It's My Turn . . . Please, After You: An Experimental Study of Cooperation and Social Conventions

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Abstract: We introduce a class of two-player cooperation games where each player faces a binary decision, enter or exit. These games have a unique Nash equilibrium of entry. However, entry imposes a large enough negative externality on the other player such that the unique social optimum involves the player with the higher value to entry entering and the other player exiting. When the game is repeated and players' values to entry are private, cooperation admits the form of either taking turns entering or using a cutoff strategy and entering only for high private values of entry. Even with conditions that provide opportunities for unnoticed or non-punishable "cheating", our empirical analysis including a simple strategy inference technique reveals that the Nash-equilibrium strategy is never the modal choice. In fact, most subjects employ the socially optimal symmetric cutoff strategy. These games capture the nature of cooperation in many economic and social situations such as bidding rings in auctions, competition for market share, labor supply decisions in the face of excess supply, queuing in line and courtship.

Keywords: cooperation, incomplete information, random payoffs, strategy inference, experimental economics.

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1 Introduction

In our economic and social interactions, we face the decision whether to cooperate with other individuals on a daily basis. Cooperation often requires that one person cede his place to another or else conflict or congestion ensues. Consider, for instance, two strangers who reach the check-in counter at the airport at the same time. They can argue about who arrived first or, what is more socially efficient, the person whose flight does not leave for another four hours can allow the hurried passenger to go ahead. As a result, the person with the higher value for the action pursues it, while the other person acquiesces. Such a cooperative outcome may well arise when individuals value the same outcome differentially, even in the absence of repeated play, if acquiescence is not too costly for one of the players.

When the same pair of individuals plays against one another repeatedly and players' values to cooperation vary over time, the cooperative solution whereby the person with the higher value to defection does so, while the other play cooperates is optimal and likely to emerge. However, when players' values to cooperation are private and players are unable to communicate or signal these values, this first-best cooperative outcome is no longer feasible. Instead, a different convention needs to arise to provide for some measure of cooperation and to avoid conflict. Two alternatives are possible.

First, players can take turns cooperating. Cooperation dilemmas in families are often resolved by implementing this alternating strategy. Spouses take turns making important decisions; parents avoid favoring one child over another by rotating favors between them; and siblings settle scores by recalling who enjoyed the same privilege (like riding in the front seat) last time. Firms that compete with one another in multiple markets or in the same markets repeatedly, or bidders who compete for similar objects auctioned off sequentially can cooperate by taking turns capturing the market, instead of pricing or bidding aggressively in each market. Zillante (2003) presents evidence that the four baseball card manufacturers alternate the timing with which they each introduce new product lines in order to reduce intra-period competition.[1]

A second form of cooperation available to players when values are private and cannot be communicated or signaled is play according to cutoff strategies. Cutoff strategies entail entering when the value to doing so exceeds some threshold or cutoff value and cooperating by not entering otherwise. Firms might implicitly collude by staying out of relatively high-cost or low-demand markets with the expectation that rival firms will reciprocate. For instance, auction participants might bid only when the object is sufficiently valuable so as not to inflate the winning bid unnecessarily. The spectrum auctions conducted in the U.S. and Australia in which licenses were split up into numerous regional markets were susceptible to such collusion,[2] while in many European spectrum auctions nationwide licenses were sold and incumbent firms varied from country to country providing less repeat interaction among bidders and consequently less opportunity for cutoff-value collusion. Collusion in the form of alternating nonetheless posed a problem in those European spectrum auctions in which spectrum licenses were divisible and the available licenses outnumbered incumbents. In 1999, German firms T-Mobil and Mannesman evenly split the bidding on ten homogeneous licenses forcing the cessation of the auction after 2 rounds. In the Austrian 3G mobile-spectrum auction, the 12 licenses were also divided evenly among six unequally sized incumbents with the winning bid in each case only slightly above the reservation price (see Klemperer, 2002, for further details).

In this paper, we introduce a class of two-player games with the following properties: 1) non-cooperation is the unique dominant strategy; 2) the sum of players' payoffs is higher if both defect than if both cooperate; 3) in the socially optimal outcome, one player defects and the other cooperates; 4) under incomplete information where players' values to entering

[1] Zillante (2003) discusses other known examples, such as the motion-picture and electrical switchgear industries, in which new-product-release dates have been staggered to blunt head-on competition.

[2] Indeed, the simultaneous open bidding employed in 13/16 of the FCC's spectrum auctions allowed firms to use the last digits of their bids to signal to others on which licences to bid or not bid. Cramton and Schwartz's (2000) analysis reveals that the small fraction of bidders who regularly used bid signaling paid significantly less for their licences, resulting in lost auction revenues.

are their private information, cooperation in the repeated game can take the form of cutoff strategies whereby players cooperate only if their private value for defection is sufficiently low or alternating strategies whereby players take turns cooperating.

We performed numerical optimization to select a parameterization best suited to study experimentally the potential for cooperation. In the chosen parameterization, each player receives a randomly drawn integer between 1 and 5 inclusive. A player's number is his private information. On the basis of his number, a player must decide between two actions: enter or exit. By exiting a player receives zero. By entering he receives his number if his opponent exits and one-third of his number if his opponent also enters. Thus, entering in the one-shot game is the dominant strategy; however, it imposes a negative externality on a player's opponent, since it lowers his payoff by two-thirds provided he also enters.

One feature of the game parameterization chosen is that the optimal symmetric cutoff strategy and the alternating strategy yield very similar joint expected payoffs. This raises the empirical question of which of these two strategies are subjects more likely to adopt.

We conduct this game for 80 rounds under three treatments that differ according to the point in time at which a player learns his opponent's number (at the end of the round or not at all) and the subject pairings (fixed across rounds or randomly determined). Cooperative behavior is found to be remarkably high in all treatments. We employ a simple strategy inference technique to estimate each player's best-fit strategy. The optimal symmetric cooperative cutoff strategy whereby a player enters on the numbers 3, 4 and 5, and exits otherwise is subjects' modal choice in all treatments. Revealing opponents' numbers at the end of the round is particularly conducive to cutoff strategies since entry on low values is observable and punishable.

When the opponents are fixed and their numbers are not revealed, cooperation falls off significantly and the use of alternating strategies increases only marginally; cooperative cutoff strategies continue to be employed by over 70% of subjects even though play according to these strategies cannot be observed. Surprisingly, the level of cooperative behavior is not significantly different when opponents' numbers are again revealed at the end of the round, but opponents are rematched in each round. This is true, despite the facts that defection, while observable, is not punishable and coordination on alternating strategies is no longer possible.

We believe our game and its payoff structure captures the nature of cooperation in many real-world scenarios. For example, McAfee and McMillan (1992) study collusive behavior in auctions that takes the form of bidding rings. Their main result when transfers are impossible is that every bidder whose valuation for the good is greater than or equal to the auctioneer's reservation price should bid exactly the reservation price. We test for a more sophisticated form of collusion; namely, even though a bidder's valuation may exceed the reservation price, he stays out. Moreover, individuals may choose not to enter contests or competitions if their value for the prize or probability of winning is sufficiently low and they care about other more deserving or more capable participants. Junior employees backing down from an internal promotion contest is a common occurrence. Cab drivers, bicycle messengers, golf caddies, waitstaff, sky caps and vendors in a marketplace often face the decision of whether to compete for a customer or acquiesce, with the consequences of their decisions similar to our game's payoff structure. More generally, labor supply decisions in markets characterized by excess supply carry with them the positive externality of yielding one's place to another. In addition, relaxed shoppers commonly cede their spots in line to those in a hurry, and Sunday drivers concede the right of way and willingly let in other cars. Finally, two friends cruising the town in search of companionship continually confront the dilemma of deciding who gets to pursue individuals they encounter.

In the next section, we develop the theoretical framework for this class of two-player games and through numerical optimization select a particular parameterization for our experiments. We contrast our game with related games on cooperation in section 3. In section

4, we detail our experimental design and procedures. Section 5 presents the results and analysis. In section 6, we attempt to understand differences in cooperative behavior between treatments, suggest why some cooperative strategies are more widespread than others and discuss directions for future research. Section 7 concludes.

2 Theoretical Framework

2.1 Environment

We propose a two-player game with the following general structure. Each player receives a randomly drawn integer between a and b inclusive where the probability of receiving a number n is π_n (where $\pi_n > 0$ and $\sum_{n \in \{a \ldots b\}} \pi_n = 1$) and faces a binary decision, enter or exit. By exiting a player receives zero. By entering he receives his number if the other player exits or some function f weakly increasing in his number (and possibly also a function of the other player's number) if both enter. We assume that f is less than his number; hence entry imposes a negative externality on the other player. We also assume that if it is profitable for a player to enter alone (that is, his value is greater than zero), then it is also profitable for him to enter when his opponent enters ($f > 0$ for values greater than zero). For the purposes of this paper, we consider games in which a player's number is his private information.

2.2 Solutions

There are noncooperative and cooperative solutions to this game. If each player is concerned about maximizing only his own payoff, then we can solve for the Bayes-Nash equilibrium. This yields the dominant strategy of entry for numbers greater than zero.

The cooperative solution is given by the pair of strategies that maximizes the sum of the players' expected payoffs. This can also be thought of as a Bayes-Nash equilibrium if we treat an individual player's utility as the sum of the pair's payoffs. Suppose the other player enters with probability $p(n)$ when his number is n. The joint payoff to entering with number x is,

$$\sum_{n\in\{a\ldots b\}} \pi_n \left\{x(1-p(n)) + p(n)[f(x,n)+f(n,x)]\right\}.$$

The joint payoff to staying out is $\sum_{n\in\{a\ldots b\}} \pi_n n p(n)$. If f is nondecreasing in both arguments, then the cooperative solution entails cutoff strategies (that is, for $a \leq n < b$ if $p(n) > 0$, then $p(n+1) \geq p(n)$). This is because if it is profitable to enter with number x, then it is also profitable to enter with any number greater than x. These cutoff values may be non-interior and even asymmetric. A pure-strategy cutoff is when there exists an n^* such that for all $n \leq n^*$, $p(n) = 0$ and for all $n > n^*$, $p(n) = 1$. A mixed-strategy cutoff is when there exists an n such that $0 < p(n) < 1$.

An extreme form of asymmetric pure-strategy cutoffs involves one player entering for all numbers greater than or equal to a (i.e., always enter) and the other entering for numbers greater than b (i.e., always exit). In a repeated game, this cooperative solution can admit the form of players taking turns between entering and exiting. This solution may only reasonably be expected in games in which the same pair of players interacts repeatedly.

2.3 Choosing a Particular Game

From this general framework, we selected a game to test experimentally with the goal of determining the degree and nature of cooperation. To choose a particular game, we performed numerical optimization on the space of games in which players' numbers are drawn from a uniform distribution of integers between a and b inclusive. We restricted $f(x,n)$ to be of the form x/k (where k is an integer) to aid the subjects' understanding of the game.

Our objectives were twofold: 1) to design a game for which the joint expected payoffs (to be also referred to as the expected social payoff) from the optimal symmetric cutoff strategies and the alternating strategies are very similar; 2) to maximize the difference the joint expected payoff from playing the optimal symmetric pure-strategy cutoff, c^*, and the expected social payoff associated with the second-best symmetric pure-strategy cutoff. Put another way, we want to maximize the steepness of the expected social payoff function around the socially optimal pure-strategy cutoff. Achieving this second goal maximizes the incentive for those players wishing to cooperate to enter for numbers greater than c^* and exit for numbers less than c^*. Deviations from this strategy can thus be interpreted as an intention not to cooperate fully.

Before computing the game that maximizes these objectives, we can prove general propositions about the solution for the optimal symmetric pure-strategy cutoff and about the socially optimal strategy as a function of the congestion parameter, k.

Proposition 1: *The optimal symmetric cutoff for numbers drawn independently from the uniform distribution of integers from a to b and congestion parameter k is given by,*

$$c^* = \frac{-1 - 2\,b + (2\,a - 1)\ k + \sqrt{12\,b\ (1+b)\ (k-1)^2 + (1 + 2\,b + k - 2\,a\,k)^2}}{6\ (k-1)}.$$

Proof: Let us examine the costs and benefits of extending the symmetric cutoff by one from $c - 1/2$ to $c + 1/2$. We can represent the problem on a grid that is $b - a + 1$ units by $b - a + 1$ units. Each point on the grid refers to the net gains if the numbers drawn are from that point. The uniform independent distribution implies that each grid point has equal weight. Let us refer to each point as (x, y). The points affected are $(\cdot, c)$ and $(c, \cdot)$. Divide this set of points into three groups. Group one is (c, z) and (z, c) where $z > c$. Group two is (c, z) and (z, c) where $z < c$. Group three is (c, c).

For each grid point in group one, there is a net gain of $z - (z + c)/k$. For group two, there is a net loss of c for each grid point. For group three, there is a net loss of $2c/k$. For all of the points together, there is a net gain of,

$$2\frac{m}{k} + c\cdot 2(b-c) + 2\sum_{z=c+1}^{b}(z - \frac{z+c}{k}) = \frac{b\ (1+b)\ (k-1) - (1 + 2\,b + k - 2\,a\,k)\ c - 3\ (k-1)\ c^2}{k}.$$

This is simply a quadratic with both a positive and a negative root, where the positive root is the optimal cutoff. *QED*

From the expression for c^*, we see that as the congestion parameter, k, increases, so does the optimal symmetric cutoff for a given a and b. Intuitively, as k increases, it becomes increasingly costly for both players to enter; as a result, the socially optimal threshold for entry increases. Taking the limit of c^* as k tends to infinity yields,

$$\lim_{k\to\infty} c^* = \tfrac{-1+2\,a+\sqrt{(1-2\,a)^2+12\,b\,(1+b)}}{6}.$$

Proposition 2: *When $k \leq 2$, the socially optimal strategy is a cutoff strategy. In the uniform case, as $k \to \infty$, the socially optimal strategy is alternating.*

Proof: Independent of k, alternating yields a joint expected payoff equal to the expected value of the range of numbers. Consider the case of $k = 2$: the strategy of always enter (the lowest possible cutoff) yields half the expected value for each player. Thus, the joint expected payoffs are the same for alternating and always entering. When the lowest possible cutoff is not the optimal cutoff or when $k < 2$, the joint expected payoff from the cutoff strategy will be strictly higher.

For the uniform distribution, using the grid method of the previous proof, alternating yields $(b-a+1)\sum_{z=a}^{b} z = (1+b-a)^2(a+b)/2$. Using a cutoff strategy of c^* yields a joint payoff of $2(c^*-a)\sum_{z=c^*}^{b} z = (1+b-c^*)(c^*-a)(b+c^*)$. The expression $(1+b-c^*)(c^*-a)$ reaches its maximum at $c^* = (1+a+b)/2$, yielding $(1+b-a)^2/4$. Since $(b+c^*)$ is maximized for $c^* = b$, we know the joint cutoff payoff must be strictly less than $(1+b-a)^2 \cdot\ b/2$. For $a > 0$, this is less than the joint alternating payoff. *QED*

When the distribution of values is not uniform, the second result does not generally hold. Take for example the values of 100 with probability 1/3 and 1 with probability 2/3. For large k, alternating yields a joint expected payoff of 34. Entering only when one has 100 yields 100 with probability 4/9 and ϵ otherwise. Hence, this optimal cutoff strategy yields a higher joint expected payoff.

In our search for a parameterization that yields similar joint expected payoffs for the optimal cutoff and alternating strategies, Proposition 2 suggests values of k greater than 2, but not too large: we allowed k to vary from 2 to 5. Over the range of numbers, $\{a, \ldots, b\}$, we allowed b to be any integer greater than or equal to 3, and fixed $a = 1$. This latter decision was made in part because if a is an integer less than 1, then the strategy "always enter" is no longer a unique dominant strategy in the stage game. In selecting our game parameters, for a given f, we can often increase the steepness of the expected social payoff function around the socially optimal pure-strategy cutoff by shrinking the number of integers in the range $\{a, \ldots, b\}$ (i.e., by lowering b in our case). However, when the optimal cutoff for the expected social payoff is in mixed strategies, then this need not be true. Instead, the expected social payoff function connecting the two pure-strategy cutoffs that straddle the optimal mixed-strategy cutoff can be rather flat. Indeed the optimal symmetric cutoffs are in mixed strategies for $(b = 3, k = 4)$, $(b = 4, k = 4)$, $(b = 5, k = 2)$ and $(b = 5, k = 4)$. An optimal solution in mixed strategies should be avoided due to the salience of the nearby, almost optimal, pure strategies, the improbability that both subjects will solve for, and play, the optimal mixed-strategy cutoff and the added difficulty in analyzing the data.

The two optimal steepness parameterizations are $(b = 3, k = 3)$ and $(b = 5, k = 3)$. For our experiments, we chose $(b = 5, k = 3)$. Although the difference between the optimal expected social payoff and the second-best expected social payoff from $(b = 3, k = 3)$ is 0.30 per round, 0.06 units higher than the next-best parameterization of $(b = 5, k = 3)$, we decided against the former; with only three numbers in the range, arriving at the social equilibrium of exiting on 1 and entering on 2 and 3 is too easy. We prefer a parameterization for which the Nash and cooperative cutoff solutions differ by at least two numbers.

Figure 1 displays the results of our search for the range of numbers $\{1, \ldots, 5\}$ and $k \in$

$\{2, 3, 4, 5\}$. The figure reveals that the optimal pure-strategy cutoff value equals 1.5 for $k = 2$, equals 2.5 for $k = 3, 4$, and equals 3.5 for $k \geq 5$.[3] The figure also shows that the steepness around c^* is maximized for $k = 3$. For $k = 3$, the pair's expected payoff if each player employs the optimal cutoff, $c^* = 2.5$, is 216/75. For $c = 3.5$, the pair's expected payoff decreases to 198/75 and to 196/75 for $c = 1.5$. For $c = 4.5$, the pair's expected payoff is 130/75 and for $c = 0.5$ (always enter) it is 1.

[insert Figure 1 here]

For our chosen parameterization, the alternating strategy actually yields the pair slightly more in expectation than the optimal symmetric pure-strategy cutoff:[4] from alternating the pair earns 3 units of profit in expectation, 9/75 units more than from $c^* = 2.5$. That these two strategies perform almost equally well despite their qualitatively very different natures raises the empirical question of which one, if any, will be adopted by players.[5] Not only is the expected pair's payoff from playing the alternating strategy (3) higher compared to the optimal symmetric cutoff strategy (216/75), the variance of the expected payoff is also lower: 2 compared to 2.42. Part of the intuition why the payoff variance is lower for the alternating strategy is that this strategy always yields at least one unit of profit, while with probability 4/25 the optimal cutoff strategy yields 0.

3 Related Literature

The best known and most frequently tested cooperation game, the prisoners' dilemma, has a unique dominant-strategy equilibrium in which both players defect; however, if both players

[3] We express all cutoffs as halves to denote unambiguously that the player enters on all integers greater than the cutoff and exits otherwise.

[4] We persist with the cumbersome language of "optimal symmetric pure-strategy cutoff" because the alternating strategies can be thought of as asymmetric pure strategies in which one player uses a cutoff of $c = 0.5$ and the other uses $c = 5.5$.

[5] Notice that had we chosen $k = 2$, not only is the social payoff function much flatter around the optimal cutoff value, $c^* = 1.5$, but the alternating strategy yields the identical expected social payoff as always enter ($c = 0.5$).

could commit to cooperation, both would be better off. The standard public-goods game is an n-player extension of the prisoners' dilemma in which each player decides how to allocate his endowment between a private good (which benefits the player alone) and the public good (which benefits all players equally). In the socially optimal outcome, all players contribute their entire endowments to the public good; this conflicts with the unique dominant-strategy equilibrium in which each player contributes his entire endowment to the private good. Noncooperation (enter) is also the unique dominant-strategy equilibrium of our class of games. Unlike the prisoners' dilemma and public-goods games, however, the socially optimal outcome in our game involves one person defecting and the other person cooperating. A second distinction of our game is that if both players defect they are better off than if both cooperate.

Amnon Rapoport and his coauthors have conducted various versions of a market entry game. In an early version, Rapoport (1995), n symmetric players independently decide whether to enter a market with capacity $c \leq n$. Staying out yields a fixed payoff, whereas entering yields a payoff that decreases in the number of entrants and yields less than the fixed payoff from staying out in the case of excess entry.[6] In subsequent versions of the market entry game, Rapoport and coauthors have explored the effect of deciding whether to enter in one of two markets where each market's capacity changes in each period (Rapoport, Seale and Winter, 2000) and asymmetric entry costs that are held constant throughout the experiment (Rapoport, Seale and Winter, 2002). These games have large numbers of pure-strategy and mixed-strategy equilibria, all characterized by some subset of players entering the market with positive probability. Beginning with Kahneman's (1988) original experiments on the market entry game, the main result across all of these variations is that subjects learn to coordinate on one of the Nash equilibria. Moreover, Erev and Rapoport (1998) have shown that a variant of a reinforcement learning model can account for the mixed-strategy equilibria

[6] The special case in which the payoff for entering changes only in going from within-capacity to over-capacity is known as the El Farol Problem (see Arthur, 1994).

observed in the play of standard market entry games.

Overall, these games and ours share the feature that entry imposes a negative externality on other entrants. The most important differences are the uniqueness of the Nash equilibrium in our setup and the fact that it is at odds with the full-information, social optimum whereby one player cooperates and the other defects, whereas a multiplicity of Nash equilibria, all of which are efficient, characterize standard market entry games. Moreover, exit is a strictly dominated strategy in our class of games for $a > 0$ and $f > 0$. Put another way, if both players enter ("excess entry"), unlike the market entry game, each entrant still earns more than if he had exited.

4 Experimental Design and Procedures

4.1 Experimental Design

All experiments were conducted in (not necessarily fixed) pairs. Each player in the pair received an independently and randomly drawn integer between 1 and 5 in each round. Subsequently, each player independently decided whether to enter or exit. The decision to exit yields 0, whereas entry yields the value of the number if the opponent exits and 1/3 of the value of the number if the opponent also enters. All experiments were conducted for 80 rounds with 5 initial practice rounds.[7]

We conducted three experimental treatments that differ by the point in time at which a player learns his opponent's value (after the round or never) and by the opponent's identity (fixed or random). In the baseline treatment, "*AfterFixed*", the pairs are fixed for 80 rounds (but different from the 5 practice rounds) and each player learns his opponent's value at the

[7] We opted for a known rather than a probabilistic terminal round both for reasons of simplicity of design and to keep the theoretical analysis similar to the one-shot game. Moreover, Normann and Wallace (2004) show that except for end-game effects, subjects' cooperative behavior in a prisoners' dilemma game is unaffected by the termination rule.

end of the round. This provides relatively favorable conditions for cooperation. For example, the pair may coordinate on and enforce both the alternating and the cutoff strategies. If a player enters when it is not his turn to enter or on a low number, say 1, he recognizes that his opponent will observe this defection and can retaliate by entering out of turn or the next time he receives the number 1. Thus, for a sufficiently long horizon, when cooperation is the status quo, uncooperative entry is unprofitable.[8]

The two additional treatments are both one variation away from *AfterFixed* and are hypothesized to make cooperation more difficult to achieve. In the second treatment, "*NeverFixed*", pairs remain fixed, however, a player does not observe his opponent's number at the end of the round, only his decision to enter or exit. Thus, with cutoff strategies, if a player decides to enter, his opponent does not know if he entered because he drew a high number or because he is playing uncooperatively. This lack of information clearly renders cooperation less likely. Another way to make cooperation more difficult is to change players' opponents in each round.[9] In the third treatment, "*AfterRandom*", like the baseline treatment, players observed their opponents' numbers at the end of each round; however, pairs were randomly reformed in each round. Random opponents make it impossible for a pair of players to build cooperation between them. Moreover, if pairs aren't fixed, the cooperative strategy by which players alternate entering is no longer feasible.

In a repeated game, cooperation can be maintained even when players are self-interested by means of punishment. Punishment is easiest in *AfterFixed*: if alternating or cutoff strategies are employed, any deviation is easily detected and punishable. Punishment is hardest in *AfterRandom*: while deviation is detectable, punishment is unattainable. *NeverFixed* represents an intermediate case for punishment: although deviations from alternating strategies

[8] In all of our treatments, due to the certainty in the number of rounds, to always enter is the unique Nash equilibrium in the repeated game as well as the unique dominant-strategy equilibrium in the one-shot game.

[9] Andreoni and Croson (forthcoming) survey the evidence on the impact of fixed partners versus random rematching on cooperation in public goods games.

are easily detected and punishable, detection in particular is difficult for cutoff strategies. Frequent entry may just reflect lucky draws of high numbers. A rule could be adopted whereby more than 7 entries in the past 10 rounds constitutes a deviation; however, efficiency would be lost if more than 7 of the last 10 draws exceeded the cutoff of 2.5. Furthermore, how does the pair coordinate upon the rule of 7 out of 10, or any other?

4.2 Experimental Procedures

Upon arrival, each subject was seated in front of a computer terminal and handed the sheet of instructions (see the Appendix). After all subjects in the session had completed reading the instructions, one of the experimenters read them aloud. To ensure full comprehension of the game, subjects were given a series of knowledge-testing questions about the game (the questions are also contained in the Appendix). Participation in the experiment was contingent upon answering correctly all of the questions.[10] Five practice rounds were then conducted with identical rules to the actual experiment. To minimize the influence of the practice rounds, subjects were rematched with a different opponent for the 80-round experiment.

In the first two treatments, subject pairs progressed through the 80 rounds at their own pace. After completing the experiment, subjects completed a questionnaire and remained seated until others had finished to avoid discovering their partners' identity. In the random rematching treatment, the pairs could be formed randomly each round only after the last subject had made a decision.

An important feature of our experimental design that allows us to compare subjects' behavior across pairs and across treatments is our use of one pair of randomly drawn sequences of 80 numbers (85 numbers including the five practice rounds) from 1 to 5. Before beginning the experiments, we drew two 80-round sequences, one for each pair member. We

[10] No one was excluded from participating. All subjects who showed up answered correctly all of the questions in the allotted time.

applied these sequences to all subjects in all sessions and treatments.[11] Thus, for instance, in round 56 regardless of pair, session or treatment, the subject arbitrarily designated player A received a value of 2, while player B received a value of 4.[12]

4.3 Subjects and Payments

Since the experiment requires a very basic knowledge of probabilities, participation was limited to economics, engineering, business, natural science, mathematics and computer science students. Students who had taken a class in experimental economics were not allowed to participate.

Sixty-two subjects participated in one of the three *AfterFixed* sessions, 62 subjects in one of the three *NeverFixed* sessions, and 46 subjects in one of the two *AfterRandom* sessions (24 in one session and 22 in the other). A session took between 75 and 85 minutes for the first two treatments, and approximately 100 to 110 minutes for the *AfterRandom* treatment. To compensate the students in the random rematching treatment for the extra time required, a fixed payment of 10 shekels was added to their experimental earnings. In order to hold constant the marginal incentives across treatments, the experimental-currency-to-shekel ratio was fixed at 1:0.6 for all three treatments.

[11] In practice, due to an undetected bug in the software, the order of numbers varied slightly between some sessions, sometimes causing numbers intended for the practice rounds to replace numbers from the experimental rounds. Notwithstanding, the two sequences of numbers remain nearly identical across pairs and sessions.

[12] The astute reader will note that to preserve the identical sequence of values in the random rematching treatment requires that each subject be designated either a player A or a player B and that the random rematching of player As be restricted to player Bs.

5 Results

5.1 Cooperation across Treatments

Table 1 presents the percentage of rounds in which subjects entered for a given number by treatment. Thus, in the baseline treatment, *AfterFixed*, subjects entered only 16.3% of the time they drew the number 1. These summary statistics reveal a number of findings. First, as expected, cooperation increases by increasing information or by fixing partners. Second, not all subjects are playing the Nash equilibrium. Exit is the modal decision for the number 1 in all treatments and also for the number 2 in the *AfterFixed* treatment. Moreover, the sharp spike in entry percentages in going from the number 2 to 3 in all three treatments suggests that many subjects may be employing the optimal symmetric cutoff strategy of 2.5. Finally, that not all subjects are entering all of the time on numbers 4 and 5, particularly in *NeverFixed*, suggests the use of alternating strategies for which entry and exit decisions are independent of the numbers received. In the next subsection, we estimate either the cutoff or alternating strategy that best fits each individual subject's observed decisions.

[insert Table 1 here]

Comparing entry on different numbers across treatments, Table 1 reveals that the frequency of entry is markedly higher in *NeverFixed* than in *AfterFixed* for the number 1 (30.8% vs. 16.3%) and for 2 (53.8% vs. 29.4%). A χ^2 test of proportions rejects the equality of the entry proportions for the distribution of numbers 1 to 5 across the *AfterFixed* and *NeverFixed* treatments, $\chi^2 = 94.38$, $df = 4$, $p = .001$. By the same token, we can reject the equality of the entry proportions by number for the *AfterFixed* and *AfterRandom* treatments, $\chi^2 = 108.40$, $df = 4$, $p = .001$. On the other hand, although Table 1 suggests a slightly higher tendency to enter on numbers 2 and 3 in the *AfterRandom* treatment, we find no significant difference between the proportions of entries by number in the *NeverFixed* and *AfterRandom* treatments, $\chi^2 = 4.58$, $df = 4$, $p = .334$.

Further evidence that cooperation in *AfterFixed* is significantly higher than in *NeverFixed* or *AfterRandom*, but that there is no significant difference between the latter two treatments comes from a comparison of subjects' profits. We computed average subject earnings by treatment as a percentage of the full-information, efficient outcome in which only the player with the higher number enters (in the case of ties, only one player enters), given the actual distribution of numbers drawn over the 80 rounds. While this outcome is not feasible in our experiments with private information and no communication, it serves as a useful benchmark. In *AfterFixed*, subjects earned on average 71.6% of this first-best, social optimum, significantly higher than the 67.6% achieved in *NeverFixed* and 66.9% in *AfterRandom*. All of these yields are markedly higher than the 53.8% offered by Nash play, attesting to the relatively high levels of cooperation in all three treatments.[13]

We estimate a random effects Probit model to explain the variation in subject i's decision to enter in period t. The specification for our random effects Probit model for each of the three treatments is as follows,[14]

$$\begin{aligned} \widetilde{Enter}_{it} \quad = \quad & constant + \beta_1 * C_{1.5} + \beta_2 * C_{2.5} + \beta_3 * C_{3.5} + \beta_4 * C_{4.5} + \\ & \beta_5 * Enter_{i,t-1} + \beta_6 * Enter_{-i,t-1} + \beta_7 * first10 + \beta_8 * last10 + \epsilon_{it}, \end{aligned} \tag{1}$$

$$\text{where} \quad \epsilon_{it} = \alpha_i + u_{it}$$

$$\text{and} \quad Enter_{it} = \begin{cases} 1 & \text{if } \widetilde{Enter}_{it} \geq 0 \\ 0 & \text{otherwise.} \end{cases}$$

The dummy variable $C_{1.5}$ equals one if player i's period t number is 2, 3, 4 or 5 and equals zero if it is 1; similarly, $C_{2.5}$ equals one for numbers 3, 4 and 5, and zero otherwise,

[13] Other efficiency measures include play according to the optimal symmetric pure-strategy cutoff of 2.5, which yields 75.9%, the alternating strategy, which yields 78.9% if player A enters in the odd rounds or 82.5% if player B does, and the outcome in which both players exit in every round, which returns 0%.

[14] The presence of the lagged dependent variable as a regressor renders our estimates inconsistent. To correct for this, we estimated a correlated random effects model (Chamberlain, 1980) in which subject i's first-period entry decision and number were also included as regressors. (In the *AfterRandom* treatment, the first-period entry decision is dropped since all 46 subjects entered in period 1.) Because all of the results are qualitatively identical to our random effects Probit results, we report the latter for simplicity.

and so forth for $C_{3.5}$ and $C_{4.5}$. The marginal effects of the estimated coefficients on these variables can be interpreted as the marginal propensity to enter for numbers 2, 3, 4 and 5, respectively. Also included in the regression equation are the subject's own last-period entry decision, $Enter_{i,t-1}$, and that of his opponent, $Enter_{-i,t-1}$. Finally, we control for initial learning and end-game effects by including dummies for the first 10 and last 10 periods, respectively. The error term, ϵ_{it}, is composed of a random error, u_{it}, and a subject-specific random effect, α_i.

Table 2 displays the regression coefficients and marginal effects for each of the three treatments. All of the variables are significant in *AfterFixed*. In particular, the computed marginal effects displayed in the second column indicate that a subject is 13.9% more likely to enter on a 2 than a 1, 58.7% more likely to enter on a 3 than a 2, 22.1% more likely to enter on a 4 than a 3 and 5.5% more likely to enter on a 4 than a 5. These estimates correspond closely to the differences in percentages of entries by number reported in Table 1, despite the inclusion of a number of other significant controls in the regressions. For instance, if a subject entered in the previous round, he is less likely to enter this round, while if his opponent entered last round, he is more likely to enter this round. Both of these findings are consistent with the pair employing alternating strategies. Finally, the significance of "first10" and "last10" supports initial learning and end-game effects in the anticipated direction: subjects are less likely to enter early on and more likely to enter toward the end of the game.

[insert Table 2 here]

The regression results from the *NeverFixed* and *AfterRandom* treatments are very similar, the main differences being that the $C_{4.5}$ variable is no longer significant in *NeverFixed*, while neither $C_{3.5}$ nor $C_{4.5}$ is significant in *AfterRandom*. Table 1 reveals an entry frequency of 97.2% (693/713 times) on the number 3 in *AfterRandom*, offering little scope for more frequent entry on the number 4.

Moreover, the initial learning effect captured by the "first10" variable is not significant in either of these treatments. Intuitively, subjects do not adapt their behavior in response to their opponents' early choices (with the exception of unrequited alternating) because reciprocity cannot easily be dispensed in these treatments; in *NeverFixed*, since the opponent's number is never revealed, his motive for entering remains ambiguous, while fair play cannot be rewarded and cheating cannot be punished in *AfterRandom* because the opponent keeps changing.

One curiosity in *AfterRandom* is the continued significant, negative coefficient on the subject's own previous-period decision, indicative of alternators in spite of the impossibility of coordinating on alternating strategies when partners are randomly rematched each round. Anticipating the strategy inference results in the next subsection, there exists one subject who alternated, entering in odd rounds and exiting in even ones in 79/80 rounds. To account for this outlier, we estimate an additional specification that includes an interaction dummy variable for subject 17 and his previous-period decision. The coefficient of -6.29 on $subject17 * Enter_{i,t-1}$ is strongly significant ($p < .01$), whereas the coefficient on $Enter_{i,t-1}$ is no longer significant ($p = .48$), suggesting the absence of correlation between one's previous-period and current-period decisions, after controlling for the number received in each period.

The estimates of ρ in Table 2 measure the fraction of the error term's variance accounted for by subject-specific variance. The highly significant estimates ranging from 0.395 in *AfterFixed* to 0.569 in *AfterRandom* indicate that between 40% and 57% of the variance in the error term is explained by subject heterogeneity.

5.2 Individual Strategies

To understand better the heterogeneity in subject behavior, we infer the strategy that best fits each subject's observed decisions. For each subject, we compare the ability of the different cutoff and alternating strategies to classify correctly the subject's entry and exit choices. For different time horizons over the 80-round game, we compute the goodness of fit for each of the possible pure-strategy cutoffs, $c \in \{0.5, 1.5, 2.5, 3.5, 4.5, 5.5\}$, and the two alternating strategies, enter in even rounds, exit otherwise and enter in odd rounds, exit otherwise. The strategy that minimizes the number of errors in classifying the subject's observed decisions is selected as the one that the subject most likely employed.[15]

[insert Table 3 here]

Table 3 reports the distribution of individuals' best-fit strategies for rounds 11–70 by treatment. In the case where two strategies explain a subject's decisions equally well, each of the tied strategies receives half a point. Thus, for instance, nine subjects are playing according to the Nash equilibrium strategy of $c = 0.5$; for one of these subjects, the cutoff strategy $c = 1.5$ fits his decisions equally well. Excluding the first 10 and the last 10 rounds reduces the error rates by minimizing the influences of the observed learning and end-game effects. All but one to three (depending on the treatment) of the individual best-fit strategies are robust to the different time horizons tested, like all 80 rounds, the last 60 rounds, the last 40 rounds and rounds 16–65.

Overall, this simple inference technique fits the data well as seen in the error rates of 6%, 8% and 5% for each of the three treatments respectively. Thus, of the 3720 decisions made by the 62 subjects in *AfterFixed* between rounds 11 and 70, 3479 of them correspond to the best-fit strategy inferred for each subject. By comparison, if we assume that all subjects are playing the Nash equilibrium strategy, then the third-to-last row of data in Table 3 indicates that the error rates jump to between 21% and 32% depending on the treatment. In

[15] This methodology is a much simplified version of the strategy inference technique developed in Engle-Warnick and Ruffle (2004) because it permits only one decision rule of the form "if [condition satisfied], then Enter; otherwise Exit". We do not allow for nested rules. Accordingly, the technique does not allow for changes in subjects' strategies over time. Furthermore, our simple technique implicitly assumes a common prior over all strategies under consideration. Its simplicity notwithstanding, this technique does remarkably well in organizing subjects' decisions, as reflected in the very low error rates in Table 3.

addition, we generated random decisions for subjects calibrating the probability of entry to match the observed overall rate of entry in each treatment (.677, .744 and .793 for the three treatments, respectively). We then calculated the error rate from these random decisions for each subject's best-fitting strategy and for each subject assuming Nash play. The results in the bottom two rows of Table 3 again demonstrate that our inferred strategies on the actual data fit the data much better than the best-fitting and Nash strategies on the randomly generated data. This suggests that subjects are indeed playing in a non-random, methodic fashion that can be captured by cutoff and alternating strategies.[16]

Despite the slight payoff advantage and lower payoff variance of the alternating strategy, we find that the optimal symmetric cutoff strategy of $c^* = 2.5$ best characterizes the decisions of 39/62 subjects in the *AfterFixed* treatment. In fact, several pairs coordinate on this strategy without even a single error, while in other pairs, one partner occasionally deviates by entering on the number 2. Pair 17 is a case in point. Player 17B decides according to the cutoff $c^* = 2.5$ flawlessly through all 80 rounds; his opponent's best-fit strategy is also the cutoff $c^* = 2.5$; however, in rounds 35 and 52, he "cheats" by entering on a 2. Nine subjects appear to be employing the cutoff of 1.5, nine other subjects' strategy is to enter all of the time ($c = 0.5$), four subjects (two of whom form a pair) use the hyper-cooperative cutoff of 3.5, and only one pair of subjects uses alternating strategies. Pair 21 begins alternating in period 33 and continues without deviation through period 80.

Table 4 displays the numbers and decisions for a pair of subjects from each of the three treatments. The number of errors for each pure-strategy cutoff value and the alternating strategies for rounds 11–70 are displayed below the decisions of each subject, with the number of errors for the best-fit strategy highlighted in bold.[17] Pair 10 (shown in Table 4)

[16] A complementary method to determine the strategies subjects play is to ask them. We did this in a post-experiment questionnaire. For cases in which their responses are interpretable, they match our inferred strategies exceptionally well, with the caveat that many subjects claim to decide randomly when in fact their decisions display a clear tendency to enter on higher numbers and exit on lower ones.

[17] We display subject pairs with above average error rates for the simple reason that the behavior of subjects who stick to a strategy with few or no errors is easily and more parsimoniously described in words.

demonstrates the necessity that both pair members employ the complementary alternating strategies for them to endure. Player 10A begins alternating in period 1, exiting in odd rounds and entering in even ones. Her opponent shows signs of alternating, except when he receives a 4 or 5 in which case he enters. Player 10A continues to alternate through period 16 despite four entries and one exit out of turn by 10B. In round 17, 10A receives a 5 and enters, breaking her alternating pattern. The pair eventually appears to coordinate on the cutoff strategy $c^* = 2.5$, until round 64 in which 10B enters on a 2. From round 71 through the final round, both players enter in every round.

[insert Table 4 here]

The *NeverFixed* treatment is a more likely candidate for alternating because the playing of cutoff strategies cannot be observed and, as a result, cannot be enforced. Still, a meager two out of 31 pairs coordinate on the alternating strategies. Pairs 5 and 7 adopt the alternating strategies in rounds 2 and 8, respectively, and play them without error for the duration. An additional subject whose best-fit strategy is enter in odd rounds eventually abandons this strategy after his opponent failed to adopt the complementary alternating strategy.

The distribution of best-fit strategies shown in Table 4 reveals a marked shift from higher to lower entry cutoff values in going from *AfterFixed* to *NeverFixed* or from *AfterFixed* to *AfterRandom*. For example, the percentage of subjects playing the optimal symmetric pure-strategy cutoff of 2.5 declines from 62.1% in *AfterFixed* to 38.7% in *NeverFixed* or to 38.0% in *AfterRandom*, while those who play the Nash equilibrium increases from 13.7% to 20.2% (*NeverFixed*) or 22.8% (*AfterRandom*). Like the overall proportions of entry by number and by treatment in Table 1 and subjects' actual earnings as a percentage of the social optimum, both discussed in section 5.1, the individual inferred strategies again point to a decline in cooperation when less information is provided or partners are randomly reformed, but no difference in the cooperative behavior between these two conditions.

The percentage of entry decisions by number displayed in Table 1 and the Probit regression results from Table 2 also reveal subjects' willingness to cooperate in these experiments. What our strategy analysis adds is the observation that pair members typically coordinate on the same cooperative strategy. In the *AfterFixed* treatment, of the 30 pairs that employ cutoff strategies, 22 of them coordinate on the same cutoff values, while 16/28 pairs do so in *NeverFixed*, despite not being able to observe the other's numbers. Moreover, for all 12 pairs in which partners do not coordinate on the same cutoffs, their inferred cutoffs differ by only one integer value and their error rates tend to be above average due to an ambivalence between two competing cutoff values. Pair 30, displayed in Table 4, represents a case in point. Player 30A begins by alternating, entering if and only if the round number is odd. Player 30B, however, has his own agenda, consistently exiting on 1s and 2s and entering on 3s, 4s and 5s, with only 3 exceptions over the entire 80 rounds (namely, entering on a 2 in rounds 30 and 41 and on a 1 in round 80). Because his opponent does not adopt the complementary alternating strategy, 30A enters defiantly on a 1 in rounds 18 and 20, before adopting the cutoff of 1.5 and playing it with few deviations until the end.[18]

6 Discussion

6.1 Is the shame of being seen cheating enough?

The finding that play in *AfterRandom* is no less cooperative than in *NeverFixed* is, in our view, surprising. In *NeverFixed*, if a player does not play cooperatively and enters every period or "too often", his opponent may retaliate by entering in every period. Such recourse is not available when opponents are randomly rematched in every round. The mere fact

[18] Player 30A is among the few subjects for whom a nested strategy would substantially improve the errors in classifying his decisions. Allowing a nested strategy of the form, "if round <18, then Enter on Odd rounds; otherwise (if number >1, then Enter, otherwise Exit)", decreases the subject's errors from 9 to 4 for rounds 11–70 and from 15 to 6 for all 80 rounds.

that cheating or non-cooperative play is fully observable (even if it isn't punishable) in *AfterRandom* appears to be sufficient to keep players in line. The question remains whether this result extends to a much larger sample population where the probability is infinitesimally small that player X will ever meet someone who has played against him, or whether he will ever meet someone who has played someone who has played against player X, *ad infinitum*.[19]

6.2 What makes a cooperative strategy ubiquitous?

Although the pair's expected profit from employing the alternating strategy is slightly higher (by 9/75 of a unit per period) and the variance lower than those from the optimal symmetric cutoff strategy of $c^* = 2.5$, the overwhelming majority of subjects employ the latter strategy. We believe that there are three important reasons for this.

First, the alternating strategy must be implemented by both pair members to be effective; unilateral use of this strategy is very costly, and, as we saw with the individuals who attempted to implement it alone, eventually abandoned. By contrast, cooperation according to a cutoff strategy involves staying out on the lowest numbers, when it is least costly to do so.

Second, the alternating strategy ignores the values to entry in each round. Instead it relies on an algorithm seemingly void of economic appeal to determine whether to enter. The lack of economic appeal becomes especially salient when a player receives the number 5 and it is his turn to exit.

Third, suppose a player fears his opponent might tremble in implementing his intended strategy. In the case of the alternating strategy, an error means that a player enters when it is not his turn (when his opponent enters) and exits when he is supposed to enter. In the former, the mistake reduces his entering opponent's payoff by 2/3 and, in the latter, the opponent's payoff of zero from exiting is unchanged. In the case of the symmetric cutoff

[19] An experimenter can avoid even this indirect contact by forming pairs using the turnpike method, which requires at least twice as many subjects per session as rounds.

strategies of $c^* = 2.5$, a tremble by a player means that either he enters with numbers 1 and 2 or exits with numbers 3, 4, and 5. If each of these errors is equally likely, then an error means that the player is entering less frequently (with probability 2/5 compared to 3/5 with no errors). As a result, a player's error actually benefits his opponent.

With these disadvantages associated with the alternating strategy, the slight 0.12 unit per round advantage for the pair was inadequate. One could magnify the alternating strategy's joint-expected-payoff advantage, thus making its adoption more likely, by shrinking either the absolute or percentage difference between a and b. For instance, we would expect to see more alternating when players' integers are drawn from a uniform distribution between 6 and 10 where the joint expected per round payoff from alternating is 8 compared to 6.35 from $c^* = 6.5$. By shrinking the absolute difference between a and b to the extreme case where $a = b$, we would expect all players to adopt alternating. In short, alternating makes increasing sense as players' values to entering become more alike. If children's utilities from riding in the front seat are similar, they will take turns enjoying this privilege. By the same token, firms with similar expected profits from introducing a new product into the market seem able to coordinate on rotating the timing with which they do so, as demonstrated by the examples of motion-picture and baseball-card releases (Zillante 2003).

6.3 Implications of our Results and Extensions

Slight changes in our experimental parameters can produce a very different game. For instance, a negative lower bound on the range of numbers, a, allows for spite. A subject who receives a negative number and enters has points subtracted from his profit. His choice to enter despite a negative payoff stems from a desire to punish his partner. Spiteful behavior has been observed and resulted in more efficient contributions to public goods (Cason, Saijo and Yamato 2002; Fehr and Gachter 2000) and higher offers in proposer-responder games (Andreoni, Harbaugh and Vesterlund 2003). Moreover, we explored in this paper two realizations of the timing-at-which-a-subject-learns-his-opponent's-number variable (*After* and *Never*). We could also permit subjects to observe their opponents' numbers *Before* deciding whether to enter or exit. Under this full-information condition, the socially optimal strategy changes to enter for the subject with the higher number and exit for the other subject.[20] The pair's expected per-period payoff increases to 3.80,[21] compared to 3 for alternating and 2.88 for $c^* = 2.5$.

There are additional ways to achieve this socially optimal outcome, even in the absence of full information. For instance, if we allow subjects to transmit a number or series of numbers to their opponents (cheap talk), then the decision to reveal truthfully and precisely one's number can permit optimal cooperation. Alternatively, if subjects are allowed to offer side payments (bribes) to their opponents prior to entry decisions, then the size of the side payment may signal perfectly the player's number and optimal cooperation may be achieved.

In the absence of communication, our results demonstrate notably high levels of cooperation, especially when compared to repeated prisoners' dilemma and public-goods experiments in which convergence toward the unique dominant strategy of defection has been documented in dozens of experiments. Accordingly, our results speak to the ability of duopolists to collude implicitly, suggesting that even if antitrust authorities commit more resources to monitoring and punishing communication between firms and through such efforts succeed at preventing it, implicit collusion will prevail. This begs the question of whether more than two firms are able to collude in our environment.

[20] Note that with full information and $k < 2$, the socially optimal strategies depend on players' numbers. For example, with numbers are 3 and 5, both should enter; however, if their numbers are 2 and 5 and $7/5 < k < 2$, then only the high-value player should enter.

[21] This assumes that the pair coordinates on only one person entering whenever they have the same number; if they both enter whenever they have the same number, then their expected payoff is 3.40.

7 Conclusions

There are a large number of opportunities for cooperative behavior in the real world that have heretofore not been studied theoretically or tested experimentally. These situations are characterized by a tension between the unique noncooperative equilibrium in which both players defect and the socially optimal outcome in which one player cooperates and the other defects.

In this paper, we introduce such a game. Our game is unique in that the socially optimal outcome involves one player defecting and the other cooperating or backing down. Because cooperation yields a payoff of zero, it cannot reasonably be expected in a one-shot game, except under very special circumstances (e.g. when the value to defection is sufficiently low). In a repeated game, the challenge lies in coordinating who will back down and under what circumstances. Accordingly, we conduct our game repeatedly under different conditions with the goal of determining whether and what kind of cooperation will emerge when players' values for defection are private. Cooperation generally takes the form of cutoff strategies whereby players cooperate when their values for defection are sufficiently low. We observe very high levels of cooperation even when defection cannot be observed or punished. What is more, pair members coordinate exceedingly well on the same cooperative strategies. For whatever reason, few pairs elect to coordinate on the cooperative strategies whereby they take turns cooperating and defecting.

In this paper, we have tested cooperative behavior in only a small number of games (all with private information) from those possible given the generality of the game structure. Future research will explore other variations and their cooperative and efficiency properties under different informational conditions.

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Appendix

Pre-Experiment Questions

1. How many numbers are there in the range of 1 to 5?

2. What is the probability of obtaining the number “4” in any given round?

3. What is the anticipated average of the numbers you will receive over the entire 80 rounds of play?

4. Suppose that you have received the number “1” during three consecutive rounds. What is the probability of receiving another“1” in the next round?

5. Suppose that you receive the number “1” and your opponent receives the number “2” in a particular round.

a. If you both enter, what will be your payoff from this round? What will be your opponent’s payoff?

a. If you enter and your opponent exits, what will be your payoff from this round? What will be your opponent’s payoff?

b. If you both exit, what will be your payoff from this round? What will be your opponent’s payoff?

c. If you exit and your opponent enters, what will be your payoff from this round? What will be your opponent’s payoff?

Instructions to Participant

The experiment in which you will participate involves the study of decision-making. The instructions are simple. If you follow them carefully and make wise decisions, you may earn a considerable amount of money. Your earnings depend on your decisions. All of your decisions will remain anonymous and will be collected through a computer network. Your choices are to be made at the computer at which you are seated. Your earnings will be revealed to you as they accumulate during the course of the experiment. Your total earnings from the experiment will be paid to you, in cash, at the end of the experiment.

There are several experiments of the same type, which are taking place at the same time in this room.

This experiment consists of 80 rounds. You will be paired with another person. This person will remain the same for all 80 rounds. Each round consists of the following sequence of events. At the beginning of the round, you and the person with whom you are paired each receives a randomly and independently drawn integer number from 1 to 5 inclusive. This number is your private information, that is, the other person will not see your number and you will not see the other person’s number. After seeing your numbers, each of you must decide separately between one of two actions: enter or exit. At the end of each round, your number, your action, and the other person’s action determine your round profit in the following way. If you both chose to exit, then you both receive zero points. If you chose to exit and the other person chose to enter, then you receive zero points and the other person receives points equal to his number. On the other hand, if you chose to enter and the other person chose to exit, you receive points equal to your number

		Other Person	
		Enter	Exit
You	Enter	x/3, y/3	x, 0
	Exit	0, y	0, 0

and the other person receives zero points. If you both chose to enter, then you receive points equal to half of your number and the other person receives points equal to half of his number. The table below summarizes the payoff structure.

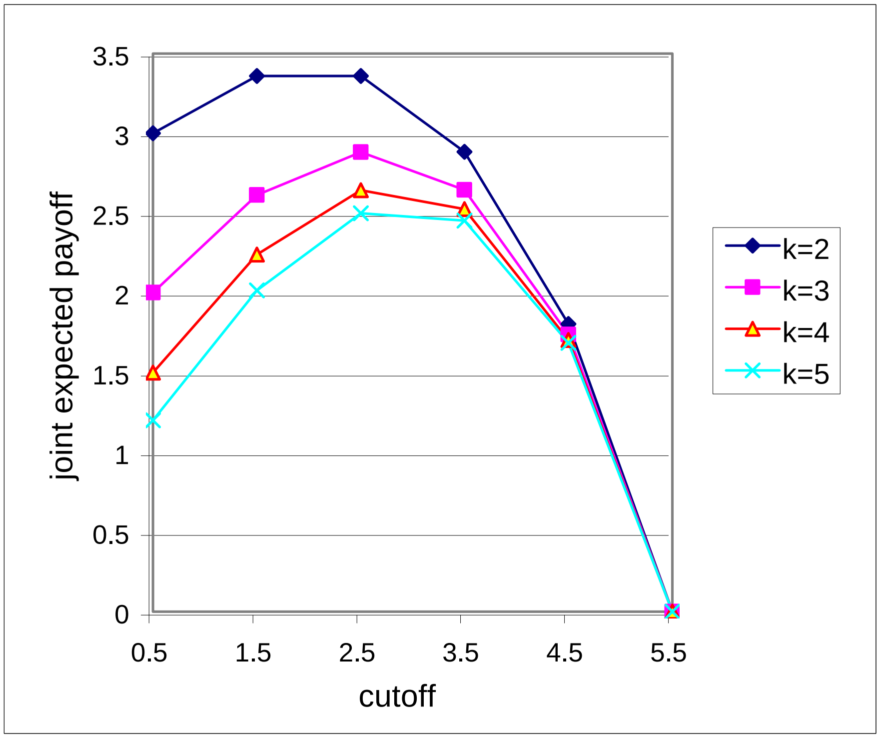
Suppose you receive a number, x, and the other person receives a number, y. The round profits for each of the given pair of decisions are indicated in the table below. The number preceding the comma refers to your round profit; the number after the comma is the other person's round profit.

After you have both made your decisions for the round, you will see the amount of points you have earned for the round, the other person's decision and his number. When you are ready to begin the next round, press Next.

At the end of the experiment, you will be paid your accumulated earnings from the experiment in cash. While the earnings are being counted, you will be asked to complete a questionnaire. Prior to the beginning of the experiment, you will partake in a number of practice rounds. The rules of the practice rounds are identical to those of the experiment in which you will participate. Note well that for the purpose of the practice rounds, you will be paired with a different person from the actual experiment. The purpose of the practice rounds is to familiarize you with the rules of the experiment and the computer interface. The profits earned in these practice rounds will not be included in your payment. If you have any questions, raise your hand and a monitor will assist you. It is important that you understand the instructions. Misunderstandings can result in losses in profit.

Figure 1

Joint expected payoff as a function of players' symmetric cutoff strategies and k



The pair's joint expected payoff as a function of symmetric pure-strategy cutoffs 0.5 to 5.5 for the range of numbers 1 to 5 and the indicated values of k.

Table 1

Entry by Number and by Treatment

Number	*AfterFixed*	*NeverFixed*	*AfterRandom*
1	16.3%	30.8%	31.0%
2	29.4%	53.8%	64.0%
3	86.2%	88.8%	97.2%
4	98.0%	95.6%	98.1%
5	98.5%	95.4%	98.9%
Overall	67.7%	74.4%	79.3%

For each number, each cell indicates the percentage of entry across all subjects in the treatment.

Table 2

Random Effects Probit Models for Entry Decisions in all 3 treatments

Variable	Treatment							
	AfterFixed		*NeverFixed*		*AfterRandom*			
	coefficient (std. error)	marginal effect	coefficient (std. error)	marginal effect	coefficient (std. error)	marginal effect	coefficient (std. error)	marginal effect
$C_{1.5}$	0.513*** (0.079)	0.139	0.790*** (0.070)	0.210	1.386*** (0.096)	0.205	1.473*** (0.102)	0.112
$C_{2.5}$	2.161*** (0.081)	0.587	1.522*** (0.083)	0.377	2.088*** (0.138)	0.268	2.344*** (0.157)	0.171
$C_{3.5}$	1.039*** (0.112)	0.221	0.653*** (0.105)	0.129	0.231 (0.175)	0.000	0.334 (0.213)	0.000
$C_{4.5}$	0.257* (0.156)	0.055	0.025 (0.118)	0.000	0.290 (0.208)	0.000	0.382 (0.271)	0.000
Enter $_{i,t-1}$	-0.257*** (0.065)	-0.078	-0.734*** (0.066)	-0.124	-0.350*** (0.094)	-0.190	-0.071 (0.100)	0.000
subject17*Enter $_{i,t-1}$	---	---	---	---	---	---	-6.290*** (0.515)	-0.993
Enter $_{-i,t-1}$	0.356*** (0.065)	0.088	0.563*** (0.064)	0.135	0.162* (0.092)	0.000	0.197** (0.098)	0.000
first10	-0.246*** (0.089)	-0.062	-0.123 (0.082)	0.000	-0.036 (0.110)	0.000	-0.035 (0.116)	0.000
last10	0.563*** (0.091)	0.103	0.542*** (0.086)	0.088	0.519*** (0.128)	0.239	0.654*** (0.140)	0.009
constant	-1.247 (0.104)		-0.655 (0.106)		-0.594 (0.150)		-0.585 (0.183)	
Number of Obs.	4898		4898		3634		3634	
ρ	0.395 (0.031)		0.406 (0.029)		0.512 (0.030)		0.569 (0.039)	
Log L	-1244.3		-1486.3		-773.0		-685.2	

The dependent variable is subject i's entry decision in period t.

*** p-value less than .01

** p-value less than .05

* p-value less than .10

Random effects Probit regression results for each of the three treatments. The entry decision of subject *i* in period *t* is regressed on dummy variables for the numbers received, the subject's and his opponent's last-period entry decision and whether the game is in the first 10 or last 10 rounds of play.

Table 3
Strategy Inference Results by Treatment

	Strategy	Treatment AfterFixed	NeverFixed	AfterRandom
	c*=0.5 (always Enter)	8.5 (.137)	12.5 (.202)	10.5 (.228)
	c*=1.5	9 (.145)	19.5 (.314)	17 (.370)
	c*=2.5	38.5 (.621)	24 (.387)	17.5 (.380)
	c*=3.5	4 (.064)	1 (.016)	0
	c*=4.5	0	0	0
	c*=5.5 (always Exit)	0	0	0
	Enter in odd rounds	1 (.016)	3 (.048)	1 (.022)
	Enter in even rounds	1 (.016)	2 (.032)	0
	Total	62 (1)	62 (1)	46 (1)
	experimental data			
probability of error	best-fitting strategies	0.06	0.08	0.05
	Nash equilibrium strategy	0.32	0.26	0.21
	randomly generated data			
	best-fitting strategies	0.32	0.25	0.22
	Nash equilibrium strategy	0.33	0.25	0.22

Number (fraction) of subjects whose best-fit strategy based on their decisions from rounds 11-70 corresponds to the one indicated. The average error rates from classifying subjects according to these inferred strategies and from the assumption that all subjects are playing the Nash equilibrium are shown along with the average error rates for randomly generated data.

Table 4

Decisions and Errors by Strategy for a Pair of Subjects in each Treatment

	AfterFixed				***NeverFixed***				***AfterRandom***			
	Numbers		**Players**		**Numbers**		**Players**		**Numbers**		**Players**	
Round	A	B	10A	10B	A	B	30A	30B	A	B	8A	OppB
1	4	5	Exit	Enter	3	5	Enter	Enter	3	5	Enter	Enter
2	3	4	Enter	Enter	1	2	Exit	Exit	1	2	Enter	Exit
3	3	5	Exit	Enter	2	1	Enter	Exit	2	1	Exit	Enter
4	4	2	Enter	Exit	5	4	Exit	Enter	5	4	Enter	Enter
5	2	4	Exit	Enter	5	1	Enter	Exit	5	1	Enter	Exit
6	1	3	Enter	Exit	4	3	Exit	Enter	4	3	Enter	Enter
7	3	3	Exit	Enter	1	5	Enter	Enter	1	5	Exit	Enter
8	1	2	Enter	Exit	2	5	Exit	Enter	2	5	Exit	Enter
9	1	3	Exit	Enter	3	2	Enter	Exit	3	2	Enter	Enter
10	4	4	Enter	Enter	1	3	Exit	Enter	1	3	Exit	Enter
11	1	5	Exit	Enter	2	3	Enter	Enter	2	3	Enter	Enter
12	2	2	Enter	Exit	3	2	Exit	Exit	3	2	Enter	Enter
13	2	1	Exit	Exit	5	4	Enter	Enter	5	4	Enter	Enter
14	4	2	Enter	Enter	4	2	Exit	Exit	4	2	Enter	Enter
15	2	2	Exit	Exit	2	2	Enter	Exit	2	2	Exit	Enter
16	1	5	Enter	Enter	4	3	Exit	Enter	4	3	Enter	Enter
17	5	2	Enter	Enter	1	4	Enter	Enter	1	4	Exit	Enter
18	2	4	Exit	Enter	1	1	Enter	Exit	1	1	Exit	Exit
19	1	3	Exit	Enter	5	3	Enter	Enter	5	3	Enter	Enter
20	3	4	Enter	Enter	1	1	Enter	Exit	2	5	Exit	Enter
21	4	4	Enter	Enter	5	4	Enter	Enter	5	5	Enter	Enter
22	4	4	Enter	Enter	5	1	Enter	Exit	5	3	Enter	Enter
23	3	3	Enter	Enter	4	5	Enter	Enter	5	3	Enter	Enter
24	3	2	Enter	Exit	5	2	Enter	Exit	4	3	Enter	Enter
25	2	4	Enter	Enter	1	4	Exit	Enter	1	1	Exit	Exit
26	1	4	Exit	Enter	5	3	Enter	Enter	2	4	Enter	Enter
27	4	3	Enter	Enter	4	5	Enter	Enter	4	4	Enter	Enter
28	3	5	Enter	Enter	3	4	Enter	Enter	3	5	Enter	Enter
29	1	2	Exit	Enter	3	5	Enter	Enter	4	4	Enter	Enter
30	2	1	Enter	Exit	4	2	Enter	Enter	1	4	Exit	Enter
31	5	4	Enter	Enter	2	4	Enter	Enter	3	2	Enter	Exit
32	5	1	Enter	Exit	1	3	Exit	Enter	3	1	Enter	Exit
33	4	3	Enter	Enter	3	3	Enter	Enter	1	5	Exit	Enter
34	1	5	Exit	Enter	1	2	Exit	Exit	5	5	Enter	Enter
35	2	5	Exit	Enter	1	3	Exit	Enter	5	2	Enter	Exit
36	3	2	Enter	Exit	4	4	Enter	Enter	3	1	Enter	Exit
37	1	3	Exit	Enter	1	5	Enter	Enter	3	2	Enter	Enter
38	2	3	Exit	Enter	2	2	Enter	Exit	5	4	Enter	Enter
39	3	2	Enter	Exit	2	1	Enter	Exit	4	2	Enter	Enter
40	5	4	Enter	Enter	4	2	Enter	Exit	4	4	Enter	Enter
41	4	2	Enter	Exit	2	2	Exit	Enter	3	4	Enter	Enter
42	2	2	Exit	Exit	1	5	Exit	Enter	3	3	Enter	Enter
43	4	3	Enter	Enter	5	2	Enter	Exit	5	5	Enter	Enter
44	1	4	Exit	Enter	2	4	Enter	Enter	1	2	Exit	Exit
45	1	1	Exit	Exit	1	3	Exit	Enter	3	2	Enter	Enter
46	5	3	Enter	Enter	3	4	Enter	Enter	1	1	Exit	Exit

47	2	5	Exit	Enter	2	5	Enter	Enter	5	4	Enter	Enter
48	5	5	Enter	Enter	5	5	Enter	Enter	5	1	Enter	Enter
49	5	4	Enter	Enter	5	3	Enter	Enter	4	5	Enter	Enter
50	2	5	Enter	Enter	5	3	Enter	Enter	5	2	Enter	Enter
51	1	5	Exit	Enter	4	3	Enter	Enter	1	4	Enter	Enter
52	2	3	Enter	Enter	1	1	Exit	Exit	5	3	Enter	Enter
53	1	3	Exit	Enter	2	4	Enter	Enter	4	5	Enter	Enter
54	4	1	Enter	Exit	4	4	Enter	Enter	3	4	Enter	Enter
55	5	3	Enter	Enter	3	5	Enter	Enter	3	5	Enter	Enter
56	5	3	Enter	Enter	4	4	Enter	Enter	4	2	Enter	Exit
57	4	3	Enter	Enter	1	4	Enter	Enter	2	4	Enter	Enter
58	1	1	Exit	Exit	3	2	Enter	Exit	1	3	Exit	Enter
59	2	4	Enter	Enter	3	1	Enter	Exit	3	3	Enter	Enter
60	4	4	Enter	Enter	1	5	Exit	Enter	1	2	Enter	Exit
61	3	5	Exit	Enter	5	5	Enter	Enter	1	3	Exit	Enter
62	4	4	Enter	Enter	5	2	Enter	Exit	4	4	Enter	Enter
63	1	4	Exit	Enter	3	1	Enter	Exit	1	5	Enter	Enter
64	3	2	Enter	Enter	3	2	Enter	Exit	2	2	Enter	Enter
65	3	1	Exit	Exit	5	4	Enter	Enter	2	1	Exit	Exit
66	1	5	Exit	Enter	4	2	Enter	Exit	4	2	Enter	Exit
67	5	5	Enter	Enter	4	4	Enter	Enter	2	2	Enter	Enter
68	5	2	Enter	Enter	3	4	Enter	Enter	1	5	Exit	Enter
69	3	1	Exit	Exit	3	3	Enter	Enter	5	2	Enter	Enter
70	3	2	Enter	Exit	5	5	Enter	Enter	2	4	Enter	Enter
71	5	4	Enter	Enter	1	2	Exit	Exit	1	3	Exit	Enter
72	4	2	Enter	Enter	3	2	Enter	Exit	3	4	Enter	Enter
73	4	4	Enter	Enter	4	4	Enter	Enter	4	4	Enter	Enter
74	3	4	Enter	Enter	4	4	Enter	Enter	4	4	Enter	Enter
75	3	3	Enter	Enter	5	4	Enter	Enter	5	4	Enter	Enter
76	5	5	Enter	Enter	2	5	Exit	Enter	2	5	Enter	Enter
77	1	2	Enter	Enter	1	5	Exit	Enter	1	5	Enter	Enter
78	3	2	Enter	Enter	2	3	Enter	Enter	2	3	Enter	Enter
79	1	1	Enter	Enter	1	3	Enter	Enter	1	3	Enter	Enter
80	5	4	Enter	Enter	4	1	Enter	Enter	4	1	Enter	Enter

errors by strategy (rounds 11-70)					
c=0.5	23	16	12	19	13
c=1.5	11	8	**9**	12	**6**
c=2.5	**10**	**5**	16	**2**	9
c=3.5	15	18	26	14	21
c=4.5	26	32	34	30	33
c=5.5	37	44	48	41	47
Enter Odd rounds	37	28	26	21	29
Enter Even rounds	23	32	34	39	31
minimum errors	10	5	9	2	6

The entry and exit decisions for one pair of subjects in each of the treatments. For each of the cutoff and alternating strategies, the number of incorrectly classified decisions are displayed at the bottom, with the number of errors for the best-fit strategy in boldface. The column "OppB" represents the decisions of subject 8A's randomly changing opponents in the *AfterRandom* treatment.