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Bidding Behavior in the Price Is Right Game: An Experimental Study

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Abstract

In this paper, we present the design and the results of an experiment in which subjects participate in a bidding game identical to the one seen on the television game show "The Price is Right". Four players make sequential guesses about the price of an item, and the player whose guess is closest to, but without exceeding, the price, wins the item. We compare our experimental data to field data from the actual game show analysed by Berk, Hughson and Vandezande (1996). We find that the patterns in the data from the experiment closely resemble those from the television game show. The data exhibit consistent departures from the subgame perfect equilibrium of the game.

Keywords: Price is Right, Experiment, Bidding, Subgame Perfection

JEL Classification: C7, C9

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1. Introduction

In a recent article, Berk, Hughson and Vandezande (1996) studied behavior in a bidding game played on a popular television program, *The Price is Right*. In the bidding game there are four bidders, who are presented with a commonly used commercially sold item, and who each submit a guess of the retail price of the item. The four bidders announce their guesses publicly and in sequence so that the guesses of previous bidders are known when a player makes his decision. The bidder, whose guess is the closest to the actual retail price without exceeding the price, receives the item and the possibility of winning more prizes later in the program. If all four guesses (which we call bids) exceed the actual price, the bidding process is repeated. The winner does not make any payment in exchange for receiving the item.

The game is of independent interest to economists because it is equivalent to other situations that arise in industrial organization. One example is a situation in location theory. Consider four firms deciding where to locate their businesses (say gasoline stations) on a one-way street or highway. Traffic enters at various points along the street and stops at the first business it encounters. Each of the firms would like to locate in such a way as to maximize the percentage of incoming traffic that reaches it before reaching another firm. Another example, modeled by Cancian et al. (1995), is the scheduling of television evening news by competing networks. This is analogous to the one-way location situation described above in that each network chooses the time to schedule its newscast to maximize the number of viewers for whom its newscast is the first they see after arriving home at the end of the workday.

In their analysis of the data from *The Price is Right*, Berk et al. (hereafter BHV) compare the observed data from the television program to the subgame perfect equilibrium of the bidding game and find striking discrepancies. For example, it is always optimal for bidder 4 (the fourth and last mover) in the game to either (a) *cut off* one of the other three bidders by bidding higher than the other bidder by the minimum permissible bid increment, or to (b) bid the minimum possible value. However, Berk et al. observe that 43% of the time, players do not choose from that simple subset of their strategy set. In the subgame perfect equilibrium, players make bids in descending order; the first player submits the highest bid, the fourth player the lowest. In BHV's data, players bid in descending order in only 3.76% of games.

The authors argue that the lack of cutoff behavior is evidence of bounded rationality rather than reciprocity. To support of the notion of bounded rationality, they document the fact that cutoff bids increase when players observe other cutoff bids over the course of the program, indicating that learning is taking place over time. The reciprocity explanation is refuted by the fact that a player acting as bidder four, who submits a cutoff bid or a bid at the bottom of the support of positive prices, is not cut off more frequently later in the program. Thus, taking advantage of his position as the fourth bidder and leaving the player that he cuts off almost zero probability of winning does not appear to lead to revenge. Whereas the existence of bounded rationality is consistent with a large body of previous experimental work, the absence of reciprocal behavior contrasts with many experimental studies.[1]

In this paper, we construct an experiment to explore the stark differences between the theoretical predictions and the data from the game show.[2] The fact that the rules are stated so

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[1] The presence of reciprocal behavior has been documented by many experimental studies. See Hoffman et al. (1998) for a discussion. A well-known example is in the experimental research on the ultimatum bargaining game, first studied by Guth et al. (1982). In the game a proposer makes a take it or leave it offer to divide surplus between himself and another agent, the responder. The responder can either accept the proposal, in which case it is implemented, or reject the offer, in which case neither agent receives any of the surplus. Typically, a responder will reject an offer that gives him too small a share of the surplus to be divided in order to punish the proposer for attempting to take too large a share. Another example is the experimental work on labor markets by Fehr et. al. (1993). They find that workers reciprocate higher wage offers by putting forth more effort.

[2] Friedman (1998) conducts an experiment that is similar in spirit to ours. His experiment is based on Monty Hall's Three-Door problem on the television game show "Let's make a Deal". A contestant is presented with three closed doors. Behind one of the doors is a valuable prize and behind two of the doors, there are prizes with little or no value. The contestant is awarded a property right to whatever (unobservable) prize is behind one of the doors. One of the other doors, behind which is a valueless prize, is opened so that the valueless prize is revealed to the contestant. The contestant than has the opportunity to choose between the contents behind the door he currently "owns", or those behind the other unopened door. It is optimal to switch to the other unopened door. Friedman conducts an individual choice experiment in which subjects are presented with the same decision situation. He finds that the majority of subjects choose the suboptimal alternative of "remaining," i.e. not switching. He finds significant increases in the incidence of optimal decisions when subjects are required keep track of how their earnings compared with their

precisely in the game show allows us to attain an unusual degree of parallelism between our experiment and the field data. We can reproduce a game in the laboratory with the same rules as in the field. However, in the experiment, we can make the distribution of prizes common information and thereby give subjects enough information so that they can, at least in principle, calculate the subgame perfect equilibrium of the game. This allows us to test game-theoretic predictions. Each of our subjects experiences the bidding process 50 times so that we are able to observe many more choices by individual subjects than is possible on the television program. The 50 repetitions provide a long time horizon in which to study the nature of changes in behavior over time.

We first consider whether the data conform to game theoretic predictions. We study whether or not the last mover uses his best response, whether bidders bid in descending order, and how well overall behavior conforms to the subgame perfect equilibrium. In our experiment, we find that subjects behave in a suboptimal manner that closely resembles that observed by BHV on the actual *Price is Right* game show. We interpret the similarity of results in the two data sets as evidence that the main factors that affect decisions on the television show have been successfully reproduced in the experimental environment. The similarity between our results and those observed by BHV provides an unusually clear illustration of the level of parallelism with field data that laboratory experiments can attain[3].

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hypothetical earnings had they always switched or always remained. Optimal behavior was also more likely when subjects were shown the results of the decisions of other subjects, including a comparison of the percentage of "switch" choices and the percentage of "remain" choices that won the valuable prize.

[3] Behavior in location games has been studied experimentally by Sherstyuk (1998), Brown-Kruse, Cronshaw and Schenk (1993) and Brown-Kruse and Schenk (2000). Sherstyuk studies behavior in a three-player location game in which players simultaneously choose where to locate in a linear city (a line segment from 0 to 1. Consumers are located uniformly in the linear city and always purchase from the closest seller, so that a seller's payoff is proportional to the fraction of the line segment that lies closer to her than to any of the other sellers. In the game, there are no pure strategy equilibria but there is a mixed-strategy equilibrium. For the parameters she studies, the mixed strategy equilibrium involves players locating with equal probability at all points between the 25 and 75 percentiles of the line. She finds that behavior corresponds well to the theoretical prediction, but with players locating near the center too infrequently, presumably for fear of being caught between the two other players and receiving a small market share. The departures from the subgame perfect equilibrium she observes are consistent with the presence of risk aversion.

Since we observe behavior that deviates substantively from the game-theoretic predictions, we consider the source of the deviations and we evaluate the bounded rationality and the reciprocity hypotheses considered by BHV. We consider whether departures from optimal behavior on the part of bidder 4 are due to reciprocity by running two different treatments that differ in their level of anonymity. In one of the treatments, called the *Public* treatment, any subject can identify the player who carried out a particular action in earlier plays of the game and can target them specifically for (positive or negative) reciprocation. In the other treatment, called the *Anonymity* treatment, the subject cannot associate individual subjects with the actions they choose, making it impossible to reciprocate at the individual level. In the Public treatment, if the likelihood of a subject i cutting off another subject j increases, the more j had cutoff i in previous periods (over any overall trend of increase in cutoff behavior over time), it indicates that targeted reciprocal cutting off does occur.

The long time horizon also allows us to evaluate the bounded rationality hypothesis as formulated by BHV, by checking whether optimal strategies are more likely to be chosen as subjects gain more experience. We also consider how subjects learn to cutoff other bidders. If the likelihood of a subject i cutting off a subject j increases when i has been cut off by another subject k, it suggests that i has learned from the experience of being cut off, and has adopted it as his own strategy. If the likelihood of a subject i cutting off other subjects increases, the more he observes subject j being cut off by subject k, it indicates that observational learning is taking place.

Brown-Kruse et al. (1998) studied behavior in Hotelling's (1929) location game. Two players choose their locations in a linear city and they then sell a product at a predetermined price. Consumers buy from the closer seller, provided she is not so far away that price plus transport cost exceeds the utility of consumption. The authors study the role of communication between the two players in facilitating or hindering cooperation in an infinitely repeated version of the game. They find that if communication is not permitted, the two players locate at the center, which is the unique Nash equilibrium of the one-shot game. If subjects are allowed to communicate, they tend to play the Pareto-dominant supergame equilibrium in which they differentiate themselves spatially. Brown-Kruse and Schenk (2000) extend the analysis to consider non-uniformly distributed consumers and a reduced-form 2x2 action version of the game. They find that simplifying the decision environment and allowing communication each lead to more cooperation between agents.

As we document in detail in section four, we find that the incidence of cutoff behavior increases over time. There is more cutting off overall in the Anonymity treatment than in the Public treatment, which is consistent with the hypothesis that subjects anticipate reciprocal behavior on the part of others in the Public treatment. However, we also find no evidence that players actually target those who cut them off for retribution. This suggests that the penalty for cutting off others lies not in being targeted for cutoffs in future plays of the game, but rather merely in being publicly observed cutting off others. This cost is presumably lower in the laboratory than on the television game show, which is typically seen by millions of viewers, including acquaintances of the players.

Though the probability of player i cutting off player j does not increase when j cuts off i, we find that the tendency of i to cut off j increases the more cutoffs that i has observed in earlier periods. There is no additional effect of actually having been cut off: player i is not more likely to cut off j when player k has cut off i than when k has cut off some other player m. All cutoffs have the same effect on player i's future propensity to cut off others. Players learn as much from observing cutoffs as from experiencing them directly. The same results are obtained by BHV in their data.

The next section describes the game and the procedures of the experiment. Section three presents our hypotheses about behavior in the experiment. These hypotheses are based on the work of BHV. In section four we present our results, and in section five we provide a summary and some concluding remarks.

2. Procedures

The experiment consisted of five sessions. All of the sessions were held in classrooms or computer labs in the Krannert School of Management at Purdue University and the subjects for this experiment consisted entirely of undergraduate students from Purdue University. In each session, subjects played the *Price is Right* bidding game 50 times. We will refer to each play of the game as a period. The winner of each period was awarded $2 for a total of $100 given to each group of four subjects. Thus the average subject received $25. Sessions took on average approximately two hours. The first four sessions, which we refer to as sessions 1-4 in the remainder of the paper and which constituted the Public treatment, were conducted by hand and on separate days. In each of these four sessions, there were four subjects, who interacted with each other for 50 periods. The last session, which constituted the Anonymity treatment, was computerized and had twelve subjects divided into three groups, who all interacted at the same time. In this session, subjects were informed that they were matched with the same group of 3 other subjects throughout the entire 50 periods. The data from the three groups will be referred to as sessions 5a-5c. All subjects were paid in cash at the end of their session.

2.1 The Public Treatment

The sessions in the Public treatment were conducted by hand. Participants were seated at desks facing the chalkboard. The instructions for the experiment were read aloud as participants followed along with printed copies. The instructions were available for reference for the duration of the experiment. The full text of the instructions is given in the appendix. Subjects were then given a chance to ask questions regarding the procedure of the experiment. Following the instructions, one practice period of the experiment was conducted which did not count for money. After the practice period, fifty periods were conducted with monetary payments. The data were recorded both on paper and on the chalkboard. At any time, subjects could observe the history of all subjects' actions for between ten and twenty immediately preceding periods.

The timing of activity in each individual period was as follows: After fifteen seconds, the experimenter signaled to bidder 1 that he could declare an integer between 1 and 1000 (inclusive) whenever he was ready. The fifteen-second interval was meant to encourage subjects to take time to analyze the decision situation they faced. After bidder 1 verbally submitted his number, it was recorded on the chalkboard so that all other subjects could observe the choice. After another fifteen-second delay, bidder 2 was allowed to submit her number. Again, the number was recorded on the chalkboard. This same process continued with bidder 3 and bidder 4. After bidder 4's number was recorded on the chalkboard, the experimenter rolled a 10-sided die and a 100-sided die simultaneously. The ten-sided die had values 0 through 9 and the 100-sided die had values 0 through 99. The two numbers were concatenated to form a three-digit number with the 10-sided die representing the first digit and the 100-sided die representing the last two. If both dice returned zero, the experimenter's number was 1000. The subjects were occasionally given the chance to roll the dice and to read the numbers.

After the experimenter's number was recorded on the chalkboard, and if the experimenter's number was greater than at least one player's number, the winner for the period was selected. The winner was the bidder whose choice was closest to the experimenter's number without exceeding it. The winner's bid was circled, he was informed that he had won $2, and the experiment proceeded to the next period. All data from the chalkboard was recorded on paper by a second experimenter seated at the back of the room.

If all four bidders' numbers were greater than the experimenter's number, then no winner was determined, and play continued with a resale round. The procedure for resale rounds was identical to the initial round of each period. When described to the subjects, a resale round was labeled in a way that underscored the link between the original round and the resale round. For example Period 3.1 was the first resale round in Period 3. If all bidders' numbers were again greater than the experimenter's number in Period 3.1, then play continued to Period 3.2, etc. Subjects were frequently reminded that no money would be awarded if all four numbers were greater than the experimenter's number and that resale rounds would continue until a winner was determined for the period. Subjects were also reminded that 50 periods would be played during the session (not including the practice period at the beginning) so it was common knowledge that the $2 prize would be awarded exactly 50 times.

In sessions 1 and 2, subjects rotated positions after 25 rounds such that the subject initially acting as bidder 4 and the subject initially acting as bidder 1 switched roles, as did those subjects acting as bidders 2 and 3. In sessions 3 and 4, subjects rotated once every 10 rounds, so that the subject initially acting as bidder 1 became bidder 4 after 10 rounds, bidder 3 after the 20th round, bidder 2 after the 30th round, and finally bidder 1 for the final 10 rounds. All other subjects were rotated in the same order of "1-4-3-2-1", that is 10 periods in the role of player 1 was followed by 10 periods in the role of player 4, followed by 3, etc.... This rotation scheme encouraged backward induction since the subject acting as bidder 3 had previously been acting as bidder 4 and thus understood bidder 4's incentive to cut off certain bids. The rotation scheme also allowed a subject to rotate from the "powerless" bidder 1 position to the "powerful" bidder 4 position and reciprocate the behavior of the other three players.[4]

2.2 The Anonymity Treatment

The last sessions (5a-5c) of the experiment were computerized and consisted of three groups interacting simultaneously in a large computer lab. These three sessions increased the level of anonymity in the experiment by ensuring that subjects could not associate the actions and the identity of other players. Recall that in the Public treatment, players could be observed as they chose their bid prices. This was not the case in the Anonymity treatment. Under the Anonymity treatment, the 12 subjects were spaced throughout the lab and instructed to direct their Web browser to the experiment's web site. Each subject was given a unique login ID and password. The players received a game name and a starting player number. They then reviewed instructions explaining the bidding procedure and the use of the Web page for viewing and submitting bids.

Subjects were given printed copies of these instructions to which they could refer throughout the experiment.

We conducted fifty periods, not including one practice period that did not count toward subjects' earnings. Each round consisted of the following sequence of events: After logging into their assigned game, each subject continually viewed a table which displayed the round number, each of the bidders' bids as they were made, the experimenter's number, and the winning number for each of the previous rounds, including the current round. At the bottom of the table was a status bar that indicated how much money the subject had won during the course of the experiment.

At the beginning of the round, bidder 1's browser displayed a pop-up window into which he was able to input a number after 15 seconds. After entering the number, all players saw it appear in their table under "Player 1" for the current round. Bidder 2's browser then displayed a pop-up window after a 15-second delay into which she could enter a number. Again, the number was immediately made available to all other players in the game. The process continued with bidders 3 and 4.

After bidder 4 entered her number, the computer randomly generated a number from a discrete uniform distribution between 1 and 1000 and determined the winner. The experimenter's number and the winning player's number were highlighted in all of the players' tables. The game was then advanced to the next period. If all players entered numbers greater than the experimenter's number, then the next round was a resale round (labeled for example 3.1 for the first resale round of period 3) and a "0" was placed in the column of the table labeled "Winner". The resale round process continued until a winner for the period was determined.

After 10 rounds, the Web browser instructed subjects to log out of their game and log into the next "rotation" of 10 rounds. The bidding procedure was identical, but the subjects were rotated to a new bidder position according to the aforementioned "1-4-3-2-1" scheme. Subjects

[4] The rotation proceeds in a similar manner on the game show.

were not informed of the rotation scheme and were thus unable to positively identify any other subject's role as she rotated through the bidder positions. Therefore, it was difficult for a subject to target another subject for reciprocation. In order to punish a player by cutting her off, one risked a 2/3 probability of cutting off the wrong player. [5]After the 10th round of the 5th rotation (or, the 50th round in total,) the subjects were told to sit quietly until all players were finished, so that the last group of four subjects to finish could not identify the other members of their group.

3. Hypotheses

3.1: Hypotheses derived from Game Theory

BHV derived several game-theoretic propositions that are readily testable in our experimental design. The propositions, relabeled here as hypotheses 1-3, require successively higher levels of rationality. Hypothesis 1 requires the fourth bidder to choose one strategy from a set of undominated strategies. It can be easily shown that adopting any strategy that does not involve cutting off a previous bidder or bidding 1 must be a dominated strategy.

Hypothesis 1a: The fourth bidder cuts off one of the previous bidders or bids 1.

For example, if the first three bidders submit bids of 100, 600, and 750, the four actions of bidder four that are consistent with hypothesis 1a are 101, 601, 751 and 1. All other strategies are dominated by one of the four strategies above. For example, a strategy of submitting 200 is

[5] In principle, a subject could calculate the current position of a player who cut her off earlier under the assumption that all bidders followed the same rotation. However, there was no way that she could be certain that all players rotated in the same pattern as she did. Furthermore, it would take at least three rotations before players could reasonably conjecture the entire rotation scheme. We used the 1-4-3-2-1

dominated by a strategy of submitting 101. By submitting 200, bidder 4 wins at any price between 200 and 600, a 40.1% chance of winning in the current round in addition to a probability of winning in a future round if the item has to be resold. By submitting 101, bidder 4 wins at any price between 101 and 600, a 50% chance of winning in the current round in addition to the probability of winning by resale.

Each of the four strategies consistent with hypothesis 1a leads to a probability of winning. By picking the lowest number in the right interval, the fourth bidder maximizes his probability of winning. Hypothesis 1b is that the fourth bidder chooses the action that gives the highest expected return for the entire period.

Hypothesis 1b: The fourth bidder chooses the element from the set of four actions listed in hypothesis 1a that maximizes his probability of winning.

In the example in the last paragraph, the probabilities of winning of the four actions are (a) for 101, .5 + .1(prob. of winning on resale), (b) for 601, .2 + .1(prob. of winning on resale), (c) for 751, .25 + .1(prob. of winning on resale), and (d) for 1, .1. Thus the option with the highest expected payoff for bidder 4 would be to bid 101, and hypothesis 1b predicts that 101 would be chosen in the example.[6]:

Hypotheses 1a and 1b require no assumption on bidder 4's beliefs about other players, because bidder 4 is the last mover in the game. Making fairly weak assumptions about the beliefs of the four subjects allows the derivation of some additional theoretical results. Suppose that each

rotation scheme in the Anonymity treatment because it facilitated a direct comparison with the data from sessions 3 and 4, which used the same rotation scheme.

[6] In our theoretical analysis, we maintain the assumption that bidders will choose the same strategies in resale rounds as they did in the initial round, the probability of any given bidder winning the period can be found by the formula $p(Win\$2) = \frac{p(WinCurrentRound)}{1 - p(ResaleRoundOccurs)}$. To see that this is true, consider that if a is the probability that Player 4 wins the current round and b is the probability that nobody wins the current round,

subject has "rational expectations" in the sense that he knows (a) the distribution of the true price of the item, and (b) his probability of winning the prize given his position in the bidding order. Then it can be shown that hypotheses 2a-c must hold.

Hypothesis 2a: The fourth bidder wins at least as often as the third bidder. The third bidder wins at least as often as either the first or the second bidder.

Hypothesis 2b: The fourth bidder wins at least 1/3 of the time.

Hypothesis 2c: The first and second bidders together do not win more than 4/9 of the time.

Proofs of hypotheses 2a-2c are provided by BHV. An outline of the argument is the following. 2a holds because bidder 4 always has the option of cutting off bidder 3 and therefore can always attain at least as great an expected payoff as the third (or any other bidder.) Bidder 3 can always ensure (perhaps by cutting off bidders 1 or 2) the second highest probability of winning, leaving the greatest probability for bidder 4.

To see that hypothesis 2b is correct, consider the following argument. Let y_1, y_2 and y_3 be the probabilities of bidder 4 winning in the *current* round (not including the probability of winning in a resale round) if she cuts off bidders 1, 2, and 3 respectively. This implies that $1 - y_1 - y_2 - y_3$ is the probability of winning if bidder 4 bids at the bottom of the support of possible prices. We assume that bidder 4 optimally chooses a strategy that maximizes her probability of winning the prize awarded in the period. We refer to this probability as p(Win\$2). The optimal strategy for player 4 must satisfy:

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thus forcing a resale round, and if all players chose the same bids on all subsequent resale rounds, then the

$$\max\{p(Win\$2 \mid ResaleOccurs) * (1 - y_1 - y_2 - y_3) + \max\{y_1, y_2, y_3\}, (1 - y_1 - y_2 - y_3)\} \quad \textbf{(1)}$$

The first expression is the probability of winning by cutting off a bidder to maximize over y_j. By adopting this strategy there is a probability $1 - y_1 - y_2 - y_3$ that a resale round will occur. The term $1 - y_1 - y_2 - y_3$ is also the probability of winning by bidding at the bottom of the support of the distribution of possible prices. It follows from (1), that if bidder 4 is maximizing p(Win$2),

$$p(Win\$2) \geq p(Win\$2 \mid ResaleOccurs) * (1 - y_1 - y_2 - y_3) + \max\{y_1, y_2, y_3\} \quad \textbf{(2)}$$

Since the resale round is identical to the initial round, it must be the case that the conditional probability of winning the prize if the resale round is reached is identical to the probability of winning the prize given that the period is in its initial round. Setting p(Win $2) = p(Win $2 | resale) and solving for p(Win $2) yields:

$$p(Win\$2) \geq \frac{\max\{y_1, y_2, y_3\}}{y_1 + y_2 + y_3} \quad \textbf{(3)}$$

Since any maximum over y_1, y_2, and y_3, must be greater than or equal to the average of the three numbers, the above equation implies that p(Win$2) ≥ 1/3. Finally, Hypothesis 2c is a consequence of the fact that bidder 4 wins with at least probability 1/3 which implies that with probability 2/3, one of bidders 1-3 win the period. Bidder 3 must be at least as likely to win as bidders 1 or 2, since it is always possible for bidder 3 to cut off either bidders 1 or 2 in a manner in which bidder 4 would not cut off 3.

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probability of winning the $2 is the infinite series $a + b(a + b(a + ... = a\frac{1}{1-b}$

We will interpret support for hypotheses 2a-2c as a failure to reject assumptions (a) and (b) concerning rational expectations. The methodology of the experiment includes informing the subjects about the distribution of experimenter prices and using physical devices (dice) to convince the subjects that they indeed face a uniform distribution, which represents an attempt to impose assumption (a). Assumption (b), that the subjects correctly anticipate their probability of winning is presumably more and more likely to be satisfied as subjects repeat the process over the course of their session.

Under the assumption that all agents are completely rational and this rationality is common knowledge, the standard assumptions of game-theoretic analysis, then a unique subgame perfect equilibrium can be derived. The equilibrium pattern of bids must have the following properties:

Hypothesis 3:The four bidders bid in descending order. The first three bidders win with probability 2/9 and the fourth bidder wins with probability 1/3.

See BHV for a derivation. For our parameters, in which the price of the item is drawn from a discrete uniform distribution on 1-1000, the actions chosen along the subgame perfect equilibrium path are: bidder 1 bids 779, bidder 2 bids 557, bidder 3 bids 334[7] and bidder 4 bids 1. The rationality assumptions underlying hypothesis three are stronger than those underlying hypothesis 2. Hypothesis 2 merely requires accurate probability assessments, whereas hypothesis 3 requires the rationality and common knowledge of rationality assumptions standard in game theory. Hypothesis 2, in turn requires weaker assumptions on the rationality of agents than does hypothesis 1.

[7] These are the bids along the subgame perfect equilibrium path if the distribution of prices is the discrete uniform on 1-1000.

3.2. Hypotheses about bounded rationality and reciprocity

Hypothesis four asserts the existence of bounded rationality. The hypothesis considers whether subjects acting as bidder 4 have a tendency to increase their propensity to cut off others over the course of the sessions and how they might learn to do so. Hypothesis 4a considers whether the likelihood of optimal behavior on the part of bidder 4 increases with experience. If so, it would indicate that departures from optimal behavior early in the experiment are due to bounded rationality in the sense of BHV, since they dissipate as subjects acquire more experience with the decision situation.

Hypotheses 4b and 4c concern the presence and nature of the learning process on the part of agents and the way subjects learn cutoff behavior. Hypothesis 4b asserts the existence of behavior that is consistent with learning about the optimality of cutting off from the experience of being cut off. The hypothesis claims that subject *i*, after he has been cut off by subject *j*, will be more likely to cut off other subjects (including *j*). Hypothesis 4c asserts that subject *i* is more likely to cutoff subject *j* the more total cutoffs he observes, of himself as well as of any other player, and therefore learns to cut off by observing cutoff behavior.

Hypothesis 4a: The incidence of optimal behavior on the part of bidder 4 increases over time.

Hypothesis 4b: If subject i is cut off by subject j, the likelihood that i cuts off other subjects increases.

Hypothesis 4c: If subject k is cut off by subject j, the likelihood that i cuts off other subjects increases.

Hypothesis 5a asserts the existence of reciprocal cutoffs. According to the hypothesis, subject i is more likely to cut off another subject j the more often j has cut him off previously. This is consistent with revenge for earlier cutoffs. Hypothesis 5b considers whether the lack of cutting off behavior in the game show is related to the lack of anonymity of the decision-makers. Subjects may refrain from cutting off other subjects if they believe that it will increase the probability that they themselves are cut off in the future. If so, under the Anonymity treatment, under which subjects cannot be targeted for reciprocation, one would expect more cutoff strategies to be employed. There is no obvious other reason for the incidence of cutting off to be lower in the Anonymity treatment, since there is no reason for learning about the optimality of cutting off to occur more slowly in the Anonymity treatment than in the Public treatment.

Hypothesis 5a: If subject j cuts off subject i, the likelihood that i cuts off j increases.

Hypothesis 5b: Cutoff strategies are more likely in the Anonymity treatment than under the Public treatment.

In the next section, we report an analysis of the results of the data and characterize the level of support for each of the five hypotheses above.

4. Results

4.1. Tests of Game Theoretic Predictions and Comparison to BHV

Table 1 indicates the percentage of bids that were consistent with hypotheses 1a and 1b for each of the seven groups of four subjects. The bidder 4's bid is optimal in the sense of hypothesis 1a if it cuts off a previous bid or is equal to 1. The bid is optimal in the sense of hypothesis 1b if it maximizes the probability of winning, taking into account the possibility of resale. The data in the third column are the percentage of bidder 4 choices that are less than 50 above another bidder's choice or between 1 and 50. These data account for bids that satisfy hypothesis 1a if a margin of 50 is allowed.

[Table 1: About Here]

The data in table 1 indicate consistency with hypothesis 1a at about the same level as in the data of BHV in the first ten periods of the sessions. In our data bidder 4 cuts off another bidder or bids 1 53.3% of the time compared to 56.5% of the time in the BHV study. The frequency of decisions consistent with hypothesis 1a increases over to time to 73.3% in the last 10 periods. However, we obtain strong support for hypothesis 1a, if an interval of 50 is allowed, other than in session four. The second column comprises at most 20% of the possible bids but accounts for 84% of the total observations. In the last 10 periods, 98.7% of all bids are less than 50 points greater than some other bidder's bid or within 50 points of the lower bound of 1 (if session 4 is excluded). It appears that by the last 10 periods, bidder 4 clearly understands that it is optimal to submit a cutoff bid or 1, though there appears to be some reluctance to bid the minimum increment higher than another bidder.

There is also some support for hypothesis 1b, suggesting that bidder 4 can calculate his best response, even taking into account the case in which all bidders overbid and lead to a reauctioning of the item. Consistency with hypothesis 1b increases over time, so that in the last 10 periods of the sessions, bidder 4 makes an optimal decision more than 45% of the time, far greater than the 29% in the first ten periods of the sessions. This increase over time is consistent with the presence of boundedly rational behavior at the beginning of the session, as bidders' decisions improve over time. The dynamics of behavior over time are explored in more detail in the next subsection.

It is instructive to study those observations satisfying 1a but not 1b. 81.77% of these differences are due to bidding too low a number and only 18.23% are due to bidding too high a number. In 60.71% of the instances of bidding too low, bidder 4 suboptimally bids 1, suggesting either a failure to take into account the resale rounds or reluctance to cut-off other players.

The data in table 1 clearly indicate that the incidence of optimal behavior was much different in session 4 than in the other sessions. Bidder four followed optimal behavior in only 1.8% of the rounds. Only once in the entire session did bidder 4 cut off another bidder (the other optimal bids in the sense of hypothesis 1a were all bids of 1). The fact that the first subject in the position of bidder four made only one cut-off bid out of 10 opportunities may have led to positive reciprocation on the part of the other three subjects when they were placed in the position of bidder 4 later in the session. We explore the existence of reciprocal behavior in the next subsection.

Table 2 shows the winning percentage by bidder and allows us to consider the level of support for hypothesis two. The table indicates considerable support for Hypotheses 2a-2c. The frequencies are very close to those obtained by BHV. In the pooled data for the seven groups, the fourth bidder wins more often than the other three bidders and bidder three wins more often than bidders 1 and 2. The fourth bidder wins well over 1/3rd of the time and the first and second bidders combined win less than 4/9ths of the time. The fourth bidder is in a position to exploit any departures from the subgame perfect equilibrium to his advantage. The support for hypotheses 2a-2c is consistent with the assumption that subjects have unbiased estimates of their probability of winning the game given their position in the bidding order.

[Table 2: About Here]

Table 3 shows the frequency of each possible ordering of the magnitude of bids in a single round, from greatest to least. The subgame perfect equilibrium ordering is 1234; bidders bidding in descending order. The data in the table reveal that hypothesis 3 is firmly rejected in our data, as it is in the empirical analysis of BHV. Bidders rarely ever bid in descending order, as they would in the subgame perfect equilibrium. The frequencies are remarkably close to those reported by BHV, as shown in table 3. Only 1.69% of the time is the bidding order the one predicted in the subgame perfect equilibrium, and in no period did all four bidders use the subgame perfect equilibrium strategy profile. In our data, as well as the data of BHV, each of the 24 possible orderings occurs in at least 1% of the rounds, representing a remarkable degree of variability in outcomes.

[Table 3: About Here]

The modal ordering in our data is 1432. Bidder 1 bids a high number, apparently to reduce his chance of being cut off (751 was the most common "safe" bid. This bid would be player 1's bid in a subgame perfect equilibrium if no resale rounds were possible.) The remaining three bidders then submit bids in *ascending* order, which is exactly the opposite of the game-theoretic predictions. The second most common ordering in our data, which is also the modal ordering in the BHV study, is 4321. Thus, we observe some tendency for bidders to submit bids in ascending order, with the frequent exception of bidder 1, who appears to often bid defensively against potential cutoffs by the other three bidders.

4.2 Bounded Rationality and Reciprocity

As noted earlier, the fact that the incidence of optimal behavior on the part of bidder 4 is increasing over time suggests a bounded rationality explanation to the suboptimal behavior of bidder 4. He "learns" over time to cut other bidders off. However, a first glance at the data from session four also suggests that reciprocity may play a role. In session four there were almost no cutoffs observed at all in the entire session. In this subsection, we report the results of regression estimations that isolate these two potential explanations of the changes in the incidence of cutoff behavior over time and that test hypotheses 4 and 5. In each of the regressions, the dependent variable c_t^{ij} equals 1 if subject *i*, who has the role of bidder 4 in period *t*, cuts off subject *j* in period *t*. c_t^{ij} equals 0 if *i* does not cut off *j* in *t*. The following variables were used in these regression equations:

CutoffsExperienced = # of times the subject currently acting as bidder 4 has been cut off between periods 1 and *t-1* (inclusive).

CutoffsObserved = Total # of cutoffs that have occurred in the session between periods 1 and *t-1* (inclusive).

Period = # of periods that have already elapsed in the current session.

CutoffByJ = Total # of times that subject *j* cut off subject *i* before the current period.

Optimal = 1 if cutting off subject *j* is the optimal decision for player *i* given the bids of the first three players, and equals 0 otherwise.

$$c_t^{ij} = \beta_0 + \beta_1 CutoffByJ + \beta_2 CutoffsExperienced + \beta_3 CutoffsObserved + \beta_4 Period + \beta_5 Optimal \quad \textbf{(4)}$$

Equation (4) considers the determinants of the increase in cutoff behavior that are consistent with a reduction in bounded rationality over time, and is estimated for the data from the Public treatment. A positive coefficient on the variable *CutoffByJ* in (4) would indicate the presence of reciprocity, since it would reveal that players are especially likely to target players who cut them off for reciprocation. Since the variable *CutoffsExperienced* is included in the equation, the coefficient on *CutoffByJ*, measures additional propensity to reciprocate cutoff behavior over any overall effect from being cut off by any player. A positive coefficient on

CutoffsObserved would indicate that subjects who observe more cutoffs are more likely to cut off others later on. A positive coefficient on the variable *CutoffsExperienced* would indicate an additional tendency for players to respond to being cut off by adopting cutoff behavior themselves, in addition to the effect of *CutoffsObserved.* A positive coefficient on *Period* would indicate that there is a trend over time not explained by the two other variables, and would suggest an increase in cutoff behavior related purely to deductive reasoning independent of cutoffs observed or experienced. A positive coefficient on *Optimal* would indicate that i is more likely to cut off j when it is his best response to do so.

The next equation (5) is estimated to study the presence and nature of reciprocal behavior in the data. The data from both treatments are used in the estimation. The variable *Anonymous* in (5) is a dummy variable that equals 1 under the Anonymity treatment and 0 under the Public treatment. The equation measures the effect of anonymity on the incidence of cutoffs. A positive coefficient on *Anonymous* would suggest that players are more willing to cut off when they can not be observed, due to anticipated reciprocal actions on the part of others or to a social sanction against cutting off other players.

$$c_t^{ij} = \beta_0 + \beta_1 Period + \beta_2 Anonymous + \beta_3 Optimal \quad \textbf{(5)}$$

In table 4 we also report estimates of equations (4')-(5'), which are identical to (4)-(5) except that the data from session 4 (in which almost no cutoff behavior was observed) are removed. Equations (6) and (6') are slightly different specifications of (4) and (4') which consider the robustness of the estimates obtained in (4) and (4') by omitting the variable Period.

[Table 4: About Here]

The estimates from all of the equations are given in table 4. All of the equations show a highly significant coefficient on the variable *Optimal*, and the coefficient on *Optimal* has a magnitude of at least 34% in all of the estimations. This means the probability of i cutting off j was at least 34% higher if i maximized his payoff by doing so.

The variable *Period*, which measures any change in the tendency for cutoff behavior over time, is significantly positive in equation (5) and (5'). This verifies that cutoff behavior is increasing over time. The estimates of equation (4) show that *CutoffsExperienced* and *CutoffByJ* are not significantly positive, but that *CutoffsObserved* is positive and significant. The lack of significance of these two variables indicates that individuals do not cut off in response to being cut off themselves. They do not learn to cut off from the experience of being cut off. Instead, they respond to all cutoffs, experienced or observed, by increasing their propensity to cut off in later periods by the same magnitude.

The Anonymity treatment encourages cutoff behavior as evidenced by the significant coefficient on the variable *Anonymous* in (5) and (5'). However, the variable *CutoffByJ* is significantly negative at the 5% level in all of the equations in which it is estimated. The ability to conceal decisions increases the amount of cutoff behavior, even though cutting off others does not cause the player who has been cut off to reciprocate. This suggests that the real penalty from being observed cutting off others is not being cut off in return, but rather a non-monetary social sanction from being identified as taking unreasonable advantage of one's position as last mover.

5. Discussion

The data from our experiment demonstrate the extent to which the laboratory can attain parallel outcomes with corresponding field data. In this study, we replicate the patterns in the data from the television game show analysed by BHV. We find that at the beginning of our sessions, the incidence of cutoff behavior is roughly the same as in the BHV study. In both studies, the proportion of cutoff bids increases as the game is repeated. The probability of a player winning the prize given his position in the bidding order is very close in the two studies. We also reproduce the very diffuse results observed by BHV on the order of bids. In our view, the similarity of our results with those observed in the field is remarkable when one considers that the average value of the items bid for on the game show is several hundred times greater than the two dollar prizes in our experiment. This provides an illustration of how the monetary payments in experiments such as ours can be sufficient to induce the same decisions as would result with much larger payments.

In our data, the subgame perfect equilibrium was not an accurate predictor of the actual bids. However, many other properties that are consistent with rational behavior are observed in the data. Player four has an increasing tendency to cut off other players over time, indicating that subjects are learning over time to play optimal strategies. The probabilities of winning are consistent with unbiased estimates on the part of subjects of the probability of winning given their position in the bidding order. This is consistent with the interpretation that bidder 4 recognizes that cutting off or bidding 1 is optimal (though they may not actually cut off due to the cost of being observed doing so). Players also recognize that bidder 4 is in the most advantageous position, followed by bidder 3, and take this into account. However, the common knowledge that subsequent players will play optimally, which must be present on the part of all players to attain the subgame perfect equilibrium, appears not to be present. Players do not have confidence that later movers will backward induct, and so have no reason to backward induct themselves.

The simplest decision situation is that of bidder 4, who does not have to perform a backward induction. However, he does have to reason forward and take into account the consequences of affecting the probability the game reaches the resale round. Some of the suboptimal behavior of bidder 4 (about 23%) may be due to a failure to properly take into account the possibility of reauctioning the item. This is measured by the number of bids equal to 1 on the part of bidder 4 when cutting off one of the others was optimal, as a fraction of the total number of suboptimal plays by bidder 4. However, many bids still involved neither bidding 1 nor cutting off another player, and these departures from equilibrium play cannot be explained by failure to account for the possibility of resale in player 4's calculations.

Over time, the incidence of optimal decision-making increases. The dynamics are similar to those documented by BHV. Subjects' probability of cutting off other players increases the more cutoffs they observe. This pattern is consistent with learning that cutting off or bidding 1 is optimal by observing others' cutoffs. There is no additional effect on the propensity of a player to cut off from having *been* cut off rather than having *observed* a cutoff. The data from session four illustrates how a pattern of behavior in which players do not cut off others can arise and be maintained. An initial failure to cut off can cause a reaction where *all* players refrain from cutting off *any* other players, not just the player or players who refrained from cutting off at the beginning. This failure to cut off occurs through observation rather then reciprocation.

More generally, we replicate the observation of BHV that the probability of being cutoff is not greater for players who cut others off than of players who do not. We find no evidence of targeted reciprocal behavior at the individual level. However, we found that cutoffs were more likely to occur when players could not be associated with their actions. This indicates that players perceived a cost to being observed cutting off other players or a benefit of being observed not cutting off players when presented with an opportunity to do so. This effect would not have been observed in the BHV study, in which the ability to associate players to their actions could not be varied. It suggests that other-regarding behavior does indeed manifest itself in this game, as it does in so many previous experimental studies of games.

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Table 1: Percentage of Bids Consistent with Hypotheses 1a and 1b

Session	Percent of bids optimal in the sense of Hypothesis 1a	Percent of bids optimal in the sense of hyp. 1a (within 50)	Percent of bids optimal in the sense of Hypothesis 1b
1	76.2	98.3	42.3
2	100	100	66.7
3	63.4	90.5	36.5
4	10.7	25	1.8
5a	75.9	91.3	39.7
5b	86.7	96.7	58.3
5c	75.8	86.2	48.3
Pooled Data	69.8	84.0	41.9
Final 10 Periods (All Sessions)	73.3	87.2	46.5
Final 10 Periods (Ses.4 Excluded)	82.3	98.7	54.7
First 10 Periods (All Sessions))	53.3	77.3	29.30
Berk et al	56.5	N/A	N/A

Table 2: Winning Percentages by Player

Session	1st Player	2nd Player	3rd Player	4th Player
1	14	8	34	44
2	24	22	14	40
3	14	20	18	48
4	26	20	16	38
5a	18	18	14	48
5b	10	20	36	34
5c	12	25	14	51
Pooled Data	16.7	19.4	20.9	42.9
Last 10 Pers. (Pooled Data)	21.4	17.1	24.3	37.1
Berk et al.	19.4	18.2	22.8	39.5
Equilibrium	22.2	22.2	22.2	33.3

Table 3: Bidding Order Percentages

Bidding Order*	Occurrence Frequency (Experiment)	Berk et al. (Percent)
(Descending)	(Percent)	
1234	1.69%	3.76%
1243	7.00%	2.42%
1324	2.42%	4.84%
1342	4.35%	2.69%
1423	5.31%	3.76%
1432	9.90%	3.23%
2134	3.14%	2.96%
2143	6.04%	4.30%
2314	1.45%	2.69%
2341	1.45%	2.69%
2413	3.14%	1.34%
2431	3.62%	4.03%
3124	3.86%	4.30%
3142	4.35%	3.50%
3214	3.86%	6.99%
3241	3.62%	3.76%
3412	2.17%	2.96%
3421	4.35%	4.57%
4123	3.38%	4.57%
4132	6.28%	3.76%
4213	3.62%	5.91%
4231	2.90%	3.23%
4312	4.35%	5.65%
4321	7.73%	12.10%

* The numbers are given in descending order. For example 2314 means that player 2 (the bidder that moved second), made the highest bid. Player 3 made the second highest bid, etc…

Table 4: Estimates of Models of Cutoff Behavior

Equation and data used	Constant	Optimal	Period	Anonymous	Cutoff By J	Cutoffs Experienced	Cutoffs Observed	R^2
(4)Public treatment	.0321 (.0271)	.4003 (.0268)	-.0045 (.0012)	---	-.0144 (.0061)	.0001 (.0051)	.0091 (.0015)	.297
(5)Both treatments	-.0132 (.0217)	.5393 (.0219)	.0012 (.0006)	.1120 (.0188)	---	---	---	339.
(6)Public treatment	-.0400 (.0197)	.3971 (.0270)	---	---	-.0144 (.0061)	-.0039 (.0051)	.0075 (.0014)	.282
(4')Pub.exc. session 4	.0285 (.0370)	.5395 (.0331)	-.0027 (.0037)	---	-.0127 (.0064)	.0013 (.0056)	.0058 (.0033)	.350
(5')Both.exc. session 4	.0718 (.0295)	.3441 (.0324)	.0022 (.0009)	.0637 (.0249)	---	---	---	.101
(6') Pub.exc. session 4	.0110 (.0280)	.5394 (.0331)	---	---	-.0127 (.0064)	.0005 (.0054)	.0037 (.0017)	.349

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