This did not significantly affect the results, so that results for raw probabilities are presented. The only arrangement where D_G entered significantly included only I_A, I_B and D_G, with no session factors. In this

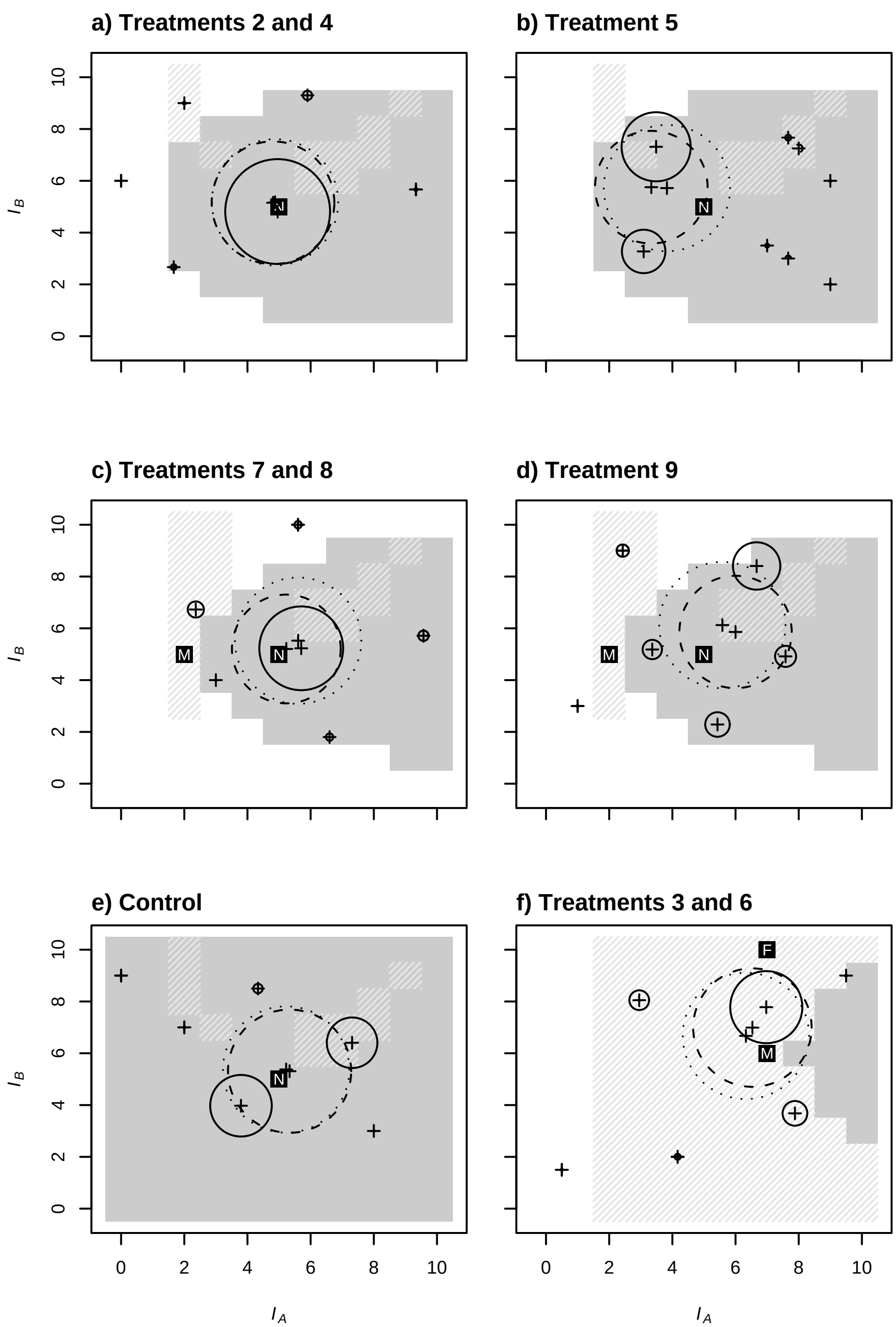

Figure 5: Cluster centroids and size for six, three, and one cluster for each treatment group. Circle radii indicate size of cluster. Shaded region is myopically rational to choose $G_B = 1$. Hashed cells indicate combinations where joint return exceeds Nash outcome for control.

Table 8: Logistic regression results. Dependent variable is G_B, and α_0 is the intercept. P values are for z scores. The last column reports the Akaike Information Criterion, which is calculated as $-2LLF + 2k$, where LLF is the log of the likelihood function and k is the number of parameters. D_G is a dummy variable equal to one when $V_B(G_B = 1|I_A, I_B) > V_B(G_B = 0|I_A, I_B)$. Values are bold when significant at the 10% level.

			$\pi(I_A, I_B)$		$\Delta V_B - C_B$		D_G		
Sessions	α_0	P	β	P	β	P	β	P	AIC
2+3+5+6	**-2.746**	**0.000**	**5.488**	**0.000**	**0.020**	**0.076**	0.304	0.328	415.15
2	**-6.978**	**0.004**	**14.20**	**0.002**	**0.107**	**0.020**	-1.811	0.174	62.69
3	-1.301	0.183	1.604	0.130	0.035	0.326	16.98	0.993	88.54
5	1.418	0.267	1.198	0.591	-0.024	0.414	-0.586	0.537	87.42
6	**-9.714**	**0.000**	**14.34**	**0.000**	**0.135**	**0.011**	-1.627	0.275	52.70
8	**-7.769**	**0.032**	**17.43**	**0.031**	0.076	0.256	-2.191	0.254	36.97
9	**-3.694**	**0.047**	**11.19**	**0.001**	-0.033	0.310	-0.012	0.992	60.98

situation, the weak relationship between D_G and the odds and net gain is coming through as a significant value on D_G.

If B is choosing G_B as a one shot rational response to I_A and I_B, and B is maximizing expected payoff, then the only significant explanatory variable should be D_G. However, this variable is never significant. For the individual regressions, $\pi(I_A, I_B)$ is significant in four of six cases, and $\Delta V_B - C_B$ is significant in two of six cases. The sign on the $\pi(I_A, I_B)$ term is always positive, indicating that an increase in the probability that I_A will be set to zero increases the probability that B will choose $G_B = 1$. The sign on $\Delta V_B - C_B$ is positive in four of six individual regression cases, and in both of the significant cases. A larger potential gain leads to a higher probability of choosing $G_B = 1$.

If B is not an expected payoff maximizer, then indifference between cer-

Table 9: Lagged dependent variable regressions.

Lagged:			I_A		I_B		G_B		
Dependent	α_0	P	β	P	β	P	β	P	R^2
I_A	**3.999**	**0.000**	**0.374**	**0.000**	-0.038	0.456	**-0.827**	**0.001**	0.137
I_B	**4.76**	**0.000**	**0.207**	**0.001**	0.078	0.178	-0.554	0.053	0.052

tain return when $G_B = 0$ and expected return when $G_B = 1$ is not an appropriate criterion for selecting the equilibrium. Since individual subjects would have different risk attitudes, they are expected to have different cut-off values for expected gain and success probability that will result in their choosing $G_B = 1$. In aggregate, this would manifest itself as an increasing probability of choosing $G_B = 1$ as $\pi(I_A, I_B)$ and $\Delta V_B - C_B$ increase. The fact that there are cases where $G_B = 1$ and the expected return is negative suggests that some subjects may have been risk loving with respect to the lottery presented in this experiment. Such behavior is expected to diminish if payments are increased.

With some evidence that behavior is gravitating towards mutually beneficial outcomes, another pair of explanatory regressions considered the relationship between investment levels in a particular period and the investment level in previous periods. Results are presented only for pooled models. A complete fixed effects model was also estimated for both cases, but neither was found to differ significantly from the pooled case. Given that a lagged dependent variable was included, the fixed effects models were also estimated allowing for an AR(1) process in the residuals. These specifications were also found to add no explanatory power relative to the pooled models presented in table 9.

The results in table 9 show that any dependence of I_B on lagged values of I_A, I_B, or G_B is at best weak, given that $R^2 = 0.063$. The significant positive relationship between I_B and the lagged value of I_A suggests that on average when A increased its investment last period, then B's response this period is to increase its own investment. Conversely, a decrease in I_A last period leads to a decrease in I_B this period. This supports the conjecture that B seeks to maintain a credible threat as a means of containing increases in I_A, if we assume that last period's investment by A is a good predictor of this period's investment. If I_A falls, then A is better protected in the event that B chooses $G_B = 1$. B can respond to this so as to offset the protection by reducing I_B.

A's investment is influenced by lagged values of I_A and G_B. The value on I_B is not significant. This suggests that A's choice is influenced more by whether or not B set $G_B = 1$ last period than by B's choice of I_B. The absence of an I_B effect could be because B's risk attitude is unobservable to A. For a particular combination of I_A and I_B, A does not know if B will consider the risk premium adequate to set $G_B = 1$. If it was observed that last period B did choose $G_B = 1$ then A can conclude that the combination played last period was within the risk zone. Therefore, if A desires that B choose $G_B = 0$, A should reduce I_A. Conversely, if A observed $G_B = 1$ last period, then last period's combination did not provide adequate risk compensation. A may therefore be able to increase I_A and not induce $G_B = 1$. We would expect such oscillating behavior to continue until an equilibrium is established. The fact that the parameter on G_B is less than one suggests convergence.

Drawing these results together provides some comment on rivers shared in volatile regions. First, and not surprisingly, risk aversion likely plays an important role in choosing whether or not to launch an attack. When lives are at stake, the payoffs are very large, which likely results in careful deliberation. In this experiment, we find that the analog to war does not always occur, even when it is the Nash equilibrium. In real world situations, this effect is likely strengthened.

A second implication which follows from these results is that a dynamic, cross country relationship is expected in military investment decisions. The experimental results show such a relationship. For the 'downstream' player, this period's own investment depends on the 'upstream' player's previous period investment. Statistically, the upstream player responds strongly to whether it has been attacked last period, with no statistical effect generated by the 'downstream' player's investment. Since the cost of attacking in this experiment is low cost, relative to the cost in the international sphere, experiment players were likely using the presence or absence of an attack to identify the downstream player's threshold. Among nations, therefore, where attacks are less likely, downstream investment may have a larger influence on upstream decisions, or an analog to an attack, such as threats or protests, may serve the role of an attack in the experiment in terms of predicting upstream investment choices.

5 Conclusion

The experiment reported in this paper was designed simulate one aspect of the incentives facing two nations sharing a resource. The specific resource that motivated the theoretical development was water, and the rights to that water are de-facto riparian. However, the core insights carry over to other situations where the responder to an ultimatum can probabilistically reverse the payoff ranking, such as a child's temper tantrum. Before opting for or against the probabilistic option, players each make an investment choice, with the probability of a payoff reversal depending on the relative investments. When opting for the random payoff reversal is costly, the game may not have a Nash equilibrium. Alternative solution concepts include the maximin strategy combination, and cooperative equilibria, in the spirit of the Folk theorem.

The results of this experiment suggest that the myopic Nash solution has relatively good predictive value in those implementations where a pure strategy Nash equilibria exists. When a pure strategy Nash equilibria does not exist, the maximin solution does not contribute much predictive power, while there is weak support for convergence towards a cooperative equilibria. This support comes from both a spatial examination of the pattern of strategy combinations and a lagged dependent variable regression.

These results emphasize the importance in resource sharing arrangements of a more complex strategy set. Nations frequently have options beyond those related directly to the resource being shared. The relative gain of adopting these other strategies will change the range of strategy combinations that can be sustained through an agreement. The apparent importance of risk aversion also highlights the lack of applicable realism of knife-edge solutions such as those commonly found in the anarchy literature where military aggression is modeled. The results of this literature are valuable in highlighting how a deterrence balance of power can develop and be stable, but are somewhat distant from actual outcomes when they rely on risk neutrality.

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