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LOSS-AVOIDANCE AND FORWARD INDUCTION IN EXPERIMENTAL COORDINATION GAMES

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We report experiments on how players select among multiple Pareto-ranked equilibria in a coordination game. Subjects initially choose inefficient equilibria. Charging a fee to play (which makes initial equilibria money-losing) creates coordination on better equilibria. When fees are optional, improved coordination is consistent with forward induction. But coordination improves even when subjects must pay the fee (forward induction does not apply). Subjects appear to use a "loss-avoidance" selection principle: they expect others to avoid strategies that always result in losses. Loss-avoidance implies that "mental accounting" of outcomes can affect choices in games.

In games with multiple equilibria that are Pareto-ranked, players must somehow coordinate their choices to achieve Pareto efficiency. Games of coordination have been widely used in economics to study macroeconomic cycles, technology adoption, sticky prices, organizational design, bank runs, and other phenomena.[1] These theories cover a lot of economic ground but generally leave unanswered a central question. Why is one equilibrium selected rather than another? Experimental analysis is well suited to help answer this question because the specialized conditions of a coordination game can easily be created in the laboratory. Then a wide range of variables can be altered to help infer the principles that guide selection of equilibria. In this paper we describe a new selection principle, called "loss-avoidance," and show that the empirical success of a related principle, "forward induction," is partly attributable to loss-avoidance.

Table I shows payoffs in a coordination game we study experimentally in this paper. Each of nine players privately picks an integer between one and seven (inclusive), called an "action." After all the players have picked an action, the median of their actions is computed and announced. Payoffs are determined by a player's action and by the "median action," as shown in Table I. (The payoffs are in pennies.) This median-action game was originally studied by Van Huyck, Battalio, and Beil [1991, 1993] (hereinafter VBB).

TABLE I
MEDIAN EFFORT GAME PAYOFF TABLE

Your Action	Median action						
	1	2	3	4	5	6	7
1	140	150	140	110	60	−10	−100
2	130	160	170	160	130	80	10
3	100	150	180	190	180	150	100
4	50	120	170	200	210	200	170
5	−20	70	140	190	220	230	220
6	−110	0	90	160	210	240	250
7	−220	−90	20	110	180	230	260

The median-action game has two important features. First, players' payoffs are decreasing with the (absolute) difference between their own action and the median. Hence, a player's best action is to choose the number the player believes will be the median (row X in Table I is a best response to column X). Then there are seven pure-strategy Nash equilibria, located along the diagonal. Second, the seven pure-strategy equilibria are Pareto-ranked: the higher-action equilibria are better for everyone. Choosing 7 is the best of all.

In previous studies, and in our replications, subjects typically choose actions that create a median of 4–5 in the first round. When the game is played repeatedly, behavior almost always converges to the first-round median. There is persistent "coordination failure" because subjects do not coordinate on the best equilibrium and choose 7.

I. LOSS-AVOIDANCE AS A SELECTION PRINCIPLE

Previous research has investigated the "selection principles" players appear to use, tacitly, to select one of the many possible equilibria. For example, the equilibrium in which everyone chooses 7 obeys the principle of "payoff-dominance" or Pareto-dominance (see Harsanyi and Selten [1988]). But subjects typically choose actions that create a median of 4–5 in the first round, so payoff-dominance is apparently not a universally accepted principle.

The strong influence of the first round shows that "prece-

dence" is a selection principle; namely, subjects believe that an equilibrium which has been picked before is more likely to be chosen again (and their beliefs are self-fulfilling).

In this paper we describe a new selection principle, which we call loss-avoidance. The loss-avoidance principle is that players do not pick strategies that result in certain losses for themselves,[2] if other (equilibrium) strategies are available. People only pick (and expect others to pick) strategies that *might* result in a gain.

To illustrate loss-avoidance, suppose that players in the Table I median-action game must pay a commonly known fee of 225 to play or, equivalently, we subtract 225 from all the payoffs. Now the strategies 1–4 are certain to result in a loss. Even though 1–4 are still equilibrium choices, the loss-avoidance principle selects them out, and predicts that only 5–7 will be chosen.

The loss-avoidance principle is a game-theoretic cousin of findings from research on individual choice that highlight the psychological differences between gains and losses (see Tversky and Kahneman [1991]). For example, people appear to dislike losses more than they like equal-sized gains ("loss-aversion"), and people often seek risk to avoid losses, while avoiding risks that can yield equal-sized gains ("reflection"). As a result, the point of reference from which gains and losses are evaluated—or the way a choice is framed or "mentally accounted" for—can affect the choices people make.

While these features of losses are thought to guide choices of individuals, the loss-avoidance principle is distinctly different because it guides players' beliefs about the behavior of others. The difference is illustrated by some experimental sessions in which subjects had to pay a fee of 225, but did not know whether others paid the same fee or not. In those sessions, adding a fee did not change the choices players made, presumably because subjects could not tell which strategies led to sure losses for others, and hence could not use the loss-avoidance principle to shape their beliefs about what others would do.

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2. There are two variants of loss-avoidance: (i) subjects avoid strategies that have only negative payoffs (losing-strategy avoidance); (ii) subjects avoid strategies that have negative *equilibrium* payoffs (losing-equilibrium avoidance). The difference is illustrated by strategy 5, when the fee is 225. Choosing 5 yields a positive payoff only if the median is 6, so choosing 5 is ruled out by (ii) but not by (i). Since 5's are actually chosen with some frequency in the 225 fee periods, we think principle (i) is probably more typical than (ii), but further experiments could better separate the two variants.

II. LOSS-AVOIDANCE AND FORWARD INDUCTION

Now suppose that the choice of whether to pay the 225 fee and play the game is optional. Subjects who opt out earn nothing. In this case, loss-avoidance is coupled with a stronger selection principle, forward induction. In the presence of the option, a subject's decision to play a game (rather than opt out) implicitly[3] communicates the subject's expectations concerning the outcome of the game: a subject will not choose an action that guarantees a lower payoff than what could be earned for sure by opting out. This reasoning, called forward induction, is formalized by Kohlberg and Mertens [1986], van Damme [1989], and Ben-Porath and Dekel [1992]. Forward induction improves coordination because it shrinks the set of plausible equilibria in a game. However, experimental evidence on its effectiveness is mixed.[4]

Loss-avoidance and forward induction are closely linked. Loss-avoidance applies if players assume that others will avoid certain losses. Forward induction applies if players assume that others will avoid an *opportunity* loss, by choosing an equilibrium which is better for them than an option they chose to forgo. In many games the two principles lead to the same set of selected strategies. To isolate the effectiveness of loss-avoidance, we studied two kinds of median-action games. In games with options to opt out, coordination improved, which meant that the combination of loss-avoidance and forward induction selected better equilibria. But improved coordination was also observed in games with no options and possible losses, where forward induction did not apply and loss avoidance did. Hence, we conclude that loss-avoidance could explain some of the improvement in coordination which previously has been attributed exclusively to forward induction. Our data add to other experimental evidence that forward induction works largely because it coincides with other

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3. Several authors have found that some forms of *explicit* nonbinding preplay communication (or "cheap talk") among players can improve coordination. Cooper, DeJong, Forsythe, and Ross [1989] find that in battle-of-the-sexes games, allowing one player to announce a strategy without a commitment (also known as cheap talk) improves coordination, but allowing both players to communicate provides little benefits. However, Cooper, DeJong, Forsythe, and Ross [1992a] find the opposite relationship in a more symmetric coordination game. Van Huyck, Gillette, and Battalio [1992] find mixed improvements in coordination when an outside arbiter makes recommendations to the players.

4. Brandts and Holt [1990]; Van Huyck, Battalio, and Beil [1993]; and Cooper, DeJong, Forsythe, and Ross [1992b] find supporting evidence. But Cooper, DeJong, Forsythe, and Ross [1993]; Schotter, Weigelt, and Wilson [1994]; Cachon, Camerer, and Johnson [1990]; and Balkenborg [1994] find contradictory evidence.

principles (e.g., Cooper et al. [1993]), but we hesitate to jump to the possible conclusion that forward induction has *no* predictive power of its own.

III. COORDINATION IN THE MEDIAN EFFORT GAME

Table I shows payoffs (in pennies) in the median-effort game we studied. The game corresponds to a natural setting in which players choose levels of effort in a group production task. The median effort determines the group's output; higher medians yield higher common payoffs. Players are penalized for deviating from the median by exerting too little effort (below the median) or too much effort (above the median). The individual goal is to exert the median effort. The collective goal is to create the largest median effort.

In their experiments VBB [1991] found with nine players that actions in the initial trial of the game were widely distributed around a median of 4 or 5. Repeating the game for ten trials created convergence to whichever median had occurred in the initial trial. This demonstrates the strong influence of precedence: a subject expects the others to choose actions on the assumption that the median will equal the median of the previous round. Unfortunately, precedence creates substantial coordination failure. If everyone had chosen the Pareto-dominant equilibrium, 7, each subject would have made substantially more money (nearly $0.50 more per trial, or $4.50 more in an experiment that lasted about an hour and paid $9 on average).

In VBB [1993] eighteen subjects bid for the right to play the median-effort game, in an ascending-price (English) auction. The auction ended when only nine subjects were willing to pay the announced price. After the auction the nine subjects paid the auction price then played.

Since subjects could always quit bidding during the auction and earn nothing, their willingness to pay the price P signals their belief that an equilibrium paying at least P will result. Auction prices in the first trial were around $2, and subjects invariably chose actions that gave equilibrium payoffs higher than their bids. (Subjects bidding $2.10, for example, would then choose 5 or above in the coordination game; to do otherwise would violate dominance.) With repeated trials, prices converged very close to $2.60, and subjects usually chose the Pareto-efficient action 7.

Forward induction explains this behavior, but the English auction is not the only preplay mechanism to which forward induction applies. We used a simpler mechanism. Instead of using an auction to create an endogenous cost of participation, we announced to nine subjects a publicly known cost to play the game (or entry fee) and gave them a chance to opt out and avoid paying the cost. (Note, however, that allowing opting out means the number of players falls, which may itself improve coordination.) We call this the "Opt Out" condition of the median-effort game. As the game's entry fee is raised, forward induction eliminates more and more of the seven Nash equilibria, facilitating coordination on the highest-action equilibria.[5]

Loss avoidance can also be applied to the Opt Out game: players will not choose actions that are certain to yield a negative payoff. For example, with an entry fee of $1.85 a player cannot earn a positive profit by choosing an action of 3 or lower, but choosing an action of 4 or more does earn a positive profit if the outcome median is sufficiently high. Note that loss-avoidance yields the same recommendations to players as forward induction. In fact, the recommendations of loss-avoidance and forward induction always coincide in games in which forward induction applies.[6] However, unlike forward induction, loss avoidance does not require the presence of an option to opt out. Therefore, we studied behavior in a "Must Play" condition of the median-effort game, in which players were *required* to pay an entry fee before playing the game. Without a chance to opt out, forward induction does not apply in the Must Play game. Any coordination improvement resulting from higher entry costs in the Must Play game must be coming from a loss-avoidance selection principle.

A. Median-Effort Game: Design

We ran four sessions of the Must Play condition and four sessions of the Opt Out condition, with nine rounds in each session.

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5. Given the chance to opt out and earn zero, a subject will only play the game if the payoff expected in equilibrium, after paying the entry fee, is greater than the opportunity cost of opting out (zero). According to forward induction, expectations of a high median are justified because only players with high expectations will play, and they will choose high numbers. Players with low median expectations opt out, and they have no influence over the median.

6. One reader suggested trying to separate loss-avoidance and forward induction with an Opt Out condition in which players can earn $2.25 and not play, or play and pay nothing (as in Cooper et al. [1993] and Schotter, et al. [1994]), so there is no explicit entry fee. Forward induction applies in this game, but loss-avoidance does too if the opportunity cost of not earning $2.25 is viewed as a loss.

The first three rounds of both conditions were identical, to establish an observational baseline and create an empirical median. The entry cost was zero, and players could not opt out in either condition. In rounds 4–9 subjects could opt out in the Opt Out condition, but not in the Must Play condition. Players who chose to opt out receive 0 points for the round.

The entry fee was raised from 0 to $1.85 in rounds 4–6. The cost of $1.85 was chosen to keep profits positive (net of entry cost) if the initial medians were 4 or 5, as we thought they would be based on VBB's results. This change is predicted to be innocuous; it tests whether *any* change in the entry cost can trigger a shift to a higher median.[7]

The entry cost was raised from $1.85 to $2.25 in rounds 7–9. Forward induction predict subjects who opt to play in the Opt Out condition will then choose actions 6 or 7 (which pay $2.40 or $2.60 in equilibrium). Forward induction predicts nothing about the Must Play condition. Loss-avoidance predicts that subjects will play 6 or 7 in both Opt Out and Must Play conditions (since playing 5 only earns $2.20 in equilibrium, not enough to recoup the entry cost of $2.25). Precedence suggests that subjects will choose actions corresponding to the median of the previous round.

Subjects were University of Pennsylvania undergraduates recruited from announcements in classes and public sign-up sheets. Students sat in private cubicles. Each experiment began with a public reading of the instructions (see Appendix), and a quiz to ensure that each subject understood the task and how payoffs were computed. Subjects were paid in cash immediately after the experiment. Sessions took 45 minutes, and subjects earned about $9 on average.

In both conditions the subjects did not know the number of rounds in the session or the entry costs and options in future rounds. In the Must Play condition subjects did not know there was an option in other (Opt Out) sessions. Subjects were told (truthfully) that they all had the same payoff table, and the payoff table would not change during the experiment.

Each round began with the experimenter publicly announc-

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7. Cooper et al. [1993] report that the inclusion of a small entry fee, which is smaller than the lowest payoff of any equilibrium, does improve coordination. Forward induction and loss-avoidance both predict that this should have no effect on coordination, so its actual effect represents an interesting puzzle, which is probably related to players' use of timing as an inferential device.

ing the entry cost and announcing, in the Opt Out sessions, whether subjects could opt out and how much they would earn for opting out. Subjects then either chose an action or opted out. They also predicted the smallest, largest, and median action in each round. They earned a dime for each correct prediction, and were informed of their correct minimum and maximum predictions at the end of the experiment. We collected predictions from the subjects in order to compare their beliefs about the future median with their own actions. At the end of each round, players were told the median actions (but not the full distribution of actions).[8]

B. Median-Effort Game: Results

Figure I shows the distribution of action choices by the subjects in each session. In each round of a session (a column) vertical rectangles outline the range of actions picked during that round. Numbers within the rectangle represent the number of subjects choosing each action. (The numbers in each column sum to nine, the number of subjects.) The open box in each rectangle is the median action. The asterisk in each column denotes the median of the subject's predictions about the median.

Behavior across all eight sessions was similar in the first three rounds, as expected. There was wide variation in first-round actions; by the third round actions *always* converged toward a median of 4 or 5; and 71 percent (51 of the 72) subjects chose the median in the third round. These results sharply replicate VBB [1991, 1993] and confirm the strength of precedence.

When the entry cost rose in round 4 to $1.85, actions shifted upward a bit, but the median action was the same in five sessions and rose by one in three sessions. The small shift in actions suggests that changing the entry cost has some influence on beliefs and behavior but the influence is minor.

The crucial comparison between loss-avoidance and forward induction comes in rounds 7–9, when the entry cost rises from $1.85 to $2.25. Loss-avoidance predicts an increase in actions in both conditions, but forward induction predicts an increase only in the Opt Out sessions. Must Play and Opt Out conditions

8. In the Opt Out condition, when the number of subjects playing the game was even and the median was in-between two different numbers, a coin was flipped to determine which of the two was the announced median. This rule was explained to the subjects in the instructions, but there was never a need to implement it.
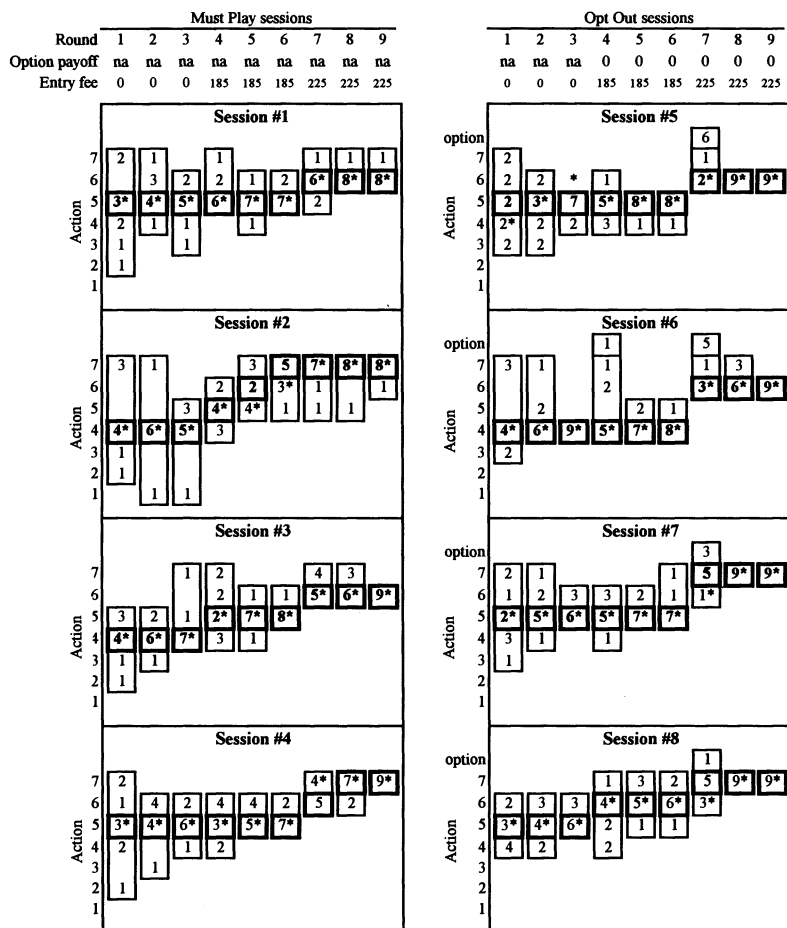
FIGURE I
Action Selections in the Median-Effort Game: Must Play and Opt Out Versions

showed similar behavior in rounds 7–9: the median increased in round 7 in seven out of eight sessions (see Table II). In the final rounds there was a total of 18 choices of 6 and 18 choices of 7 in the Opt Out sessions, and exactly the same distribution in the Must Play sessions.

Hypothesis testing suggests a modest difference in the Opt Out and Must Play conditions. Using a Fisher exact test, we reject the hypothesis (at $p = 0.11$) that actions of 6 or 7 are chosen with equal probability in round 7 of the two conditions. We can

TABLE II

TIMING OF MEDIAN CHANGES IN THE MEDIAN-EFFORT GAME

	Must Play (Sessions 1,2,3,4)		Opt Out (Sessions 5,6,7,8)		Fraction of rounds with a median change
	No change	Change	No change	Change	
First cost increase, round 4:	2	2	3	1	37.5%
Second cost increase, round 7:	1	3	0	4	87.5%
All other rounds, no cost increase:	21	3	24	0	6.3%

TABLE III

THE DISTRIBUTION OF THE DIFFERENCE BETWEEN CHOSEN ACTIONS AND PREDICTED MEDIANS IN THE MEDIAN-EFFORT GAME

Rounds	Must Play (Session 1,2,3,4)			Opt Out (Sessions 5,6,7,8)		
	Positive	Zero	Negative	Positive	Zero	Negative
1–3	12	78	18	18	77	13
4	7	26	3	5	30	1
5–6	12	47	3	8	60	4
7	3	31	2	2	19	0
8–9	7	64	1	5	66	1

reject the hypothesis (at $p = 0.10$) that the distribution of action *differences* between rounds 6 and 7 is the same in the two conditions. The data suggest that loss-avoidance, absent forward induction, does not generate *precisely* the same changes in medians (and improvement in coordination) as forward induction does, but the changes are quite similar.

There are several other findings. Table III compares the differences between actions and predicted medians.[9] Any nonzero differences (e.g., predicting the median would be 4, and playing

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TABLE IV
BEST RESPONSE DYNAMICS IN THE MEDIAN-EFFORT GAME

	Must Play (Session 1,2,3,4)			Opt Out (Sessions 5,6,7,8)		
Rounds:	4	7	1,2,3 5,6,8,9	4	7	1,2,3 5,6,8,9
Previous action higher than median:*						
Increase or same action:	5	4	24	3	4	16
Decrease action:	4	1	36	4	0	27
Previous action is best response:						
Increase action:	11	21	21	9	14	11
Same action:	11	6	87	14	3	112
Decrease action:	1	0	2	3	0	3
Previous action lower than median:						
Increase action:	3	2	31	0	0	27
Decrease or same action:	1	2	5	2	0	7

*number of subjects

5) suggest that subjects did not give careful predictions of the median, or did not best-respond to their predicted median. Only 20 percent of the actions and median predictions were different. When they differed, subjects were more likely to choose an action higher than their predicted median (a positive difference) than vice versa, perhaps trying to pull the group up to a higher median. Furthermore, positive differences between actions and expectations are evenly distributed among all the rounds. This confirms that the increases in median actions observed in round 7 are caused by rising expectations, rather than by an increased willingness to submit actions higher than expectation (which would reflect a decrease in best-response actions).

Table IV gives evidence of convergence dynamics that strongly support the influence of precedence.[10] Subjects whose actions were higher (lower) than the median in the previous

10. Crawford [1995] estimates an analytical model to explain convergence behavior in these coordination games. A critical assumption of his model is that players start with diffuse expectations regarding the median, and through adaptive modification based on observed information (history of repeated play) these expectations converge to an equilibrium. The belief data we gathered are roughly consistent with Crawford's model, since initial predictions of the median are widely dispersed, but they converge tightly around previously observed medians with experience.

TABLE V
MEDIAN BELIEFS OF THE SUBJECTS IN ROUND 7 OF THE MEDIAN-EFFORT GAME OPT
OUT SESSIONS

| | Median beliefs of subjects who: | |
	Opted out	Played
Session 5	5,5,5,5,6,6	6,6,7
Session 6	4,4,5,6,7	6,6,6,7
Session 7	5,6,6	6,6,7,7,7,7
Session 8	6	5,6,6,6,7,7,7,7

round tended to decrease (increase) their action. Subjects who chose the median tended not to change their actions (except in rounds 4 and 7, when they often increased). The data explain why the initial medians were so persistent: subjects mostly converged toward it from above *and* below, except for some upward drift in rounds 4 and 7. (Note that the upward shift is more dramatic in round 7, when 80 percent of the subjects shift upward, than in round 4 when less than half do.)

Table V shows some support for forward induction in the medians predicted by players who chose to opt out or play. The medians predicted by subjects who played are higher (95 percent predict 6 or 7) than the medians predicted by those who opted out (53 percent predicted 5 or less). The two distributions are clearly different ($\chi^2 = 11.0$, $p = 0.01$), suggesting that *some* portion of subjects may have used reasoning like forward induction to create high expectations. However, forward induction predicts high expectations for *all* subjects, so forward induction is clearly not universally applied. But universal application is not necessary for improving coordination because the subjects who do not follow forward induction opt out, and thus have no influence on the final median.

C. Median-Effort Game with Private Entry Costs

Although loss-avoidance explains the behavior observed in the Must Play sessions, it is possible that loss avoidance is confounded with another effect. There is substantial evidence in psychology that people take actions to recoup sunk costs rather than ignore them.[11] It is possible that the median rises in the median-

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11. There is considerable evidence in psychology that subjects take riskier actions to recoup sunk costs. See Arkes and Blumer [1985]; Aronson and Mills

effort game merely because each subject chooses a high number in an effort to recover the sunk entry fee.

To separate these explanations, we ran two sessions like the Must Play sessions, except that the entry fee was not announced publicly (this condition is called "Private Cost"). Each player knew his or her own entry fee, but did not know every other subjects' fee. (In fact, as in the Must Play condition, every subject had the same fee.) If subjects individually succumb to the sunk cost fallacy, an increase in the entry fees will raise the median because the aggregate effect of each subject's attempt to recover the fee will result in a higher median. However, if subjects only use the loss-avoidance principle to fix their beliefs about how *others* will play, then in the Private Cost condition actions will *not* rise when the fee is increased. (Note that even if subjects suspect others' fees are the same as their own, unless that fact is common knowledge the loss-avoidance principle cannot be applied.)

In fact, the median did *not* change when the entry fee rose in round 7 of the Private Cost sessions (see Figure II). The distribution of round 7 actions in the Private Cost sessions is significantly different than in the Must Play sessions with public costs ($\chi^2 = 20.4$, $p = 0.005$). The distribution of differences in actions from round 6 to 7 is significantly different too ($\chi^2 = 11.0$, $p = 0.005$). Thus, it appears that subjects do not exhibit a sunk cost fallacy in the Must Play setting.

D. Pass Through Median-Effort Game

Coordination improved in the Must Play sessions with a publicly announced entry fee, but loss avoidance requires only losses, not charging an explicit fee. Furthermore, it is possible coordination would improve in these sessions by merely announcing a number (such as 225) which has no influence on the subjects' payoffs. The number itself could be focal.

To test loss-avoidance without the possibility of contamination by a "focal number effect," we conducted two "Pass Through" sessions. These sessions are identical to the Must Play sessions, but there is no announcement of an entry fee. To incorporate the

[1959]; Cialdini, Cacioppo, Bassett, and Miller [1978]; Freedman and Fraser [1966], McGlothlin [1956]; and Staw [1976]. Thaler [1980], uses the tendency toward risk-preference in the domain of losses, from prospect theory [Kahneman and Tversky 1979] to explain the sunk cost fallacy. Heath [in press] modifies this view with demonstrations that people only spend a different kind of resource to recoup a sunk resource cost.

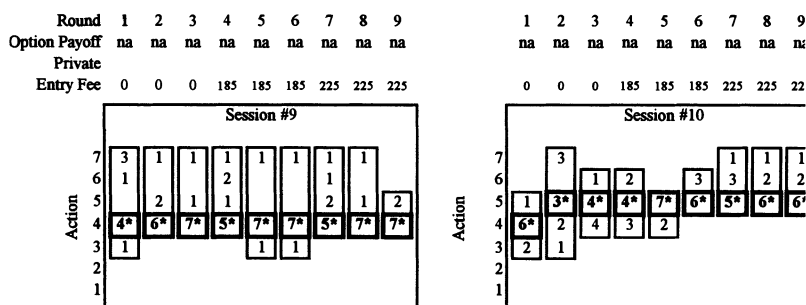| Round	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	na	na	na	na	na	na		na	na	na	na	na	na	na	na	na
Private Entry Fee	0	0	0	185	185	185	225	225	225		0	0	0	185	185	185	225	225	22

FIGURE II
Action Selections in the Private Cost Median-Effort Game

entry fee implicitly, the subjects are told that the payoff table may change from round to round. In the first three rounds the Table I payoff table is used. In the next three rounds the subjects were given a payoff table that was equivalent in structure to Table I, but all payoffs were reduced by 185. In the last three rounds the subjects used a table with the payoffs reduced by 225. In each round the experimenter collected the previous payoff table and distributed the new table. Only in rounds 4 and 7 did the payoffs in the new tables change. Since the entry fees were implicitly incorporated into the payoff table, the subjects did not know anything about fees or focal numbers.

Figure III shows that the subjects' behavior in these two Pass Through sessions did not differ much from behavior in the Must Play sessions. Initial choices are widely dispersed around the median of 4 or 5; by round 6 there is rough convergence to an equilibrium (72 percent of subjects select the median action); and in round 7 of both sessions there is an upward shift in actions and beliefs. We weakly accept the hypothesis that the Pass Through and Must Play sessions have the same distribution of actions in round 7 and 9 ($p = 0.13$ and $p = 0.15$ by Fisher exact test), and accept the hypothesis that the two types of sessions have the same distribution of median beliefs in round 7 ($p = 0.21$ by Fisher exact test).[12] We conclude that charging an *implicit* fee can affect coordination too, ruling out the theory that our Must Play results are due to focal numbers announced as explicit fees. This

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12. We reject that Pass Through and the Must Play sessions have the same distribution of action differences in round 7 ($p = 0.10$ by Fisher exact test), but this weakly significant difference is not large in magnitude.
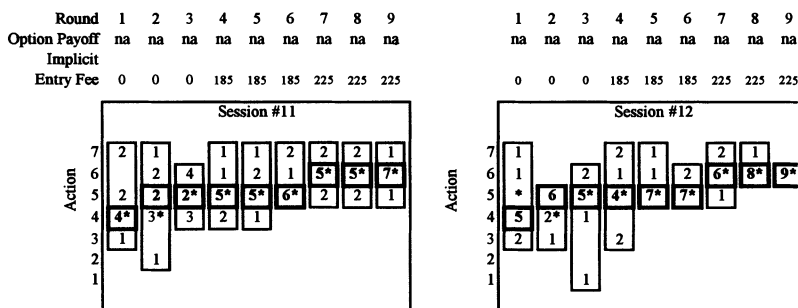
Round	1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	na	na	na	na	na	na
Implicit Entry Fee	0	0	0	185	185	185	225	225	225

Round	1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	na	na	na	na	na	na
Implicit Entry Fee	0	0	0	185	185	185	225	225	225

FIGURE III

Action Selections in the Pass Through Median-Effort Game

provides additional support for loss-avoidance as a selection principle.

E. Declining Cost Median Effort

Experience can certainly play a role in coordination. It is possible that as subjects gain experience they realize the benefit of better coordination. Unfortunately, since an inferior equilibrium is established in the early rounds, the subjects need some signal to trigger a break from the established equilibrium and initiate higher coordination. Any interruption in the normal procedure of the game, such as a change in the fee charged, could serve as a signal. Indeed, VBB [1990] find evidence that coordination does improve when a transition occurs between different treatments of the experiment (after some experience has been obtained). We conducted two sessions of the "Declining Costs" median-effort game in order to rule out experience or transition effects as primary explanations for improved coordination in round 7 of the Must Play treatments.

The Declining Costs sessions are identical to the Must Play session except the order of fees is reversed: a fee of 225 in the first three rounds, 185 in the middle three rounds, and no fee in the last three rounds. Beginning round 1 with the high fee of 225 eliminates transition or experience effects as an explanation for the improvement in coordination in round 7 that we observed in the Must Play sessions.[13]

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13. Again, we do not entirely reject the possibility of significant experience or transition effects in round 7. Instead, we wish to show that these are not the sole explanation for higher coordination when a high fee of 225 is charged.

Round	1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	na	na	na	na	na	na
Entry Fee	225	225	225	185	185	185	0	0	0

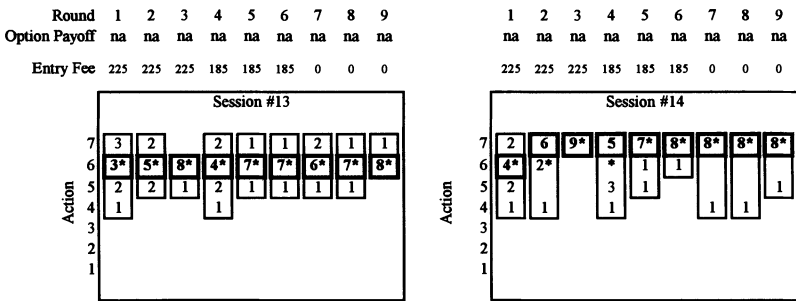| Round	1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	na	na	na	na	na	na
Entry Fee	225	225	225	185	185	185	0	0	0

Session #13

Session #14

FIGURE IV

Action Selections in the Declining Cost Median-Effort Game

Figure IV shows the distribution of actions selected in the Declining Cost sessions. They indicate that higher coordination is achieved in round 1 (with a fee of 225) than in the first round of the Must Play sessions (with a fee of zero). The distribution of actions and median predictions are higher in the Declining Costs sessions ($\chi^2 = 10.16$, $p = 0.005$; and $\chi^2 = 10.99$, $p = 0.005$). Furthermore, we accept the hypothesis that the distribution of actions in round 7 of the Declining Costs and Must Play sessions are the same (Fisher exact test, $p = 0.29$). We conclude that subjects apply loss-avoidance even with no experience, and loss-avoidance can assist in the prediction of subjects' beliefs prior to playing a coordination game.

F. Minimum-Effort Game

In the median-effort game each member's payoff depends on the group's median effort (as in tug-of-war). One slacker has little overall influence on the payoffs if others put in high effort. In the "minimum-effort" game a player's payoff is determined by the *minimum* number chosen in the group and the deviation of his or her number from the minimum. (This game is sometimes called the "weakest link" game after the expression, "A chain is only as strong as its weakest link.") In the minimum-effort game coordination is more difficult because players will choose a high action only if they believe *every other* player will choose a high action too. In previous experiments, inefficient equilibria of 1 are typical with groups of three to sixteen subjects playing repeatedly [VBB 1990; Knez and Camerer 1994].

We conducted some experiments with the minimum-effort game because it stress tests the ability of loss-avoidance to im-

Must Play sessions

Round	1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	na	na	na	na	na	na
Entry Fee	0	0	0	185	185	185	225	225	225

Opt Out sessions

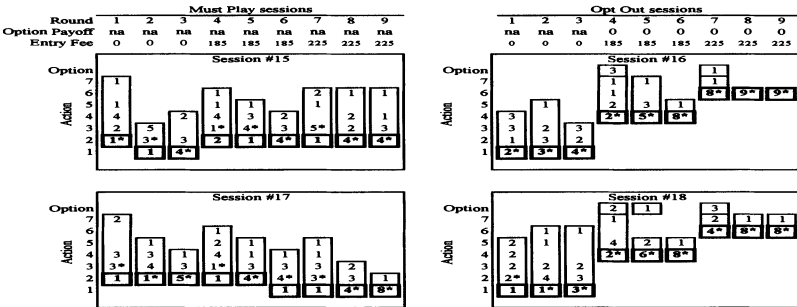| Round	1	2	3	4	5	6	7	8	9
Option Payoff	na	na	na	0	0	0	0	0	0
Entry Fee	0	0	0	185	185	185	225	225	225

FIGURE V

Action Selections in the Minimum-Effort Game: Must Play and Opt Out
Versions

prove coordination and might reveal a bigger difference between
loss-avoidance and forward induction than we saw with the me-
dian effort game. As in the median-effort game, the predictions of
loss-avoidance and forward induction are identical in the
minimum-effort game, but the subjects' belief in these concepts
must be stronger (and more uniform) for coordination to improve
when the fees are raised.

We tested Must Play and Opt Out conditions of the minimum
effort game. The payoff table used was identical to the one in the
median-effort game (see Table I), but experimental procedures
differed in three ways. First, the minimum action chosen, not the
median, was announced at the end of each round and was used
to calculate payoffs. (The full distribution of actions was never
announced.) Second, subjects were asked to make a prediction for
the minimum action, rather than the median. Third, subjects
were given $8 before the session began to prevent them from los-
ing money.[14]

Figure V shows the subjects' choices in two Must Play and
two Opt Out sessions of the minimum-effort game. Behavior in
the two conditions was dramatically different. Raising the entry
cost did not help in Must Play, but it did help in Opt Out.
The hypotheses of equal distributions in action choices in round

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14. This cash stake was provided because in a pilot session of the Must Play
condition with no stake many subjects became risk-seeking (choosing high actions
when the previous round's minimum was 1) when their total earnings became
negative. The pattern of the actual minimum in the pilot did not differ from the
two sessions with the cash stake. In two pilot sessions of the Opt Out condition
without the $8 stake, total payoffs of the subjects did not become negative, and
behavior was similar to the sessions reported.

7, and action differences from round 6 to 7, can both be easily rejected ($\chi^2 = 24.9$, $p = 0.005$; and $\chi^2 = 14.0$, $p = 0.005$). Thus, loss-avoidance alone (in Must Play) is not enough to generate co-ordination on high equilibria in the minimum-effort game, but loss-avoidance and forward induction together (in Opt Out) do improve coordination. For example, in session 13 only one subject opted out in round 7; that player then opted to play in rounds 8 and 9.

Comparison across experiments shows that round 1 choices are significantly lower in the minimum-effort game than in the median-effort game ($\chi^2 = 13.3$, $p = 0.005$). The initial difference persists. Actions in round 7 and round 9 Must Play sessions are significantly different across the minimum and median games ($\chi^2 = 30.9$, $p = 0.005$, and $\chi^2 = 45.8$, $p = 0.005$ respectively), but in the minimum and median Opt Out sessions all choices in these rounds are 6 or 7.

Loss-avoidance does have some effect in the minimum effort game, even though it is not strong enough to overcome prece-dence. In round 3 of the Must Play sessions only 16 percent of the actions were 4 or greater. When the entry cost was raised to $1.85 in round 4, 72 percent of the subjects chose 4 or greater. This behavior is also seen in Table VI, which shows convergence dy-namics. Subjects who chose an action above the previous round's minimum were likely to lower their action choice, except in

TABLE VI
BEST RESPONSE DYNAMICS IN THE MINIMUM-EFFORT GAME

	Must Play Session 1,2,3,4			Opt Out Sessions 5,6,7,8		
Rounds:	4	7	1,2,3 5,6,8,9	4	7	1,2,3 5,6,8,9
Previous action higher than previous minimum:						
Increase or same action:	9	11	31	7	2	20
Decrease action:	0	2	55	1	0	28
Previous action equals previous minimum:						
Increase action:	8	4	6	5	12	2
Same action:	1	1	15	0	0	48
Decrease action:	0	0	1	0	0	0

*number of subjects.

rounds 4 and 7. In rounds 4 and 7 there was a tendency for subjects to raise their action choices, but the tendency was not strong enough to budge the minimum because at least one subject picked the same action (or less) in each round.

A clue to the coordination success in the Opt Out sessions is found in the minima predicted by subjects who opted out or played. As in the median-effort game, the three subjects who played in round 7 had significantly higher beliefs about the minimum (thirteen of fourteen thought it would be 6) than the subjects who opted out (only one of four thought it would be 6), as forward induction predicts ($\chi^2 = 8.3$, $p = 0.025$). The more optimistic beliefs of the subjects who actually played generates coordination on a higher equilibrium.

One feature of our design may overstate the case for forward induction in the minimum effort game. In the Opt Out condition the fact that players can Opt Out implies that fewer players actually play, which reduces strategic uncertainty and makes coordination easier. (For example, VBB [1990] and Knez and Camerer [1994] found that in two-player minimum-effort games coordination was much better than in games with 3–16 players. However, in those experiments, subjects were aware of the number of their opponents, whereas in the Opt Out sessions they must form expectations regarding the number that will play.) The VBB auction design cleverly fixed the number of players, for precisely this reason, but it has not been applied to minimum-effort games.[15]

IV. DISCUSSION

Our experiments help understand how people play coordination games. First, subjects repeatedly played a coordination game, the median-effort game studied by VBB [1991], which has seven pure-strategy equilibria that are Pareto-ranked. They gravitated systematically to either of two (inefficient) equilibria.

Then we altered payoffs by imposing a fee on subjects. We imposed fees in two different conditions, called Must Play and Opt Out. In Must Play experiments, all subjects had to pay the

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15. In VBB's auction design, the number of players who actually played the coordination game was held fixed because eighteen subjects bid for nine spots in the game. A hybrid of their design and ours, in which we charge players a fee, allows them to opt out, but to fix the number of actual players (if too many opt out, then they do not play) would hold strategic uncertainty fixed in our fixed-fee design.

fee. In Opt Out experiments, subjects could pay the fee and play the coordination game (with others who had paid), or could opt not to play and earn nothing.

Notice that in the Opt Out conditions, the logic of forward induction and the loss-avoidance selection principle both predict movement to a better equilibrium when a fee is imposed. But in Must Play conditions forward induction does not apply because all subjects must pay the fee. Since we observe shifts in equilibrium in both conditions, we conclude that loss-avoidance is an effective selection principle in these games.

Two further kinds of evidence suggest that the power of forward induction is not wholly derived from loss-avoidance. First, forward induction predicts that subjects who opt in and play will have more optimistic beliefs about the resulting behavior of others than subjects who opt out. By measuring subjects' expectations directly, we saw that this was true. However, forward induction is not applied by everyone, because many subjects chose to opt out (though usually for only one round).

Second, we experimented with a "minimum-action" or weak-link game, in which coordination among *all* subjects is required to achieve the Pareto superior equilibrium. In Must Play conditions, loss-avoidance by itself did not work well enough, and subjects failed to achieve a profitable equilibrium (payoffs were below the fee). But in Opt Out conditions, the combination of loss-avoidance and forward induction enabled subjects to reach an equilibrium yielding more than the fee. So there is some evidence that forward induction, by modifying the beliefs of subjects who choose to play a game, enhances coordination better than the loss-avoidance principle alone can.

Thus, our central conclusion is that loss-avoidance is an important selection principle in its own right. Forward induction appears to have some predictive power beyond loss-avoidance, but the available data on forward induction are all clearly mixed, and further research is needed to say more.

Three variants of the median-effort game were used to clarify our understanding of loss-avoidance. First, we demonstrate that loss-avoidance improves coordination even when subjects have no experience playing a game (in our Declining Cost sessions). This is important because, as shown by Crawford and Haller [1990] and Crawford [1995], subjects' beliefs prior to playing a coordination game can influence which equilibrium they eventually coor-

dinate upon.[16] Second, the effect is distinct from a "bell-ringing effect," in which any change during the experiment serves as a device players can use to coordinate a mass switch to a better equilibrium[17] because the effect occurs even when the fee is subtracted from payoffs rather than announced (Pass Through sessions). Third, and most importantly, loss avoidance is a selection principle rather than an individual-level response to possible losses, like the "sunk cost fallacy" or reflection effect. We established this in Private Costs sessions in which the fee each subject paid was only privately known, rather than commonly known. In these sessions, raising the fee did not change behavior, so we conclude that loss-avoidance modifies a subject's belief regarding how *other* subjects will play a game.

V. REMARKS ABOUT LOSS-AVOIDANCE AND ITS IMPLICATIONS

We remark about two features of loss-avoidance as a selection principle and one implication.

1. Notice that if a game has some Pareto-ranked equilibria, subtracting a constant from all payoffs, and applying loss-avoidance, will exclude the lowest Pareto-ranked equilibria first. As the constant is increased, higher ranked equilibria are excluded, but better equilibria are never excluded before worse ones. So loss-avoidance naturally guides people toward efficiency. Hence, while loss-avoidance may be rooted in an individual tendency to distinguish losses and gains (which may be debatably rational), it clearly improves social rationality, by helping people move in the direction of higher-payoff equilibria.

2. Since loss-avoidance affects equilibrium selection, accounting manipulations that post costs at different periods of time, and mental accounting rules for coding or framing outcomes [Thaler 1993] can have real effects on behavior and efficiency. Our data illustrate this possibility concretely. Charging a fee in the first three periods (in the Declining Cost sessions) created a

16. In their work these authors assume that subjects begin with diffuse prior beliefs which they do not attempt to explain. Loss-avoidance explains part of these initial beliefs.

17. A focal number effect suggests that coordination could improve by the announcement of a number which has no monetary consequence. See Mehta, Starmer, and Sugden [1994] for a discussion of focal principles in pure coordination games.

high-payoff equilibrium in those periods, which persisted throughout the experiment due to the effect of precedent. In contrast, charging the $2.25 fee at the end (in Must Play sessions) permitted low-payoff equilibrium choices before the fee was imposed. On average, subjects earned substantially more in the Declining Costs sessions than in the Must Play sessions ($9.54 versus $7.54). Even though total fees imposed were the same, *when* the fees were imposed made a large difference.

3. Our results have one important implication for experimental design: whether payoffs are gains or losses could matter. Experimentalists usually adjust the payoffs in games or markets so that the expected payoff (under equilibrium predictions) is close to the opportunity wage of subjects, and is large enough to motivate subjects to think carefully about their choices. Less attention is paid to the range of payoffs, and especially to the possibility of losses.[18] Our data suggest that in situations with multiple equilibria, and common knowledge of payoffs, the range of payoffs is important because money-losing outcomes are less likely to be chosen. In the stag-hunt game, for example, previous experiments show strong support for the risk-dominant equilibrium and little support for the payoff-dominant equilibrium [Cooper et al. 1992a]. We conjecture that subtracting a constant from payoffs (and giving subjects a compensating fixed payment in advance) will reverse this result, shifting support to the payoff-dominant equilibrium.

APPENDIX

Instructions are shown for the Must Play, Opt Out, Private Cost, Pass Through, and Declining Costs sessions of the median effort game sessions. Text in normal typeface is common to all sessions. Text in italics is specific to a subset of the sessions. Any reference to "the TABLE COST" is replaced with "your PRIVATE TABLE COST" in the Private Cost sessions.

The minimum-effort game session instructions are not shown because they are similar to the median-effort game session

18. There is recent evidence (with old roots) that avoiding losses motivates subjects more than increasing gains does, in probability matching experiments [Smith and Walker 1993], the "beauty contest" game [Ho, Weigelt, and Camerer 1995], and Rubinstein's "electronic mail game" [Camerer, Blecherman, and Goldstein 1995].

instructions. In the minimum-effort game the section "Calculating the Median" is not included, and all references to the *median action* are changed to the *minimum action*.

After the instructions a sample quiz sheet is included. This quiz was given to each of the participants after the reading of the instructions in order to ensure that each person understood the game. The quiz included is for the Opt Out median-effort game sessions. The other sessions were given a similar quiz. A sample response sheet from the Opt Out median-effort game is also included.

INSTRUCTIONS

Welcome to a Decision Sciences experiment which is funded by a research grant. You are participating in an experiment in which you have the opportunity to earn cash. The actual amount of cash you earn depends on your choices and the choices of the other persons in the experiment. You should have, in addition to the instructions, one page labeled RESPONSE SHEET and one page labeled PAYOFF TABLE.

CALCULATING THE MEDIAN

It is important in this experiment that you understand how to calculate the median of a group of numbers. The median of a list of numbers is the number for which half of the numbers are lower and half of the numbers are higher. A simple method to determine this number is as follows. First, sort the numbers in the list from smallest to largest. With this list eliminate the smallest and largest choice in succession until only one number remains. This remaining value is the median of the list. For example, if you have the list (45, 53, 51, 47, 47), you would first sort in ascending order: (45, 47, 47, 51, 53). Next, eliminate smallest and highest values in succession: (47, 47, 51) . . . (47). This process tells you that 47 is the median of the list (45, 53, 51, 47, 47).

HOW THE EXPERIMENT IS CONDUCTED

The experiment is conducted in rounds. In each round you will earn points which will be converted to cash at the end of the experiment.

For Opt Out session:

> *A round begins with the experimenter announcing the OPTION VALUE and the TABLE COST. These numbers will*

influence the number of points you earn in the round. After this announcement you must either choose a number between 1 and 7 or choose the OPTION. Your decision will be referred to as YOUR ACTION for the round.

After each of the nine participants in the experiment has chosen an action, the experimenter will announce the ME-DIAN SELECTED NUMBER which is the median number selected from among the nine participants who select a number as their action. The subjects who select the OPTION have no influence over the MEDIAN SELECTED NUMBER.

For Must Play, Private Costs, and Declining Costs sessions:

A round begins with the experimenter announcing the [PRIVATE] TABLE COST. This number will influence the number of points you earn in the round. After the announcement of the [PRIVATE] TABLE COST, you must choose a number between 1 and 7. This number will be referred to as YOUR NUMBER ACTION for the round.

After each of the nine participants in the experiment have chosen a number action, the experimenter will announce the MEDIAN SELECTED NUMBER which is the median number selected from among the nine participants.

For Pass Through sessions:

After a round begins you must choose a number between 1 and 7. This number will be referred to as YOUR NUMBER ACTION for the round.

After each of the nine participants in the experiment have chosen a number action, the experimenter will announce the MEDIAN SELECTED NUMBER which is the median number selected from among the nine participants.

After the announcement of the MEDIAN SELECTED NUMBER, each person should determine their point payoff from the round and then the next round begins. Each round of the experiment will be conducted in the same manner.

DETERMINING YOUR POINT PAYOFF

For Opt Out sessions:

If you choose OPTION as YOUR ACTION for the round, then the points you earn equal the OPTION VALUE. If you choose a number between 1 and 7 as your action, then the

points you earn for the round are a function of YOUR AC-TION, the TABLE COST, and the MEDIAN SELECTED NUMBER.

For Must Play, Private Costs, and Declining Costs sessions:
> *The points you earn for the round are a function of YOUR ACTION, the [PRIVATE] TABLE COST, and the MEDIAN SELECTED NUMBER.*

For the Pass Through sessions:
> *The points you earn for the round are a function of YOUR ACTION and the MEDIAN SELECTED NUMBER.*

The PAYOFF TABLE will allow you to use these three numbers to determine your exact payoff. Please look at the table now. First, find the row corresponding to YOUR NUMBER ACTION and then the column corresponding to the MEDIAN SELECTED NUMBER. Your point payoff is listed in the box which is the intersection of the row and column.

For Opt Out, Must Play, Private Cost, and Declining Costs sessions:
> *However, your final POINT PAYOFF is this number mi-nus the TABLE COST.*

For example, the following table lists several combinations of choices and medians:

For Opt Out, Must Play, Declining Costs, and Private Costs:

YOUR NUMBER ACTION	MEDIAN SELECTED NUMBER	YOUR PAYOFF
1	1	140 minus the [PRIVATE] TABLE COST
3	3	180 minus the [PRIVATE] TABLE COST
3	5	180 minus the [PRIVATE] TABLE COST
5	5	220 minus the [PRIVATE] TABLE COST
5	3	140 minus the [PRIVATE] TABLE COST
7	7	260 minus the [PRIVATE] TABLE COST

For the Pass Through sessions:

YOUR NUMBER ACTION	MEDIAN SELECTED NUMBER	YOUR PAYOFF
1	*1*	*−85 minus the TABLE COST*
3	*3*	*−45 minus the TABLE COST*
3	*5*	*−45 minus the TABLE COST*
5	*5*	*−5 minus the TABLE COST*
5	*3*	*−85 minus the TABLE COST*
7	*7*	*35 minus the TABLE COST*

SUMMARY

For Opt Out sessions:

 At the beginning of the round the experimenter announces the OPTION VALUE and the TABLE COST. Each person then chooses an action. If the OPTION is chosen as an action, then the OPTION VALUE is the points earned for the round. Note, if the OPTION is selected then the points earned for the round do not depend on either the TABLE COST, or MEDIAN SELECTED NUMBER.

 If a number between 1 through 7 is selected as the action of the round, then the points earned depend on this number, the TABLE COST, and the MEDIAN SELECTED NUMBER.

 After each person has selected an action, the MEDIAN SELECTED NUMBER is determined and announced. Note that the MEDIAN SELECTED NUMBER is the median of the number actions. In other words, those subjects choosing the OPTION do not influence the median since they did not pick a number.

 After the announcement of the MEDIAN SELECTED NUMBER, each person can determine the points they have earned in the round.

For Must Play, Declining Costs, and Private Costs sessions:

 At the beginning of the round the experimenter announces the [PRIVATE] [PRIVATE TABLE COST]. Each person then chooses a number between 1 through 7. After each person has selected an action, the MEDIAN SELECTED NUMBER is determined and announced. After this announcement each person can determine the points they have earned in the round.

For Pass Through sessions:
>   At the beginning of the round each person chooses a number between 1 through 7. After each person has selected an action, the MEDIAN SELECTED NUMBER is determined and announced. After this announcement each person can determine the points they have earned in the round.

At this point the next round begins, or the experiment is ended.

COMMENTS

Each person has the same PAYOFF TABLE, and this will be the same PAYOFF TABLE in each round of the experiment.

For Must Play, Opt Out, and Declining Costs sessions:
>   Each person has the same TABLE COST.

For Private Entry Cost sessions:
>   Each person's PRIVATE TABLE COST may or may not be different in each round. You will be informed of your PRIVATE TABLE COST but not the PRIVATE TABLE COST of any other player. Furthermore, your PRIVATE TABLE COST may or may not change from round to round.

For Opt Out sessions:
>   Each person has the same OPTION VALUE and TABLE COST.

When choosing YOUR NUMBER ACTION, notice that you are choosing the *row* from which your point payoff will be determined in the PAYOFF TABLE. The column is determined only after everyone has selected a number and the experimenter has announced the median number selected.

For Opt Out Condition:
>   In some rounds the OPTION VALUE may be announced as "not available" or "N.A." In this round no subject can choose the OPTION, and therefore all nine subjects must choose a number between 1 and 7.
>   Due to choices of the OPTION there may be only an even number of numbers chosen. When there are only an even number of numbers in a list the median may not be uniquely defined. For example in the list (11, 12, 13, 14) the median can be either 12 or 13. If this occurs then the experimenter will flip a coin to determine the median.

PREDICTIONS

In addition to choosing an action in each round, you must also make three predictions for the round. In the columns titled YOUR PREDICTIONS: MIN MAX MEDIAN record your predictions for the lowest, highest and median choice, respectively, of all the number actions in the experiment for the given round. For example, your minimum prediction should be what you think will be the lowest number action taken during the round. Similarly, your maximum prediction should be the highest number action you think anyone will take during the round. Finally, your median prediction should be what you think will be the median of the nine number actions. Note that this is your *prediction* for the median and that your point payoff is based on the *actual* median. For every correct prediction you will earn 10 points. The experimenter will tell you the number of correct predictions you have made at the end of the experiment.

At the end of the experiment total up the points you have earned. Calculate the dollars you have earned based on the exchange rate of one point = $0.01 (a penny).

PLEASE DO NOT TALK DURING THE EXPERIMENT. ASK QUESTIONS AT ANY TIME.

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