

DIVISION OF THE HUMANITIES AND SOCIAL SCIENCES
CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA 91125

LOSS AVOIDANCE AND FORWARD INDUCTION
IN EXPERIMENTAL COORDINATION GAMES

Gérard P. Cachon
Duke University

Colin F. Camerer
California Institute of Technology



SOCIAL SCIENCE WORKING PAPER 937

August 1995

LOSS AVOIDANCE AND FORWARD INDUCTION IN EXPERIMENTAL COORDINATION GAMES

Gérard P. Cachon

Colin F. Camerer

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.

Figure 1 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 Figure 1. (The payoffs are in pennies.) This “median action” game was originally studied by Van Huyck, et al. [1991, 1993] (hereafter VBB).

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 Figure 1 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.

¹See Diamond, 1982; Bryant, 1983; Cooper and John, 1988; Katz and Shapiro, 1986; Ball and Romer, 1991; Milgrom and Roberts, 1990, 1992; Becker and Murphy, 1992; and Diamond and Dybvig, 1983.

In previous studies, and in our replications, subjects typically choose actions which 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.

1 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 which create a median of 4–5 in the first round, so payoff-dominance is apparently not a universally accepted principle. When the game is played repeatedly, behavior almost always converges to the first-round median. The strong influence of the first-round shows that “precedence” 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 which result in certain losses for themselves, if other (equilibrium) strategies are available. Put differently, people only pick (and expect others to pick) strategies which *might* result in a gain.

To illustrate loss-avoidance, suppose players in the Figure 1 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 which 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—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.

2 Loss-avoidance and forward induction

Now suppose 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) implicitly² 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.³

Loss avoidance and forward induction are closely linked. Loss-avoidance applies if players assume others will avoid certain losses. Forward induction applies if players assume others will avoid an *opportunity* loss, by choosing an equilibrium which is better for them than an option they chose to forego. 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 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.

²Several authors have found that some forms of *explicit* non-binding pre-play communication (or “cheaptalk”) 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. See also Cooper et al. [1994].

³Van 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] and Cachon, Camerer, and Johnson [1990] find contradictory evidence.

3 Coordination in the median effort game

Figure 1 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 which 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 \$2.00 and subjects invariably chose actions which 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.⁴

⁴Given 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

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.⁵ 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.

3.1 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. 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.⁶

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 subjects will play 6 or 7 in both Opt Out and Must Play conditions (since playing 5 only earns \$2.20 in equilibrium, not

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.

⁵One 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 Abdalla, Cooper, Dejong, Forsythe and Ross [1989], 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.

⁶Cooper 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 this should have no effect on coordination, so its actual effect represents an interesting puzzle.

enough to recoup the entry cost of \$2.25). Precedence suggests 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 announcing 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 (not the full distribution of actions).⁷

3.2 Median effort game: results

Figure 2 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; and 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. These results sharply replicate VBB [1991, 1993], and confirm the strength of precedence.

⁷In 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.

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 predict an increase only in the Opt Out sessions. Must Play and Opt Out conditions showed similar behavior in rounds 7-9: The median increased in round 7 in seven out of eight sessions (see Table I). In the final rounds there were 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 reject the hypothesis (at $p=0.10$) that the distribution of action *differences* between rounds 6 and 7 are 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 II compares the differences between actions and predicted medians.⁸ Any non zero differences (e.g. predicting the median would be 4, and playing 5) suggest 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 cause by rising expectations, rather than an increased willingness to submit actions higher than expectation (which would reflect a decrease in best-response actions).

Table III gives evidence of converge dynamics which strongly support the influence of precedence.⁹ Subjects whose action was higher (lower) than the median in the previous round tended to decrease (increase) their action. Subjects who chose the

⁸Data are pooled across sessions within a condition to improve power. Option actions are not included in the table, but subjects made predictions for the minimum, maximum and median even if they opted out.

⁹Crawford [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, they converge tightly around previously-observed medians with experience.

median tended not to change their action (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 IV 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 are 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 justify high expectations. However, forward induction justifies high expectations for *all* subjects, and hence it appears that forward induction is not universally applied. But universal application is not necessary because the subjects which do not follow forward induction opt out, and thus have no influence on the final median.

3.3 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.¹⁰ It is possible that the median rises in the Median 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 can’t be applied.)

In fact, the median did *not* change when the entry fee rose in round 7 of the Private Cost sessions (see Figure 3). The distribution of round 7 actions in the Private Cost

¹⁰There is considerable evidence in psychology that subjects take riskier actions to recoup sunk costs. See Arkes and Blumer [1985], Aronson and Mills [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.

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.

3.4 Pass through median effort game.

Coordination improved in the Must Play sessions with a publicly announced entry fee, but loss avoidance does not require 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. Thus, 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 entry fee implicitly, the subjects are told that the payoff table may change from round to round. In the first three rounds the Figure 1 payoff table is used. In the next three rounds the subjects were given a payoff table that was equivalent in structure to Figure 1, 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 4 shows that the subjects’ behavior in these two 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 convergence to an equilibrium (72 percent of subjects select the median action); and in round 7 of both sessions there is an upward equilibrium shift. We weakly accept the hypothesis that the Pass Through and Must Play sessions have the same distribution of actions in round 7 and 9 ($p=.13$ and $p=.15$ by Fisher exact test), and accept the hypothesis that the two types of sessions have the same distribution of median beliefs in round 7 ($p=.21$ by Fisher exact test).¹¹ 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 provides additional support for loss avoidance as a selection principle.

¹¹We reject that Pass Through and the Must Play sessions have the same distribution of action differences in round 7 ($p=.10$ by Fisher exact test), but this weakly significant difference is not large in magnitude.

3.5 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.¹²

Figure 5 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 $\chi^2 = 10.99$, $p=.005$). 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, $p=.29$). 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.

3.6 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 payoffs 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

¹²Again, 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.

experiments, inefficient equilibria of 1 are typical with groups of three to 16 subjects playing repeatedly [VBB, 1990; Knez and Camerer, 1995].

We conducted some experiments with the minimum effort game because it stress tests the ability of loss avoidance to improve coordination, and might reveal a bigger difference between loss avoidance and forward induction than we saw with the median 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 Figure 1), 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 \$8.00 before the session began to prevent them from losing money.¹³

Figure 5 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 7, and action differences from round 6 to 7, can both be easily rejected ($\chi^2 = 24.9$, $p=.005$; and $\chi^2 = 14.0$, $p=.005$). Thus, loss avoidance alone (in Must Play) is not enough to generate coordination 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 ($\chi^2 = 13.3$, $p=.005$). The initial difference persists: Actions in round 7 and round 9 Must Play sessions are significantly different across the minimum and median games ($\chi^2 = 30.9$, $p=.005$, and $\chi^2 = 45.8$, $p=.005$ 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 precedence. In round 3 of the Must Play sessions

¹³This 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.

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 V, which shows convergence dynamics. Subjects who chose an action above the previous round's minimum were likely to lower their action choice, except in 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 minimums 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 (13 of 14 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 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 fewer players actually play, which reduces strategic uncertainty and makes coordination easier. (For example, VBB [1993] found that in two-player games coordination was much better than in 9-player games. However, subjects were aware of the number of their opponents, whereas in the Opt Out sessions they must form expectations regarding the number which 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.¹⁴

4 Discussion

Our experiments help understand how people play coordination games. First subjects repeatedly played a coordination game, the “median effort” game studied by Van Huyck et al [1992], 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 fee. When the previous equilibria yielded a payoff less than the fee, imposing a fee caused subjects to coordinate on a higher-payoff equilibrium. It appears that subjects use the desire to avoid losses as a selection principle: Loss- avoidance directs attention away from equilibria

¹⁴In VBB's auction design, the number of players who actually played the coordination game was held fixed because 18 subjects bid for nine spots in the game. A hybrid of their design and ours, in which we charge players a fee, allow them to opt out, but 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.

that yield payoffs less than the fee and coordinates expectations on equilibria with payoffs greater than the fee.

In Opt Out experiments, subjects could pay the fee and play the coordination game (with others who had paid), or could opt to not play and earn nothing. Under these conditions, the selection principle of “forward induction” predicts a possible improvement in coordination: A player’s willingness to pay the fee signals the expectation that an equilibrium will result which yields a payoff larger than the fee. (If the player expected a payoff lower than the fee, and was rational, he or she would opt out.) Imposing the fee did move subjects to a higher-payoff equilibrium.

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, and accounts for some of the effectiveness of forward induction.

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.

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 coordinate upon.¹⁵ 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,¹⁶ because the

¹⁵In their work, these authors assume subjects begin with diffuse prior beliefs which they do not attempt to explain. Loss avoidance explains part of these initial beliefs.

¹⁶A focal number effect suggests that coordination could improve by the announcement of a

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.

5 Remarks about loss-avoidance and its implications

We remark about three 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, the way outcomes are coded or framed, or accounting manipulations which post costs at different periods of time, 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 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. There is an interesting, subtle relationship between payoff-dominance, risk-dominance, and loss-avoidance. Consider the two-person version of “stag hunt” shown in Table VI (which is a simplified minimum-action game). This game was studied experimentally by Cooper et al [1992a] (except the secure payoff of 600 was actually 800 in their games). In the no fee version, their subjects overwhelmingly chose the secure strategy 1, which yields a certain 600, even though

number which has no monetary consequence. See Mehta, Starmer and Sugden [1994] for a discussion of focal principles on coordination.

(2,2) is a payoff-dominant equilibrium. The equilibrium (1,1) is risk-dominant [Harsanyi & Selten, 1988], and intuitively less risky. Choosing 2 is riskier because its payoff could be 0 or 1000, versus the certain 600 from choosing 1. Loss-avoidance makes no prediction because all strategies yield only nonnegative payoffs.

Now consider the same game with a fee of 900 subtracted from each payoff, as shown in the middle of Table VI. Nothing in the standard equilibrium analysis changes: The equilibrium (1,1) is still risk-dominant and (2,2) is still payoff-dominant. But now loss-avoidance points toward the efficient outcome (2,2) rather than (1,1), because choosing 1 guarantees a loss and choosing 2 might yield a gain. We conjecture that strategy 2 choices will be much more common when the fee is imposed.

The change created by subtracting a fee illustrates how risk-dominance ignores the intuitive idea that risk stems from chance of loss. In the no-fee case, choosing 2 is risky because the possible payoffs are variable—either 0 or 1000. In the fee case, the payoff-variability of strategy 2 is suddenly desirable because it may yield a gain (which strategy 1 cannot). Many people report that they think of risk as a combination of probability of loss (or negative semi-variance) and payoff dispersion (e.g., MacCrimmon and Wehrung [1986]; Shapira [1995]). For such people, strategy 2 seems more risky in the no-fee case, but strategy 1 seems more risky in the fee case because it guarantees a loss. The loss-avoidance principle captures the intuitive notion that risk is the chance of loss, and predicts that subjects will avoid (and believe others will too) strategy 1 in the fee case.

Another variation in Table VI, shown on the right hand side, subtracts the fee of 900 only from player I's payoffs. This version tests the social robustness of loss avoidance. Now loss avoidance only applies to player I, so it moves choices toward (2,2) only if player II knows I avoids losses (and I knows II knows that, etc.).

4. 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. 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. 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.

Table 1: 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 2: 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

Table 3: Best response dynamics in the median effort game

	Must Play Session 1,2,3,4			Opt Out Sessions 5,6,7,8		
	4	7	1,2,3, 5,6,8,9	4	7	1,2,3, 5,6,8,9
Rounds:						
Previous action higher than median:*						
Increase or same actions:	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

Table 4: 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

Table 5: 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 actions:	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

Table VI: Payoffs in "Stag Hunt" Games

		No fee		Fee of 900		Fee of 900 Player I only	
		II		II		II	
		1	2	1	2	1	2
1		600,600	600,0	-300,-300	-300,-900	-300,600	-300,0
I 2		0,600	1000,1000	-900,-300	+100,+100	-900,600	+100,1000

Figure 1: Median effort game payoff table

		Median action						
		1	2	3	4	5	6	7
Your action:	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

Figure 2: Actions selections in the median effort game: Must Play and Opt Out versions

	Must Play sessions 1,2,3,4								
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 5,6,7,8								
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

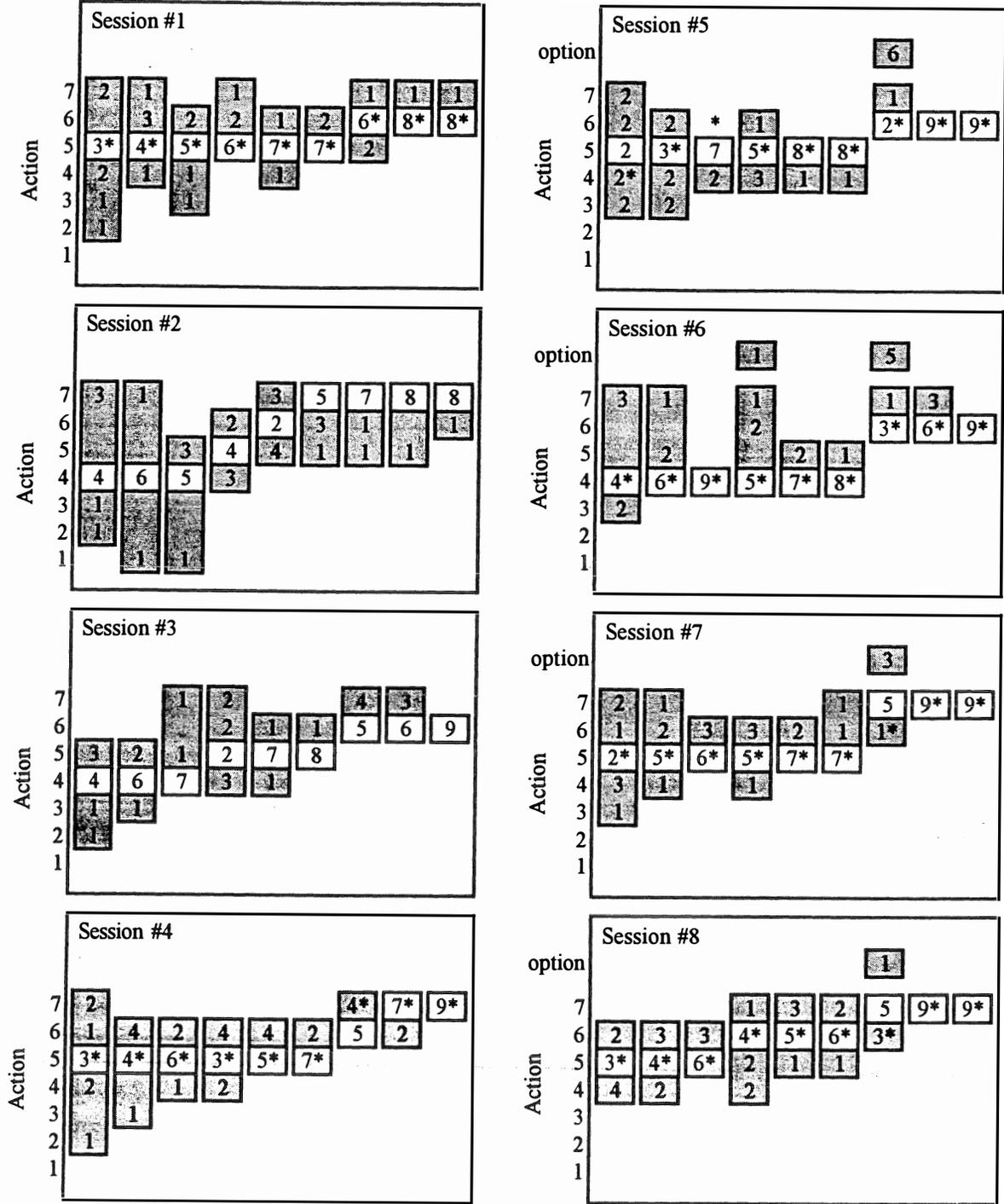
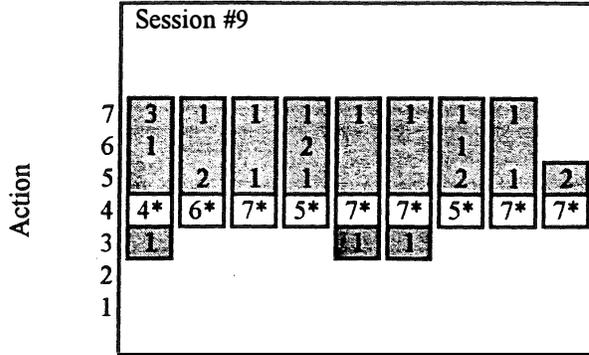


Figure 3: Actions selections in the private cost median effort game

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

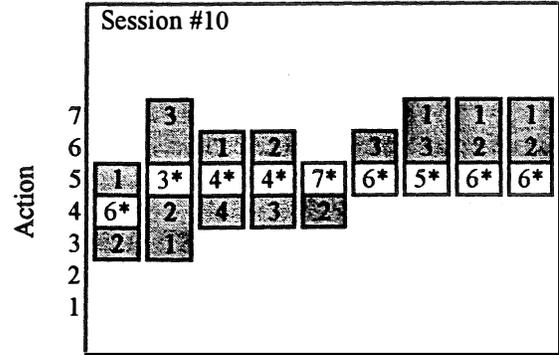
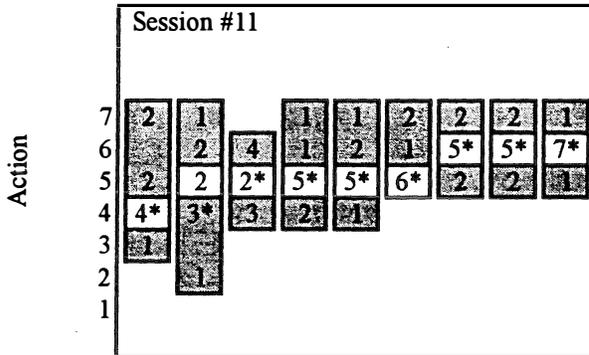


Figure 4: Actions selections in the pass through median effort game

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

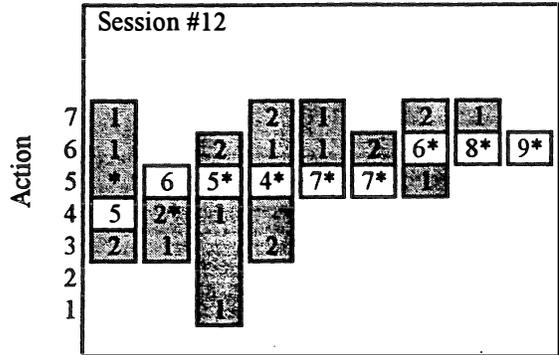


Figure 5: Actions selections in the declining cost median effort game

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

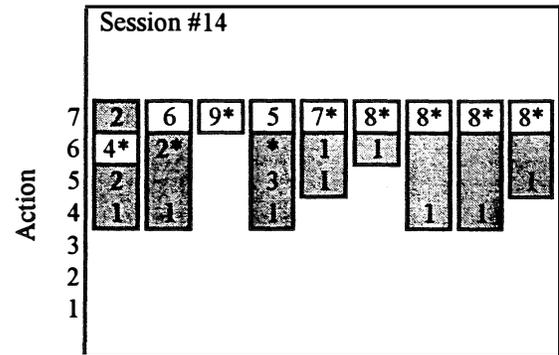
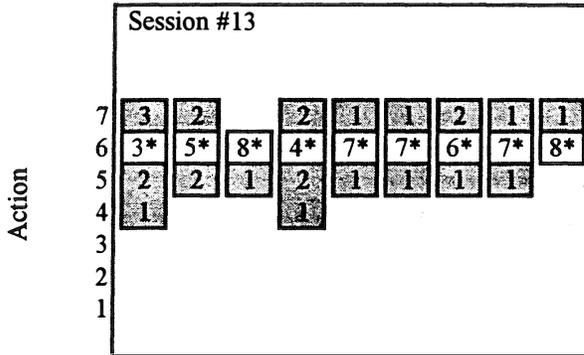
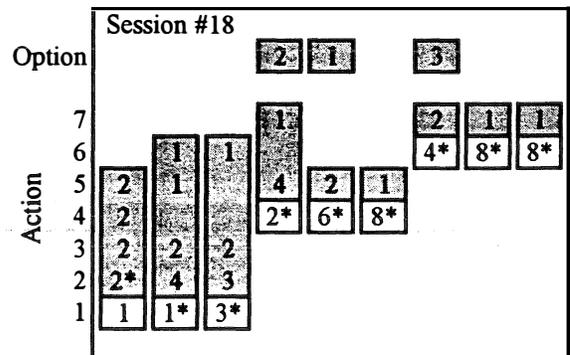
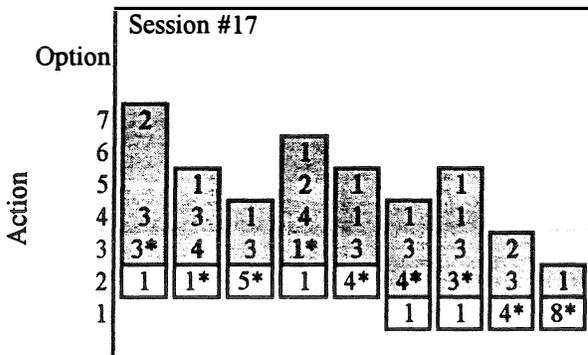
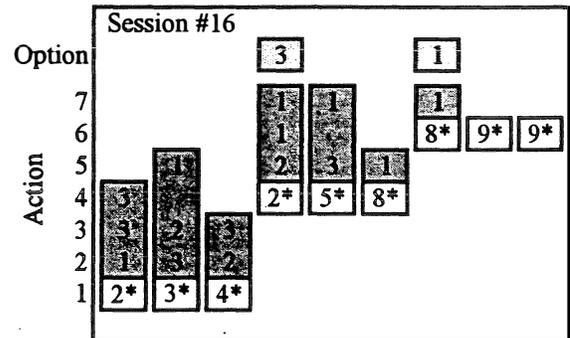
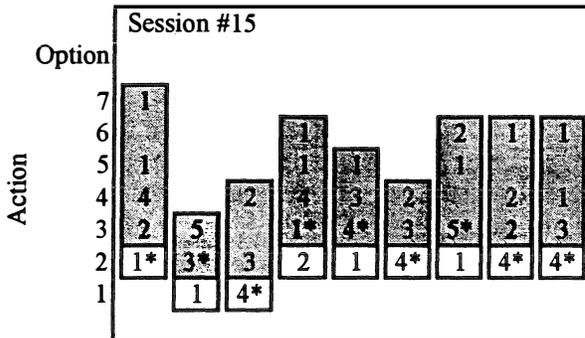


Figure 6: Actions selections in the minimum effort game: must play and opt opt versions

	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



References

- Abdalla, A., Cooper, R., Dejong, D., Forsythe, R. and Ross, T. (1989). Forward Induction in Coordination and Battle of the Sexes Games: Some Experimental Results. Department of Economics, University of Iowa, working paper series #89-22, 1989.
- Arkes, H. R. and Blumer, C. (1985). The Psychology of Sunk Costs. *Organizational Behavior and Decision Processes*, **35**, 124-140.
- Aronson, E. and Mills, J. (1959). The Effect of Severity of Initiation on Liking for a Group. *Journal of Abnormal and Social Psychology*, **54**, 177-181.
- Ball, L. and Romer, D. (1991). Sticky Prices as Coordination Failure. *American Economic Review*, **81**(3), 539-552.
- Becker, G. S. and K.M. Murphy (1992). The division of labor and coordination. *Quarterly Journal of Economics*, **107**, 1137-1160.
- Ben-Porath, E. and Dekel, E. (1992). Signalling Future Actions and the Potential for Self-Sacrifice. *Journal of Economic Theory*, **57**, 36-51.
- Bryant, J. (1983). A Simple Rational Expectations Keynes-Type Model. *Quarterly Journal of Economics*, **108**, 525-528.
- Cachon, G., Camerer, C. and Johnson, E. (1990). Forward Induction, Mutual Rationality, and Behavior in Coordination Games. University of Pennsylvania, working paper.
- Cialdini, R. B., Cacioppo, J. T., Bassett, R. and Miller, J. A. (1978). Low-Ball Procedure for Procuring Compliance: Commitment then Cost. *Journal of Personality and Social Psychology*, **36**, 463-476.
- Cooper, R., DeJong, D., Forsythe, R. and Ross, T. (1989). Communication in the Battle of the Sexes Games: Some Experimental Evidence. *Rand Journal of Economics*, **20**, 568-87.
- Cooper, R., DeJong, D., Forsythe, R. and Ross, T. (1992a). Communication in Coordination Games. *Quarterly Journal of Economics*, **107**, 739-71.
- Cooper, R., DeJong, D., Forsythe, R. and Ross, T. (1992b). Forward Induction in Coordination Games. *Economics Letters*, **40**, 167-72.

- Cooper, R., DeJong, D. V., Forsythe, R. and Ross, T. (1993). Forward Induction in the Battle-of-the Sexes Games. *American Economic Review*, **83**(5), 1303-1316.
- Cooper, R. and J Haltiwanger. (1988). Inventories and the propagation of sectoral shocks. *American Economic Review*. **80**, 170-190.
- Crawford, V. (1995). Adaptive Dynamics in Coordination Games. *Econometrica*, **63**(1), 103-143.
- Crawford, V. and Haller, H. (1990). Learning How to Cooperate: Optimal Play in Repeated Coordination Games. *Econometrica*, **58**(3), 571-595.
- van Damme, Eric (1989). Stable Equilibria and Forward Induction. *Journal of Economic Theory*, **48**, 476-96.
- Diamond, P. (1982). Aggregate Demand Management in Search Equilibria. *Journal of Political Economy*, **91**, 881-894.
- Diamond, D. and Dybvig, P. (1983). Bank Runs, Deposit Insurance, and Liquidity. *Journal of Political Economy*, **91**, 401-419.
- Freedman, J. L. and Fraser, S. (1966). Compliance Without Pressure: The Foot-in-the-Door Technique. *Journal of Personality and Social Psychology*, **4**, 195-202.
- Harsanyi, J. and R. Selten (1988). *A General Theory of Equilibrium Selection*. Cambridge, MA, MIT Press.
- Heath, Chip. (1995). Escalating and de-escalating commitment in response to sunk costs: The role of budgeting and mental accounting. *Organizational Behavior and Human Decision Processes*. in press.
- Kahneman, D. and Tversky, A. (1979). Prospect Theory: An Analysis of Decision Under Risk. *Econometrica*, **47**, 263-291.
- Katz, M. and Shapiro, C. (1986). Technology Adoption in the Presence of Network Externalities. *Journal of Political Economy*, **94**, 822-841.
- Knez, M. and C. Camerer. (1994) Creating expectational assets in the laboratory: Coordination in "weakest-link" games. *Strategic Management Journal*, **15**, 101-119.

- Kohlberg, E. and Mertens, J. (1986). On the Strategic Stability of Equilibria. *Econometrica*, **54**, 1003-1038.
- MacCrimmon, Kenneth R. and Donald A. Wehrung. Taking Risks: The management of uncertainty. New York; Free Press, 1986.
- McGlothlin, W. H. (1956). Stability of Choices Among Uncertain Alternatives. *American Journal of Psychology*, **69**, 604-615.
- Mehta, J., Starmer, C. and Sugden, R. (1994). The Nature of Salience: An Experimental Investigation of Pure Coordination Games. *American Economic Review*, **84**(3), 658-673.
- Milgrom, P. and Roberts, J. (1990). Rationalizability, Learning and Equilibrium in Games with Strategic Complementarities. *Econometrica*, **58**, 1255-78.
- Schotter, A., Weigelt, K. and Wilson, C. (1994). A Laboratory Investigation of Multiperson Rationality and Presentation Effects. *Games and Economic Behavior*, **6**(3), 445-468.
- Shapira, Zur. Risk-taking: A managerial perspective. New York: Russell Sage Foundation, 1995.
- Staw, B. (1976). Knee-Deep in the Big Muddy: A Study of Commitment to a Chosen Course of Action. *Organizational Behavior and Human Performance*, **16**, 27-44.
- Thaler, R. (1980). Toward a Positive Theory of Consumer Choice. *Journal of Economic Behavior and Organization*, **1**, 39-60.
- Tversky A. and D. Kahneman. (1991). Loss aversion in riskless choice: A reference-dependent model. *Quarterly Journal of Economics*, **106**, 1039-1061.
- Van Huyck, J. B. , Battalio, R. B. and Beil, R. O. (1990). Tacit coordination in games. *American Economic Review*, **80**, 234-248.
- Van Huyck, J. B. , Battalio, R. B. and Beil, R. O. (1991). Strategic uncertainty, equilibrium selection principles and coordination failure in average opinion games. *Quarterly Journal of Economics*, **106**, 885-910.
- Van Huyck, J. B. , Battalio, R. B. and Beil, R. O. (1993). Asset Markets as an Equilibrium Selection Mechanism: Coordination Failure, Game Form Auctions, and Forward Induction. *Games and Economic Behavior*, **5**(3), 485-504.

Van Huyck, J. B. V., Gillette, A. B. and Battalio, R. C. (1992). Credible Assignments in Coordination games. *Games and Economic Behavior*, 4(4), 606-626.