Which way to cooperate

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July 2006

Abstract: We introduce a class of games that captures many economic and social cooperation dilemmas such as bidding rings in auctions, competition for market share, labor supply decisions, queuing in line and courtship. Participants in these interactions cooperate by limiting their frequency of entry, since entry imposes a negative externality. We conduct two-player, repeated-game experiments with private values to entry where cooperation admits the form of either taking turns or using a cutoff strategy and entering only for high private values. We find that in environments with disperse private values, paired subjects coordinate on the same cutoff strategies. In environments with similar private values, cooperative subjects alternate. Our results offer insight into whether a cooperative norm will arise and what form it will take: for mundane tasks or where individuals otherwise have similar payoffs, alternation is likely; for difficult tasks that differentiate individuals by skill or by preferences, cutoff cooperation will emerge.

Keywords: cooperation, incomplete information, alternating, cutoff strategies, random payoffs, experimental economics.

JEL classification nos.: C90, Z13.

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Acknowledgements: We thank Tim Salmon, Valin Dittrich, Dirk Engelmann, Jim Engle-Warnick, Naomi Feldman, Guillaume Fréchette, Andrew Muller, Jim Myton, Mike Stutzer and seminar participants at Bar-Ilan, Ben-Gurion, Emory, Florida State, Haifa, McMaster, Northern Illinois, Ryerson and Tel Aviv Universities, Harvard Business School, MIT Sloan School of Management, the Universities of Birmingham and Exeter, 2004 World Congress of Game Theory, 2005 ESA European meetings, 2005 SAET meetings, 2005 Zeuthen Workshop, two anonymous referees and an editor of this journal for valuable comments. Tzvi Kerpzseld, Kadia Kohelet, Shy Maman, Tim Miller, Eran Ozery, Gad Rotman, Asaf Shaul, Tal Shavit, Ron Stern and Yael Uzen offered valuable research assistance. Urs Fischbacher provided us with his z-Tree software. We gratefully acknowledge financial support from Ben-Gurion University, ESRC, the Israel Science Foundation and the University of Exeter.

1 Introduction

In our economic and social interactions, we face the decision whether to cooperate with other individuals on a daily basis. Indeed, the importance of cooperation has not escaped the attention of economists. Over a thousand published papers use the prisoners' dilemma or public-goods game to study various aspects of cooperative behavior in theory and in laboratory experiments.[1] Yet a large class of cooperative dilemmas remains unexplored. To avoid conflict or an impasse, cooperation often requires that one person acquiesce while the other person pursues the action. This paper introduces a class of two-player games characterized by a unique social optimum in which one player cooperates and the other defects.

Consider the following two-player game. Each player receives a randomly drawn integer between 1 and 5 inclusive, each with equal probability. Each player then decides between one of 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.

This parameterization and the class of two-player games from which it was selected have the following stage-game properties: 1) entry (non-cooperation in the stage game) is the unique dominant strategy;[2] however, entry imposes a negative externality on a player's opponent, since it reduces his payoff provided he also enters; 2) the sum of players' payoffs is higher if they both play the dominant strategy (entry) than if they both play the dominated strategy (exit); 3) the socially optimal outcome is asymmetric, one player enters and the other exits. These features distinguish this class of games from other cooperation games like the prisoners' dilemma and public-goods games as well as coordination games like market-entry games and chicken.

[1] The Web of Science lists 951 citations for "prisoner's dilemma" or "prisoners' dilemma" with an intersection of 106 citations between the two. Public-goods experiments yield an additional 320 citations.

[2] We refer to entry as the non-cooperative action and exit as the cooperative action. In the repeated game, a cooperative strategy involves staying out with some positive probability, with the degree of cooperativeness determined by the frequency of exit. These semantic distinctions will become clearer with usage.

When players' values for pursuing the action are observable, the social optimum involves the person with less to gain acquiescing to the higher-value player. Two strangers who reach the airport check-in counter at the same time can argue about who arrived first or they can achieve higher social efficiency by having the person whose flight does not leave for another four hours allow the hurried passenger to go ahead. Pregnant women with children in arms are invited to bypass lengthy lineups. Similarly, a shopper with a week's worth of groceries can often be seen motioning to the shopper with only a couple of items to go to the front of the line.

Cooperation can be achieved in these situations thanks to the availability of visible cues that signal players' values for pursuing the action. However, when values are private and cannot be communicated or signaled, the first-best outcome whereby only the high-value player enters is no longer feasible. Instead, a different cooperative convention is needed to avoid conflict. When the same pair of players interacts repeatedly, two cooperative norms are possible.

First, cutoff cooperation entails entering when the value to doing so exceeds some threshold and not entering otherwise. Cutoff strategies thus condition on players' private information. Firms might implicitly collude by staying out of relatively high-cost or low-demand markets with the expectation that rival firms will reciprocate. Auction participants might bid only when the object is sufficiently valuable so as not to inflate the winning bid unnecessarily or receive the object when another bidder values it more.

Alternating is a second form of cooperation available when the same players face one another repeatedly. Unlike cutoff cooperation, alternating ignores private values; rather, it makes use of publicly available information, like the time of day, the round or object number. Cooperation dilemmas in families are often resolved by alternating. 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 (2005) presents evidence that the four baseball-card manufacturers alternate the timing with which they introduce new product lines in order to reduce intra-period competition.[3] Finally, when road construction forces two lanes to merge into one, drivers from the two lanes alternate letting one another go ahead.

The spectrum auctions conducted in the U.S. and Australia in which licenses were split up into numerous regional markets where bidders had different geographical preferences were susceptible to cutoff-value collusion,[4] 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 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 split evenly the bidding on ten homogeneous licenses forcing the cessation of the auction after two 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).

To address the questions of whether and what form of cooperation will emerge, we begin with a game parameterization that yields very similar joint expected payoffs for the socially optimal cutoff strategy and the alternating strategy. We conduct this game for 80 rounds

[3] Zillante (2005) 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.

[4] 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.

under four private-information 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). We find that the symmetric socially optimal cutoff strategy whereby a player enters on the numbers 3, 4 and 5, and exits otherwise is subjects' modal choice in both treatments with fixed partners. Revealing fixed opponents' numbers at the end of the round is particularly conducive to cutoff strategies since entry on low values is observable and punishable. But even when the fixed opponents' numbers are not revealed, cooperative cutoff strategies continue to be employed by over 70% of subjects even though play according to these strategies cannot be observed. In the random-partners treatments, well over half of the subjects play cooperative cutoff strategies. Very few subjects adopt alternation in *any* of the treatments.

In an effort to understand why so few subjects alternate, despite the strategy's prevalence in real-world cooperation dilemmas, we designed an additional pair of fixed-partner treatments in which we added a constant of 100 to all of the entry values. This change made the entry values relatively similar, thereby reducing the importance of players' private information. Almost all cooperators employ the alternating strategy in these new treatments. These series of experiments thus shed light on the types of cooperation dilemmas that are conducive to cutoff cooperation and those in which alternation is more likely.

We believe our game with its payoff structure captures the nature of cooperation in numerous other 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 profitable form of collusion; namely, even though a bidder's valuation may exceed the reservation price, he stays out because it is likely that another bidder has yet a higher value.

More generally, our game resembles all competitions and contests with only one winner. By competing, each entrant lowers the expected payoff of everyone else that entered. Thus, individuals may choose not to enter if their value for the prize is sufficiently low or they care about other more deserving or more capable participants. Junior employees backing down from an internal promotion contest is common.

Labor supply decisions in markets characterized by excess supply carry with them the positive externality of yielding one's place to another. For example, cab drivers, bicycle messengers, golf caddies, waitstaff, sky caps and vendors in a marketplace often face the decision whether to compete for a customer or acquiesce. A number of social conventions also share with our game similar payoff consequences as a function of the decisions taken. Sunday drivers concede the right of way and willingly let in other cars. We've already noted the common occurrence of ceding one's place in line to hurried shoppers, passengers, pregnant women and, more broadly, those with much to gain from going first. 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 the parameterization for our experiments. We contrast our game with familiar cooperation and coordination games in section 3. In section 4, we detail our experimental design and procedures. Section 5 presents the results and analysis. We attempt to understand differences in cooperative behavior between treatments and especially the paucity of alternating in these experiments. In light of these findings, we report the results of follow-up treatments designed to elicit more alternating in section 6. Section 7 explains the observed degree and mode of cooperation (cutoffs or alternation) based on computations of individuals' marginal incentives to cooperate for different strategies and game parameterizations. Section 8 concludes with insights into when to expect alternation versus cutoff strategies in real-world cooperation dilemmas.

2 Theoretical Framework

In this section, we introduce a class of two-player games. We derive the theoretical properties of these games, which may be of some independent interest since these games are new, and the theory highlights some of the differences between these games and familiar cooperation games. Moreover, the theoretical and comparative-statics results will help guide our choice of game parameterization for the subsequent experiments.

2.1 Environment

We propose a two-player game with the following general structure. Each player receives a randomly drawn integer between $\underline{v}$ and $\overline{v}$ inclusive where the probability of receiving a number x is π_x (where $\pi_x > 0$ and $\sum_{x\in\{\underline{v},\ldots,\overline{v}\}} \pi_x = 1$) 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 $f(x, y)$ increasing in his number, x, and possibly also a function of the other player's number, y, if both enter. We assume that $f(x, y)$ is strictly less than his number x; 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. Suppose the other player enters with probability $p(y)$ when his number is y. The joint expected payoff to entering with number x is,

$$\sum_{y\in\{\underline{v}\ldots\overline{v}\}} \pi_y \left\{x(1-p(y)) + p(y)[f(x,y)+f(y,x)]\right\}.$$

The joint expected payoff to staying out is $\sum_{y\in\{\underline{v},\ldots,\overline{v}\}} \pi_y y p(y)$. If f is increasing in both arguments, then the cooperative solution entails cutoff strategies (that is, for $\underline{v} \leq y < \overline{v}$ if $p(y) > 0$, then $p(y+1) = 1$). 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 c^* such that for all $x \leq c^*$, $p(x) = 0$ and for all $x > c^*$, $p(x) = 1$. A mixed-strategy cutoff is when there exists an x such that $0 < p(x) < 1$.

An extreme form of asymmetric pure-strategy cutoffs involves one player entering for all numbers greater than or equal to $\underline{v}$ (i.e., always enter) and the other entering for numbers greater than $\overline{v}$ (i.e., always exit). In a repeated game, this cooperative solution can admit the form of players taking turns 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 form 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 $\underline{v}$ and $\overline{v}$ inclusive. We restricted $f(x,y)$ to be of the form x/k (where k is an integer) to aid subjects' understanding of the game.

Our objectives were twofold: 1) to design a game for which the joint expected payoffs from alternation and the optimal symmetric cutoff strategies are very similar; 2) to maximize the difference between the joint expected payoffs from playing the optimal symmetric pure-strategy cutoff, c^*, and the second-best symmetric pure-strategy cutoff. Put another way, we want to maximize the steepness of the joint expected 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 optimally.

Before computing the game that maximizes these objectives, we first derive several theoretical propositions and comparative-statics results about this class of games. These results will aid in narrowing the range of parameters from which we determine the optimal game.

Proposition 1: *The optimal symmetric cutoff for numbers drawn independently from the uniform distribution of integers from $\underline{v}$ to $\overline{v}$ and congestion parameter k is given by,*

$$c^* = \frac{-1 - 2\,\overline{v} + (2\,\underline{v} - 1)\;k + \sqrt{12\,\overline{v}\;(1 + \overline{v})\;(k-1)^2 + (1 + 2\,\overline{v} + k - 2\,\underline{v}\,k)^2}}{6\;(k-1)}.$$

Proof: See Appendix A.

From the expression for c^*, we see that as the congestion parameter, k, increases, so does the optimal symmetric cutoff for a given $\underline{v}$ and $\overline{v}$. 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,

$$\lim_{k\to\infty} c^* = \frac{-1+2\,\underline{v}+\sqrt{(1-2\,\underline{v})^2+12\,\overline{v}\,(1+\overline{v})}}{6}.$$

Moreover, taking k and $\underline{v}$ as fixed, the expression for c^* also reveals that as $\overline{v}$ increases, so does the socially optimal cutoff.

Corollary 2: *For integer numbers uniformly distributed on $[\underline{v}, \overline{v}]$, $\underline{v} < \overline{v}$, and $k \geq 3$, the socially optimal cutoff always involves each player exiting on at least the integer $\underline{v}$.*

Proof: See Appendix A.

The surprising aspect of Corollary 2 is that no matter how small the percentage difference between the highest and lowest integers in the range of numbers, the socially optimal cutoff always involves some measure of cooperation by exiting on at least the lowest integer, $\underline{v}$, in the range.

Proposition 3: *For $k \leq 2$, the socially optimal strategy is a cutoff strategy. In the uniform case, as $k \rightarrow \infty$, the socially optimal strategy is alternating.*

Proof: See Appendix A.

In our search for a parameterization that yields similar joint expected payoffs for the optimal cutoff and alternating strategies, Proposition 3 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, $\{\underline{v}, \ldots, \overline{v}\}$, we allowed $\overline{v}$ to be any integer greater than or equal to 3, and fixed $\underline{v} = 1$.[5] This latter decision was made because if $\underline{v}$ is an integer less than 1, then the strategy "always enter" is no longer a unique dominant strategy in the stage game.

For our experiments, we chose $(\overline{v} = 5, k = 3)$. 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, c*, equals 1.5 for $k = 2$, equals 2.5 for $k = 3, 4$, and equals 3.5 for $k \geq 5$. We express all cutoffs as halves to denote unambiguously that the player enters on all integers greater than the cutoff and exits otherwise. 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 2.88. For $c = 3.5$, the pair's expected payoff

[5] In selecting parameters, for a given f, we can often increase the steepness of the joint expected payoff function around the socially optimal pure-strategy cutoff by shrinking the number of integers in the range $\{\underline{v}, \ldots, \overline{v}\}$ (i.e., by lowering $\overline{v}$ in our case). However, if the optimal cutoff is in mixed strategies, this need not be true. Instead, the joint expected 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 $(\overline{v} = 3, k = 4)$, $(\overline{v} = 4, k = 4)$, $(\overline{v} = 5, k = 2)$ and $(\overline{v} = 5, k = 4)$. 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.

decreases to 2.64 and to 2.61 for $c = 1.5$. For $c = 4.5$, the pair's expected payoff is 1.73 and for $c = 0.5$ (always enter) it is 2.

[insert Figure 1 here]

For our chosen parameterization, the alternating strategy earns the pair 3 units of profit in expectation, a mere 0.12 units more than than the optimal symmetric cutoff, $c^* = 2.5$. 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. Not only is the expected pair's payoff from playing the alternating strategy (3) higher compared to the optimal symmetric cutoff strategy (2.88), the variance of the expected payoff is also lower: 2 compared to 2.42.

3 Related Games

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 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 choose their dominant strategies (enter) they are better off than if both play their undominated strategies (exit).

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 efficient and all characterized by some subset of players entering the market with positive probability. By contrast, our games have a unique Nash equilibrium, which is inefficient and at odds with the full-information, social optimum whereby one player enters and the other exits. Moreover, exit is a strictly dominated strategy in our class of games for $\underline{v} > 0$ 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.

For a particular realization of players' numbers, the 2×2 payoff matrix in Table 1 makes precise the outcome differences between our game and others. The top row and left column are the cooperate/exit/swerve action (depending on the game in question). The bottom row and right column are the defect/enter/not swerve action. Normalizing the off-diagonal payoffs as (1,0) and (0,1), we denote the payoffs from the cooperative outcome as (a, a) and from the defect outcome as (b, b). The prisoners' dilemma restricts $a > b > 0$, and $a < 1$, but $2a > 1$ in order for the cooperative outcome to be efficient. The market-entry game requires $a = 0$ and $b < 0$. The game of chicken can be characterized as $0 < a < 1$, $b < 0$. It has the same asymmetric equilibria as the market-entry game and can be seen as a limiting case of it as $a \downarrow 0$. Finally, our game requires $0 = a < b$, and $2b < 1$ to ensure that the off-diagonal

[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).

outcomes are efficient.

The games can also be characterized by their Nash equilibria and social optima. Both our game and the prisoners' dilemma have (defect, defect) as the unique Nash equilibrium of the stage game, while the market-entry game, chicken and battle of the sexes all have (cooperate, defect) and (defect, cooperate) as both their Nash equilibria and social optima. These off-diagonal outcomes are also the social optima for our game, whereas (cooperate, cooperate) is the unique social optimum of the prisoners' dilemma. Our game is the only one for which coordination is needed to reach a social optimum that is not an equilibrium. Private information further complicates this task by making it difficult to coordinate on any social optimum at all.

[insert Table 1 here]

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 decided independently 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 four 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 matching protocol

[7] We opted for a known rather than a probabilistic terminal round both for reasons of simplicity 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 repeated prisoners' dilemma game is unaffected by the termination rule.

(fixed or random). In "*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 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]

In "*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 *AfterFixed*, 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 enforce cutoff strategies. Moreover, if pairs aren't fixed, the cooperative strategy by which players alternate entering is no longer feasible. The last treatment, "*NeverRandom*", provides the most difficult conditions for cooperation since, in addition to the impossibility of enforcing cooperative strategies, the shame of being "caught" entering on a low number doesn't even exist.

[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 stage game.

[9] In indefintely repeated two-person prisoners' dilemma games, Duffy and Ochs (2003) show that random matching inhibits cooperation, while cooperation increases over time with fixed pairings. Andreoni and Croson (forthcoming) survey the mixed evidence on the impact of fixed partners versus random rematching on cooperation in linear public goods games.

In an infinitely repeated game, cooperation can be maintained even when players are self-interested by means of a trigger-strategy punishment of always enter (Folk theorem). Although our game is finitely repeated, the conditions that affect cooperation in an infinitely repeated game should have a similar bearing in non-terminal rounds (see footnote 7). Punishment is easiest in *AfterFixed*: if alternating or cutoff strategies are employed, any deviation is easily detected and punishable. Punishment is hardest in *AfterRandom* and *NeverRandom*: while deviation is detectable in *AfterRandom*, punishment is infeasible in both random-partners treatments. *NeverFixed* represents an intermediate case for punishment: although deviations from alternating strategies are easily detected and punishable, detection 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 Appendix B). After all subjects in the session had read the instructions, the experimenter read them aloud. To ensure full comprehension of the game, subjects were given a series of knowledge-testing questions about the game (Appendix B contains the questions). 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.

An important feature of our experimental design that allows us to compare subjects' be-

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

havior 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 applied these sequences to all subject pairs in all sessions and treatments.[11]

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 precluded from participating.

Sixty-two subjects participated in one of the three *AfterFixed* sessions, 62 subjects in one of the three *NeverFixed* sessions, 64 subjects in one of the three *AfterRandom* sessions and 82 subjects in one of three *NeverRandom* sessions. To hold constant the marginal incentives across treatments, the experimental-currency-to-shekel ratio was fixed at 1:0.6 for all four treatments. A session lasted about 100 minutes on average, including the instructions phase and post-experiment questionnaire. Including a 10-shekel showup fee, the average total profit ranged from 78 shekels in the *AfterFixed* treatment to 69 shekels in *NeverRandom*.

5 Results

5.1 Cooperation across Treatments

Table 2 presents the percentage of rounds in which subjects entered for a given number by treatment. Thus, in the *AfterFixed* treatment, subjects entered only 16.3% of the time

[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. The astute reader will note that to preserve the identical sequence of values in the random-partners treatments 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.

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 four treatments suggests that many subjects may be employing the socially optimal 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 whether a cutoff or the alternating strategy best fits each individual subject's observed decisions.

[insert Table 2 here]

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 four treatments is as follows,[12]

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

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

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

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,

[12] 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* and *NeverRandom* treatments, the first-period entry decision is dropped since all of the 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 3 displays the regression coefficients and marginal effects for each of the four 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 5 than a 4. These estimates correspond closely to the differences in percentages of entries by number reported in Table 2, 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 3 here]

The regression results from the *NeverFixed*, *AfterRandom* and *NeverRandom* 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* and *NeverRandom*. Table 2 reveals an entry frequency of 98.0% and 98.3% on the number 3 in *AfterRandom* and *NeverRandom.* respectively, thereby 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 any of these treatments. Intuitively, subjects do not adapt their behavior in response to their opponents' early choices (with the exception of unrequited alternating in *NeverFixed*) 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 random-partners treatments 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 alternation with random partners. 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 -6.85 on $subject17 * Enter_{i,t-1}$ is strongly significant ($p < .01$), whereas the coefficient on $Enter_{i,t-1}$ is no longer significant ($p = .68$).

The estimates of ρ in Table 3 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 0.620 in *NeverRandom* indicate that between 40% and 62% of the variance in the error term is explained by subject heterogeneity.

To compare the degree of cooperation across treatments, we estimated random effects Probit regressions on the pooled data from all four treatments. The positive and highly significant coefficients on the three treatment variables in regression (1) of Table 4 indicate a higher propensity to enter in *NeverFixed*, *AfterRandom* and *NeverRandom* than the excluded treatment, *AfterFixed*. Regression (2) yields the same result while controlling for the subject's and opponent's previous-round entry decisions and for initial learning and end-game effects. Moreover, t-tests of coefficients from both regressions reveal significantly more cooperation in *NeverFixed* than *AfterRandom* and *NeverRandom* ($p < .01$ in all cases), but no significant difference between the two random-partners treatments.

[insert Table 4 here]

Efficiency calculations offer an additional measure of subjects' cooperative behavior across treatments. 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, substantially higher than the 67.6% achieved in *NeverFixed*, 66.0% in *AfterRandom* and 63.8% in *NeverRandom*. 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 four treatments.[13]

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 alternating and different cutoff strategies to classify correctly the subject's entry and exit choices. 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 alternating strategy, modeled as the choice of an action opposite to the one made in the previous round.[14] The strategy that minimizes the

[13] Other efficiency benchmarks 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] Although there are other ways to model the alternating strategy, such as enter in odd or even rounds only, our chosen specification based on comparing decisions in rounds t and $t-1$ is robust to mistakes: for

number of errors in classifying the subject's observed decisions is selected as the one that the subject most likely employed.[15]

Table 5 reports the distribution of individuals' best-fit strategies by treatment for rounds 11–70. Excluding the first 10 and last 10 rounds reduces the error rates by minimizing the initial learning and end-game effects documented in the regression analysis. The inferred best-fit strategies are highly robust to the different time horizons tested, like all 80 rounds, the last 60 rounds, the last 40 rounds and rounds 16–65.

[insert Table 5 here]

Despite the slight payoff advantage and lower payoff variance of the alternating strategy, our main finding is the overwhelming adoption of cooperative cutoff strategies and the paucity of alternators. The optimal symmetric cutoff strategy of $c^* = 2.5$ best characterizes the decisions of 39/62 subjects in the *AfterFixed* treatment.[16] 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. Nine subjects in *AfterFixed* appear to be employing the cutoff of 1.5; for one of these subjects, the Nash equilibrium strategy of always enter fits his decisions equally well. Eight additional subjects also play according to the Nash strategy of $c = 0.5$, while four other subjects (two of whom form a pair) use the hyper-cooperative cutoff of 3.5. Only one pair of subjects alternates, beginning in period 33 and continuing without deviation through period 80.

The *NeverFixed* treatment is a more likely candidate for alternating because the play of cutoff strategies cannot be observed or enforced. Still, a meager two out of 31 pairs coordinate on the alternating strategies. Both pairs begin alternating early on (in rounds

instance, it detects subjects who began alternating, stopped for one or more rounds and resumed alternating by coordinating differently on who enters on the odd and even rounds.

[15] This methodology is a simplified version of the strategy inference technique developed in Engle-Warnick and Ruffle (2005).

[16] In the case where two strategies explain a subject's decisions equally well, each of the tied strategies receives half a point.

2 and 8) and continue without error for the duration. An additional subject whose best-fit strategy is alternating eventually abandons it after his opponent fails to reciprocate.

Table 5 also 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* to 32.0% in *AfterRandom* and still further to 16.5% in *NeverRandom*, while those who play the Nash equilibrium increases from 13.7% to 20.2% (*NeverFixed*) and to 25.0% (*AfterRandom*). In *NeverRandom*, the Nash strategy is modal, best describing 42.1% of subjects' play. Like the overall entry proportions by number and by treatment in Table 2 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. Notwithstanding, both random-partners treatments indicate that 75% (*AfterRandom*) and 58% of the subjects (*NeverRandom*) employ cooperative strategies whereby they exit systematically some fraction of the time. In section 7, we compute a subject's marginal incentives to cooperate by strategy to explain these relatively high rates of cooperative play compared to, say, randomly matched pairs in the prisoners' dilemma (e.g., Duffy and Ochs 2003).

Overall, this simple inference technique fits the data well as seen in the error rates of 6%, 8%, 5% and 5% for each of the four 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 strategy, then the third-to-last row of data in Table 5 indicates that the error rates jump to between 15% and 32% depending on the treatment. In 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, .813 and .850 for the four 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 5 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. In sum, subjects are indeed playing in a non-random, methodic fashion that can be captured by cutoff and alternating strategies.[17]

Our strategy analysis also reveals that pair members typically coordinate on the same cooperative strategy. In *AfterFixed*, of the 30 pairs that employ cutoff strategies, 22 coordinate on the same cutoff values. If subjects independently chose their strategies according to the observed distribution of best-fit strategies, the probability of at least 22 pairs coordinating on the same strategy is 1/60. Sixteen out of 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 reflecting an ambivalence between their inferred cutoff and that of their partner. Again, if subjects drew their strategies independently from the observed distribution, the likelihood of obtaining this degree of coordination or better is 1/600.

Paired subjects' coordination on the same cutoff strategy is particularly surprising in *NeverFixed*, since opponents' values are unobservable. Over time, an opponent's entry frequency permits inference of the corresponding cutoff strategy. Differences in the paired players' cutoff strategies typically lead the more cooperative player to adjust his cutoff to match his opponent's. Cooperative play stabilizes at these levels because the short-run gains from defection is countered by the threat of punishment and a further reduction in cooperation. The breakdown of cooperation in the last ten rounds points to the effectiveness of the threat of punishment in maintaining symmetric cutoff cooperation throughout the game.

[17] 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.

Successful coordination on the same strategy should show up in subjects' profits in the form of higher profits for paired subjects playing the optimal cooperative cutoff strategy than those playing the dominant strategy of always enter. For the two fixed-partners treatments, this is the case. The right-hand columns of each treatment in Table 5 reveal that the average subject profits for c^*=2.5 are 111.6 and 106.8 in *AfterFixed* and *NeverFixed*, respectively, compared to 109.5 and 93.2 for always enter. From these numbers we observe that non-cooperative subjects earned substantially more in *AfterFixed* than in *NeverFixed*. The explanation is that 5/9 Nash players in *AfterFixed* were paired against more cooperative subjects compared to only 3/13 in *NeverFixed*. How did such a relatively high fraction of subjects in *AfterFixed* allow their partners to always enter, when entry on values of 1 and 2 is perfectly observable in this treatment? A likely explanation is that these unconditional cooperators encourage defection. A subject who enters on a 1 and observes that his opponent does not retaliate is emboldened to do so again, while in *NeverFixed* the defector as such is not observable.

Overall, these results speak to the ability of paired subjects to collude on the same strategy, even in the absence of communication and information about the rival's profit function. Applied to antitrust policy, attempts to monitor and prosecute communication between duopoly firms are unlikely to prevent implicit collusion.[18]

5.3 Why so few alternators?

Although the pair's expected profit from employing the alternating strategy is slightly higher (by 0.12 units per period) and the variance lower than those from the optimal symmetric cutoff strategy of $c^* = 2.5$, the overwhelming majority of subjects employ cutoffs. There are two possible reasons for this.

[18] Future research could explore whether cooperation can be achieved in our game extended to three or more players. Huck, Normann and Oechssler (2004) demonstrate some collusion in Cournot duopolies, but a reversion to the Nash outcome with four or more players.

First, successful alternation requires coordination on the part of both pair members. Unilateral implementation of this strategy is very costly, as witnessed by several subjects who began the game alternating, but eventually abandoned it after their partner failed to reciprocate. Cutoff cooperation can be implemented unilaterally, even if pair members do not coordinate on the same cutoff.

Second, cutoff cooperation is cheap, since it involves exiting on the lowest values, when it is least costly to do so; whereas, alternation ignores the value to entry. Thus, given that a player decides to cooperate regardless of whether his opponent reciprocates, his foregone profit from exiting only on low values is less than if he exits just as often without regard for values (as with alternating).[19]

To determine which of these reasons accounts for subjects' unwillingness to alternate, we designed an additional pair of treatments that maintains the difficulty of coordinating jointly on the alternating strategy, but makes cutoff cooperation less cheap.

6 In Search of Alternating

6.1 Experimental Game and Procedures

By shrinking the percentage difference between $\underline{v}$ and $\overline{v}$, the values to entering become more alike making cutoff cooperation less cheap. In the extreme case where $\underline{v} = \overline{v}$, one would expect all players to adopt alternating. If children derive identical utility from riding in the front seat, they will take turns enjoying this privilege.

To determine if a game parameterization with more similar values can increase the percentage of alternators, we conducted two additional treatments. We added a constant of 100 to the randomly drawn numbers 1-5. Thus, the *AfterFixed100* and *NeverFixed100* treatments

[19] An additional explanation for the absence of alternating is that subjects may believe their partner incapable of detecting the alternating strategy and reciprocating. Also, subjects may have a preference for cutoff cooperation, perhaps because alternating follows a mechanistic algorithm seemingly void of economic logic. The results presented below eliminate both of these reasons.

(to be subsequently abbreviated as *AF100* and *NF100*) are identical to the similarly named original treatments (i.e., five integers in the range, k=3), except that players' *iid* integers come from the uniform distribution 101 to 105. The dominant stage-game strategy remains entry.[20] By corollary 2, we know that the socially optimal cutoff involves exiting on at least the lowest integer in the range. Indeed, $c^* = 101.5$ is the socially optimal pure-strategy cutoff and yields the pair an expected payoff of 77.28 units per round. By comparison, alternating earns 103 in expectation, a 33% premium over $c^* = 101.5$.

Sixty and 70 subjects participated in *AF100* and *NF100*, respectively. Participation was again restricted to one experiment per subject and no subject had participated in any of the four original treatments. In selecting the experimental-currency-to-shekel ratio, we held constant the joint monetary payoff from the optimal cooperative strategy of alternating in these and the original treatments. Also, if both pair members play the Nash equilibrium, they earn the same expected monetary payoff in both sets of treatments. This implies a new exchange rate of 1:0.0175. Table 6 compares the nominal and real payoffs in the original and new treatments.

[insert Table 6 here]

6.2 Results from New Treatments

The last two columns of Table 2 reveal little variation in the entry decisions as a function of the number received in both *AF100* and *NF100*. In total, about 64% of the decisions are enter, increasing to 67% on the number 105. The stability of entry percentages across numbers attests to alternation. The strategy inference analysis in Table 7 confirms the preponderance of alternators. Alternating is found to be the best-fit strategy for 64% of subjects in *NF100* and a still higher 73% of subjects in *AF100*, even though *AF100* affords

[20] Note well that the payoff to exit remains zero. If we had also added 100 to the exit payoff, entry would no longer be the dominant strategy.

the opportunity to observe and thus coordinate on cooperative cutoff strategies. Alternating along with Nash play account for about 95% of subjects in both treatments. No subject plays according to the optimal cutoff $c^* = 101.5$ in *AF100* and only 1.5/70 adopt this cutoff in *NF100*. Put starkly, those who cooperate in these experiments alternate; the remaining quarter of the subjects are best described by entering in every round.

[insert Table 7 here]

How can we explain the shift from almost all cutoff cooperators in the original treatments to almost all alternators in these new treatments? By adding a constant of 100, both the nominal and real payoffs to entry are made very similar for all values 101-105, as shown in Table 6. It no longer matters substantively whether a player enters alone on the highest or lowest integer in the range: the difference in both monetary and nominal terms between the two outcomes is a paltry 4% compared to 400% in the original treatments. In addition, Table 6 shows that exiting on the lowest integer is about three times costlier in these new treatments than the original ones, no matter if only one player exits (foregone profit of 0.588 vs. 0.2) or both do (foregone profit of 1.765 vs. 0.6). Alternation ensures that exactly one player enters each round, thereby at once avoiding congestion and the now costlier outcome whereby both players receive low draws and exit.

The prevalence of alternators in these treatments implies that the two-person coordination problem inherent in alternating is not insurmountable. By increasing the joint-expected-payoff advantage to alternating (i.e., by making cutoff cooperation less cheap), all cooperators switch from cutoffs to taking turns.[21]

Figures 2a and 2b also attest to the pervasiveness and stability over time of the alternating strategy in both *AF100* and *NF100*. If all subjects employed the alternating strategy throughout the game, 50% of the decisions would be exit in every round; whereas exit per-

[21] These results also eliminate the two explanations for the lack of alternating given in footnote 19. Namely, subjects are in fact capable of trusting their opponent to alternate and any inherent adversity subjects may feel toward alternation can be overcome with sufficient incentives.

centages varying from 0 to 100 depending on the numbers drawn would reflect cooperative cutoff strategies. In round 3 subjects drew numbers 101 and 102 followed by 104 and 105 in round 4. Accordingly, the exit percentage swings from 57% to 17% in *NF100* and from 48% to 23% in *AF100*, suggesting that some subjects are using cooperative cutoffs in these early rounds. In *AF100*, from round 17 through round 78, the percentage of exit decisions stabilizes at about 40%, despite the randomly drawn numbers each round. In *NF100*, the percentage of exit decisions starts below 30% and it is not until round 40 that it reaches 40% where it stabilizes, again until the second-to-last round.[22]

[insert Figures 2a and 2b here]

It is surprising that *AF100* reveals a higher percentage of alternating pairs and their faster formation than in *NF100* where alternating is the only verifiable cooperative strategy. By contrast, both cooperative cutoffs and alternation are fully observable in the *AF100* treatment. We would therefore expect a higher percentage of alternators in *NF100*.

How then can we understand this opposite finding? It turns out that learning the opponent's number at the end of the round facilitates the formation of alternating pairs even though alternating in no way depends on the subject's number. A subject in *AF100* who exits on a 4 or 5 while entering on a 1 or 2 in other rounds sends a strong signal that he is not playing a cutoff strategy. *NF100* offers no such conspicuous opportunity to communicate one's intentions due to the unobservability of the opponent's number.

The other striking observation from these time series of exit decisions is the sudden drop off in exiting in the final two rounds. In *AF100*, from around 40% of all decisions in rounds 17-78, exit decisions plummet to 23% and 5% in rounds 79 and 80, respectively. Similarly, in *NF100*, exit decisions fall to 26% and 7% in the last two rounds after having stabilized at around 40% for the last half of the game. Like the endgame effects observed in the original

[22] The relatively high error rate of the best-fit strategies of 0.13 in *NF100* compared to only 0.06 in *AF100* also reflects the extra time required to converge on alternating in *NF100*.

four treatments, these sharp declines in cooperative behavior in the final two rounds suggest that cooperation throughout the game was strategic rather than other-regarding.

7 Understanding Cooperation in Our Game and Others

When a subject's value to entering alone was a randomly drawn integer from 1-5, almost all cooperators employed cutoff strategies. By adding a constant of 100 to entry values, we witnessed a sweeping switch to alternation. This result handily eliminates any suggestion that the coordination problem inherent in alternating strategies is insurmountable and validates the significance of the cheapness of cutoff cooperation in the original $\{1, \ldots, 5\}$ compared to the new $\{101, \ldots, 105\}$ treatments.

In this section, we compute a subject's marginal incentives to cooperate for different degrees of cooperation, different strategies and across different game parameterizations. We invoke these calculations to explain subjects' chosen mode of cooperation (cutoffs or alternation) in our games. This conceptual framework may also be applied to different cooperation dilemmas. We illustrate its usage by explaining the relatively high levels of cooperation observed in our random-partners treatments compared to, say, randomly matched pairs in the prisoners' dilemma.

To make more precise the sense in which exiting on low values is cheap in the original treatments, suppose player 1 exits x fraction of the time, while player 2 exits with fraction y. The total cost from player 1 exiting with fraction x is player 1's foregone profits from being cooperative, given by $C(x, y) = \Pi_1(0, y) - \Pi_1(x, y)$. The total benefit from player 1 exiting with fraction x is player 2's additional profits from player 1's cooperativeness, namely, $B(x, y) = \Pi_2(x, y) - \Pi_2(0, y)$. To evaluate the return from cooperative behavior, we compute the individual's marginal incentives in deciding whether to exit more often. We analyze this from a symmetric exit fraction z. The marginal benefit (received by player 2) at z to player 1 unilaterally increasing his fraction of exiting is $B_x(z, z)$, while the marginal cost (borne by player 1) at z is $C_x(z, z)$. Hence, the marginal benefit in terms of cost at z is $B_x(z, z)/C_x(z, z)$.[23]

[insert Figure 3]

Figure 3 plots this expression for both cutoff and alternating strategies. The plot for cutoff strategies reveals that if both players always enter (exit fraction equals 0) and one player decides to exit on 1 a small percentage of the time, the net joint expected return is six.[24] As the exit frequency increases, the return to exiting decreases since the cost increases (foregoing entry on higher integers) and the benefit declines (the opponent is also staying out more often). By comparison, the joint expected return to alternation is 2 for exit frequencies up to 1/2 (i.e., from always enter up to always exit when it is the player's turn to do so). For exit frequencies greater than 1/2 (i.e., the player exits when it is his opponent's turn to exit), the benefit is 0. Thus, Figure 3 reveals that for small amounts of cooperation cutoff strategies are much more efficient than alternation: if both pair members always defer entry on a 1 ($c = 1.5$), for instance, then the marginal return for this cutoff cooperation is four, while, as noted, the return to alternation is only two. Even when subjects' increase their cutoff cooperation to $c^* = 2.5$, the marginal joint benefit still exceeds the marginal cost. Couple this with the inherent difficulty of jointly coordinating on alternation and the prevalence of cooperative cutoff strategies becomes explicable.[25]

[23] No generality is lost by focusing on unilateral changes in cooperativeness. By considering the marginal return at z to both players jointly changing their exit percentages, we arrive at the identical expression. To see this, the joint marginal profit to both players increasing their cooperation is given by $\Pi_{1,y}(z, z) + \Pi_{2,x}(z, z) + \Pi_{1,x}(z, z) + \Pi_{2,y}(z, z)$, where the first subscript refers to the player, followed by the variable being differentiated. The first two terms of this expression represent each player's marginal benefit from the other increasing his exit fraction, while the last two terms are each player's marginal cost to exiting. Expressing the joint marginal benefit over the joint marginal cost from additional cooperation yields the sum of the first two terms divided by the sum of the last two terms. Because players' payoff functions and exit fractions are symmetric, the first term equals the second, and the third term equals the fourth, yielding a simplified expression for the marginal benefit in terms of cost, namely, $\frac{\Pi_{2,x}(z,z)}{\Pi_{1,x}(z,z)}$, which precisely equals the marginal benefit in terms of cost at z for a unilateral change in cooperation, $B_x(z, z)/C_x(z, z)$.

[24] To obtain this, the expected marginal cost in switching from always entering to exiting occasionally on 1 is $\frac{1}{3}$ (since the opponent always enters), while the expected marginal benefit is six times as much, namely, $\frac{2}{3} * 3 = 2$.

[25] Figure 3 also displays visually the socially optimal level of cooperation for each type of strategy: when

By contrast, for the new $\{101, \ldots, 105\}$ treatments, Figure 3 reveals that the marginal joint expected return from exiting occasionally on the lowest integer in the range drops from 6 in the original treatments to slightly more than 2, whereas the marginal return to alternation remains unchanged at 2 for exit frequencies up to $\frac{1}{2}$. The monotonic decline in the marginal return to exiting more frequently on 101 and the fact that the marginal cost already exceeds the marginal joint benefit when cooperation is increased to $c = 102.5$ make clear the sense in which cutoff cooperation is no longer cheap in these treatments.[26] Despite the substantially reduced return to cutoff cooperation in these new treatments (and no change in the return to alternation), according to two measures – lower entry percentages (Table 2) and higher realized profits – we obtain *more* cooperation in these new treatments than the original ones. Accentuating the payoff advantage to alternation enabled subjects to coordinate on this more efficient form of cooperation. At the same time, the impact of the reduced return to cutoff cooperation can also be seen in the much higher proportion of Nash players compared to the original treatments.

Finally, the very high social return to small amounts of cooperation in the original $\{1, \ldots, 5\}$ treatments supply the most probable explanation for the relatively high degree of cooperation observed in our random-partners treatments compared to other cooperation games that have employed random matching. For instance, in Duffy and Ochs (2003) version of the prisoners' dilemma, from (defect, defect), a player gives up 10 points by cooperating to increase his opponent's payoff by 20 points (cooperate, defect), implying a marginal joint expected return to cooperation of 2. Identically, if the remaining defector switches to cooperation, he gives up 10 points to increases his opponent's payoff by 20 points. Their

the marginal joint expected return from the strategy equals one, the marginal benefit to cooperation precisely matches the marginal cost. This criterion confirms the symmetric pure-strategy cutoff of 2.5 and each player exiting 50% of the time – that is, on alternate rounds – as the socially optimal modes of cooperation.

[26] Figure 3 also reveals that the optimal cutoff in the new treatments is actually in mixed strategies, $c = 101.5$ with probability 0.75 and $c = 102.5$ with probability 0.25. In fact, for k=3 there is no constant we can add to the original range of five integers such that the socially optimal cutoff is a pure strategy equal to $c^* = \underline{v} + 0.5$. A proof of this calculation is available upon request.

study finds that the modal subject behavior is always defect with the percentage of defectors increasing over time. This begs the question whether cooperation might be obtainable and sustainable in the prisoners' dilemma if the marginal return to cooperation is increased to, say, 6. For a (defect, defect) payoff of (10, 10), this would require increasing the (defect, cooperate) payoff to (70, 0) and the (cooperate, cooperate) payoff to (60, 60).

8 Lessons for Cooperation in the Real World

There is a large class of economic and social cooperative dilemmas that until now has not been modeled or tested experimentally. These games are characterized by a tension between the unique Nash equilibrium in which both players defect and the socially optimal outcome in which one player defects and the other cooperates.

In this paper, we introduce such a class of games, derive its theoretical properties and optimally select a parameterization to study experimentally. The asymmetric social optimum permits alternating as one cooperative repeated-game strategy. Privately known, randomly drawn values for cooperation admit cutoff strategies as another form of cooperation.

We find that when the range of values to cooperation is similar, players alternate; whereas, diffuse payoff distributions enhance the value to private payoff information and lead to the adoption of cutoff strategies. In real-world cooperation dilemmas, participants' values tend to be alike and thus, according to our results, alternation adopted, when the cooperative task is mundane or requires little skill. By contrast, individuals' values to cooperation are varied for tasks that require a particular, unequally distributed skill or tasks that elicit a strong heterogeneity in preferences. In these situations, our results reveal that cooperative participants will adopt cutoff strategies, *even if alternation yields equal expected payoffs.* For participants to overcome the costly two-person coordination required of alternation, it must provide a substantially higher payoff than cutoff strategies.

Numerous examples illustrate these distinctions. Cabdrivers at a taxistand serve customers in a predetermined order, similar to alternating. This solution distributes customers evenly and avoids conflict between cabbies, all of whom are available with identical locations. However, it is inefficient and likely to elicit complaints if a dispatcher allocates customers among cabbies dispersed throughout the city. Instead, cabdrivers can take advantage of their private information (e.g., availability, distance to the customer) to divide up customers according to their values, like cutoff strategies.

Similarly, an army sergeant, shift manager, head of a team of programmers or committee of commune members may assign mundane tasks (e.g., cleaning the latrine, unpopular shifts, routine programming) using a duty roster or other system that disregards input from group members (alternating); or, in the case of diverse values, the members may self-select their tasks based on privately known ability and preferences (e.g., combat duty, revenue-generating activities for the commune, choice shifts, challenging programming) (cutoffs).

Allowing group members to choose their tasks exploits their private information. By the same token, conflict may ensue if more than one member opts for the same task, while other unwanted tasks may remain unfilled. Alternation assigns exactly one member to each task, thus at once avoiding conflict and making sure that no opportunity is missed, while at the same time conveying an impression of an equitable distribution of assignments.

We have explored experimentally only a small subset of possible games, all with private information, within the class of two-player games introduced. Issues such as the roles of communication, spite (entering on values less than zero), endogenous timing of entry, sequential moves and team games, to name a few, on cooperative behavior can all be addressed within our game structure and await future research.

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Appendix A - Proofs to Propositions in Section 2

Proof to Proposition 1: 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 $\overline{v} - \underline{v} + 1$ units by $\overline{v} - \underline{v} + 1$ 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,

$$2\frac{c}{k}+c\cdot 2(\overline{v}-c)+2\sum_{z=c+1}^{\overline{v}}(z-\frac{z+c}{k}) = \frac{\overline{v}\ (1+\overline{v})\ (k-1) - (1+2\,\overline{v}+k-2\,\underline{v}\,k)\ c - 3\ (k-1)\ c^2}{k}.$$

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

Proof of Corollary 2: The two comparative-statics results preceding the corollary indicate that the most difficult test for the corollary is $k = 3$ and the range of integers $[\underline{v}, \underline{v}+1]$. If we can show that the socially optimal strategy is exit on $\underline{v}$ for this case, then the corollary holds for all $\overline{v} > \underline{v}$ and $k \geq 3$. Each player earns in expectation $(\frac{\underline{v}}{2} + \frac{\underline{v}+1}{2}) \cdot \frac{1}{3} = \frac{2\underline{v}+1}{6}$ if he enters on both $\underline{v}$ and $\underline{v} + 1$. But by staying out on $\underline{v}$, each player does better with expected earnings equal to $\frac{\underline{v}+1}{2} \cdot (\frac{1}{2} + \frac{1}{2} \cdot \frac{1}{3}) = \frac{2\underline{v}+2}{6}$. *QED*

Proof of Proposition 3: 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 $(\overline{v} - \underline{v} + 1) \sum_{z=\underline{v}}^{\overline{v}} z = (1 + \overline{v} - \underline{v})^2(\underline{v} + \overline{v})/2$. Using a cutoff strategy of c^* yields a joint payoff of $2(c^* - \underline{v}) \sum_{z=c^*}^{\overline{v}} z = (1 + \overline{v} - c^*)(c^* - \underline{v})(\overline{v} + c^*)$. The expression $(1 + \overline{v} - c^*)(c^* - \underline{v})$ reaches its maximum at $c^* = (1+\underline{v}+\overline{v})/2$, yielding $(1+\overline{v}-\underline{v})^2/4$. Since $(\overline{v}+c^*)$ is maximized for $c^* = \overline{v}$, we know the joint cutoff payoff must be strictly less than $(1 + \overline{v} - \underline{v})^2 \cdot \overline{v}/2$. For $\underline{v} > 0$, this is less than the joint alternating payoff. *QED*

Note that when the distribution of values is not uniform, Proposition 3 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.

Appendix B - Participants' Instructions

Pre-Experiment Questions (not intended for publication)

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

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

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

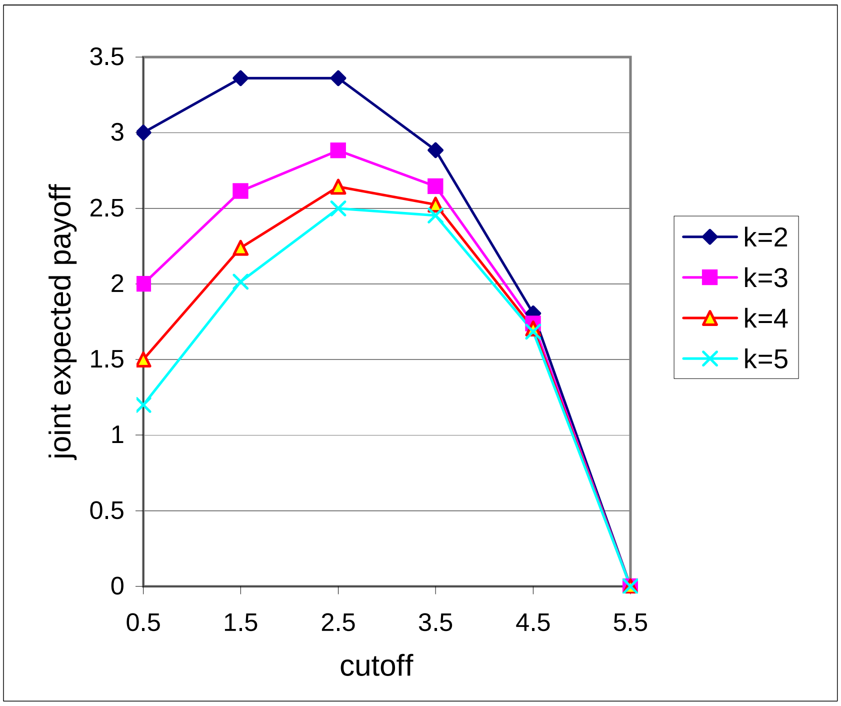
Suppose you receive a number, x, and the other person receives a number, y. The round profits for each of the given pair of decisions are indicated in the table below. The number preceding the comma refers to your round profit; the number after the comma is the other person's round profit.

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

2x2 Payoff Matrix for Cooperation and Coordination Games

	cooperate/exit	defect/enter
cooperate/exit	a, a	0, 1
defect/enter	1, 0	b, b

our game : $0 = a < b$, $2b < 1$
prisoner's dilemma : $a > b > 0$, $1 > a > 1/2$
market-entry game : $a = 0$, $b < 0$
chicken : $0 < a < 1$, $b < 0$
battle of the sexes : $b > a > 0$

Table 2
Entry by Number and by Treatment

Number	*AfterFixed*	*NeverFixed*	*AfterRandom*	*NeverRandom*	*Number*	*AfterFixed100*	*NeverFixed100*
1	16.3%	30.8%	34.8%	43.9%	101	62.6%	60.0%
2	29.4%	53.8%	69.1%	77.8%	102	58.9%	61.1%
3	86.2%	88.8%	98.0%	98.3%	103	63.1%	67.1%
4	98.0%	95.6%	98.6%	99.4%	104	65.6%	67.2%
5	98.5%	95.4%	99.2%	99.7%	105	65.7%	67.8%
Overall	67.7%	74.4%	81.3%	85.0%	Overall	63.3%	64.8%

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

Table 3

Random Effects Probit Models for Entry Decisions in each of 4 treatments

Variable	Treatment									
	AfterFixed		*NeverFixed*		*AfterRandom*				*NeverRandom*	
	coefficient (std. error)	marginal effect	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	1.507*** (0.088)	0.227	1.603*** (0.092)	0.177	1.643*** (0.080)	0.116
$C_{2.5}$	2.161*** (0.081)	0.587	1.522*** (0.083)	0.377	2.175*** (0.133)	0.276	2.432*** (0.152)	0.240	1.831*** (0.121)	0.082
$C_{3.5}$	1.039*** (0.112)	0.221	0.653*** (0.105)	0.129	0.204 (0.168)	0.000	0.326 (0.206)	0.000	0.540*** (0.176)	0.009
$C_{4.5}$	0.257* (0.156)	0.055	0.025 (0.118)	0.000	0.303 (0.197)	0.000	0.359 (0.262)	0.000	0.176 (0.230)	0.000
Enter $_{i,t-1}$	-0.257*** (0.065)	-0.078	-0.734*** (0.066)	-0.124	-0.278*** (0.086)	-0.014	-0.038 (0.091)	0.000	0.042 (0.103)	0.000
subject17*Enter $_{i,t-1}$	---	---	---	---	---	---	-6.848*** (0.452)	-0.998	---	---
Enter $_{-i,t-1}$	0.356*** (0.065)	0.088	0.563*** (0.064)	0.135	0.177** (0.087)	0.012	0.198** (0.092)	0.008	0.224*** (0.084)	0.005
first10	-0.246*** (0.089)	-0.062	-0.123 (0.082)	0.000	-0.052 (0.099)	0.000	-0.032 (0.104)	0.000	0.063 (0.089)	0.000
last10	0.563*** (0.091)	0.103	0.542*** (0.086)	0.088	0.606*** (0.116)	0.246	0.714*** (0.124)	0.015	0.322*** (0.103)	0.004
constant	-1.247 (0.104)		-0.655 (0.106)		-0.781 (0.178)		-0.980 (0.144)		-0.496 (0.125)	
Number of Obs.	4898		4898		5056		5056		6478	
ρ	0.395 (0.031)		0.406 (0.029)		0.621 (0.039)		0.622 (0.030)		0.620 (0.230)	
Log L	-1244.3		-1486.3		-956.6		-856.64		-1154.4	

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 four 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 4

Random Effects Probit Models for Entry Decisions in pooled data from 4 treatments

Variable	(1) coefficient (std. error)	(1) marginal effect	(2) coefficient (std. error)	(2) marginal effect
NeverFixed	0.125** (0.051)	0.033	0.121* (0.066)	0.032
AfterRandom	0.470*** (0.083)	0.114	0.483*** (0.133)	0.116
NeverRandom	0.568*** (0.059)	0.139	0.550*** (0.058)	0.135
Enter $_{i,t-1}$	---	---	-0.179*** (0.024)	-0.046
Enter $_{-i,t-1}$	---	---	0.163*** (0.025)	0.042
first10	---	---	-0.291*** (0.031)	-0.086
last10	---	---	0.216*** (0.033)	0.055
constant	0.560 (0.030)		0.586 (0.040)	
Number of Obs.	21600		21330	
ρ	0.244 (0.016)		0.257 (0.021)	
Log L	-10398.6		-10188.8	

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 from pooled data from all four treatments. The entry decision of subject *i* in period *t* is regressed on dummy variables for three of the treatments (AfterFixed is excluded). Regression (2) also includes controls for the subject's and opponent's last-period entry decision and whether the game is in the first 10 or last 10 rounds of play.

Table 5

Strategy Inference Results by Treatment

	Strategy	Treatment: AfterFixed number	(fraction)	ave. profit	NeverFixed number	(fraction)	ave. profit	AfterRandom number	(fraction)	ave. profit	NeverRandom number	(fraction)	ave. profit
	c=0.5 (always Enter)	8.5	(.137)	109.5	12.5	(.202)	93.2	16	(.25)	109.1	34.5	(.421)	101.9
	c*=1.5	9	(.145)	98.7	19.5	(.315)	110.4	26.5	(.414)	102.2	30.5	(.372)	98.5
	c=2.5	38.5	(.621)	111.6	24	(.387)	106.8	20.5	(.32)	97.8	16.5	(.201)	93.0
	c=3.5	4	(.065)	110.0	1	(.016)	110.0	0	---	---	0.5	(.006)	67.7
	c=4.5	0	---		0	---	---	0	---	---	0	---	---
	c=5.5 (always Exit)	0	---		0	---	---	0	---	---	0	---	---
	Opposite Previous Round	2	(.032)	117.3	5	(.081)	112.1	1	(.016)	65.3	0	---	---
	Total	62	(1)	109.5	62	(1)	105.7	64	(1)	102.0	82	(1)	98.6
probability of error	experimental data												
	best-fitting strategies		0.06			0.08			0.05			0.05	
	Nash equilibrium strategy		0.32			0.26			0.19			0.15	
	randomly generated data												
	best-fitting strategies		0.31			0.24			0.17			0.15	
	Nash equilibrium strategy		0.32			0.24			0.17			0.15	

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

Table 6

Comparison of Nominal and Monetary Payoffs in Original and New Treatments

Number	Outcome	Payoff		Number	Outcome	Payoff	
		Nominal	Monetary			Nominal	Monetary
---	Exit	0	0	---	Exit	0	0
1	Enter Alone	1	0.6	101	Enter Alone	101	1.765
2	Enter Alone	2	1.2	102	Enter Alone	102	1.783
3	Enter Alone	3	**1.8**	103	Enter Alone	103	**1.8**
4	Enter Alone	4	2.4	104	Enter Alone	104	1.817
5	Enter Alone	5	3	105	Enter Alone	105	1.835
1	Both Enter	0.333	0.2	101	Both Enter	33.667	0.588
2	Both Enter	0.667	0.4	102	Both Enter	34	0.594
3	Both Enter	1	**0.6**	103	Both Enter	34.333	**0.6**
4	Both Enter	1.333	0.8	104	Both Enter	34.667	0.606
5	Both Enter	1.667	1	105	Both Enter	35	0.612

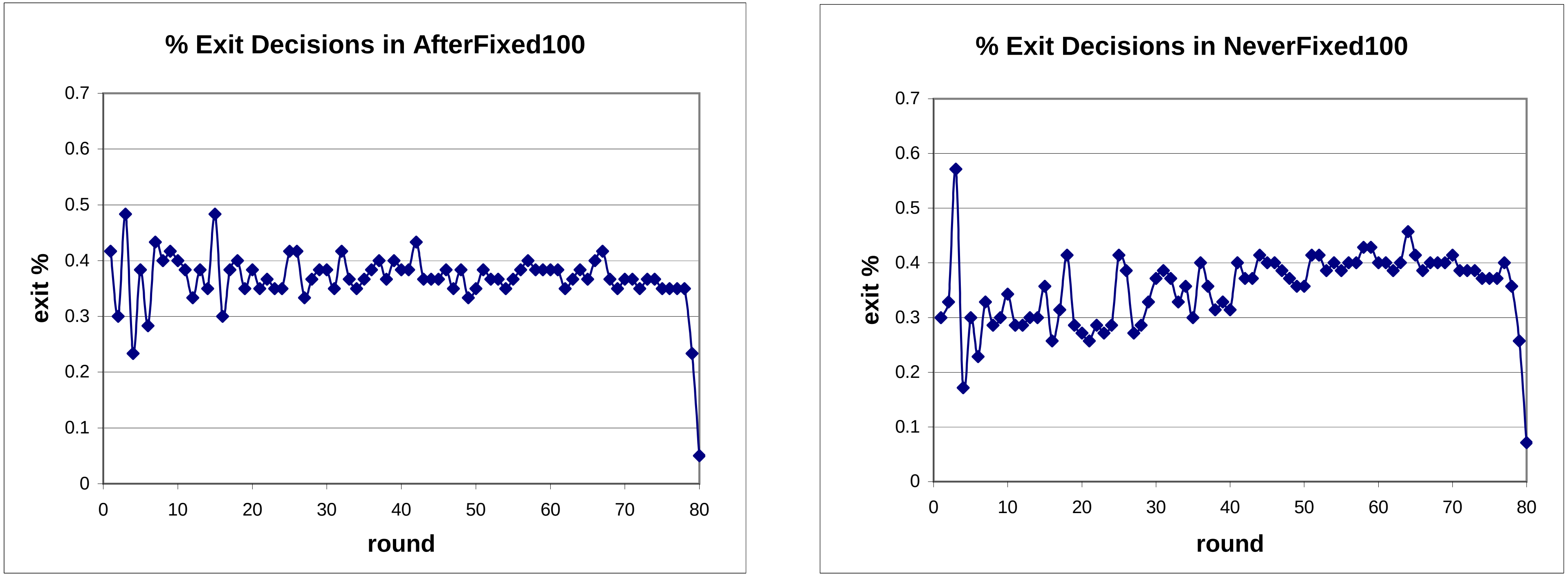
Table 7

Strategy Inference Results (Treatments with Constant of 100 Added to Entry Values)

	Strategy	AfterFixed100 number	AfterFixed100 (fraction)	AfterFixed100 ave. profit	NeverFixed100 number	NeverFixed100 (fraction)	NeverFixed100 ave. profit
	c=100.5 (always Enter)	14	(.233)	2885	21.5	(.307)	3166
	c*=101.5	0	---	---	1.5	(.021)	3596
	c=102.5	2	(.033)	3397	2.5	(.036)	3375
	c=103.5	0	---	---	0	---	---
	c=104.5	0	---	---	0	---	---
	c=105.5 (always Exit)	0	---	---	0	---	---
	Opposite Previous Round	44	(.733)	3945	44.5	(.636)	3853
	Total	60	(1)	3679	70	(1)	3619
	experimental data						
probability of error	best-fitting strategies		0.06			0.13	
	Nash equilibrium strategy		0.37			0.36	
	randomly generated data						
	best-fitting strategies		0.37			0.36	
	Nash equilibrium strategy		0.38			0.37	

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

Figure 2a and 2b



The percentage of exit decisions by round pooled across all subjects for the *AfterFixed100* (left panel) and *NeverFixed 100* (right panel) treatments.

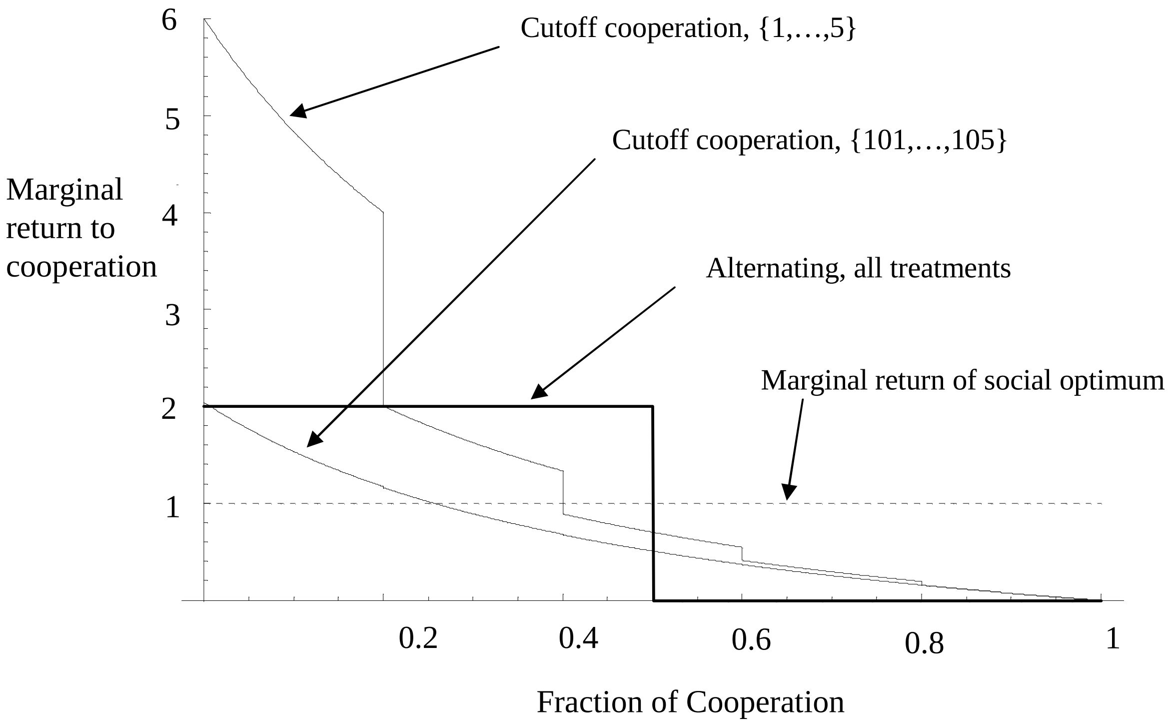


Figure 3: Graphical demonstration of the marginal return to cooperation for the cutoff and alternating strategies in the original {1,…,5} and new {101,…,105} treatments.