THEORY AND MISBEHAVIOR OF FIRST-PRICE AUCTIONS: THE IMPORTANCE OF INFORMATION FEEDBACK IN EXPERIMENTAL MARKETS

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Abstract

This article reports the results of a market experiment designed to test the predictions of the constant relative risk aversion model and to study the importance of information feedback in repeated first-price sealed-bid auctions. The data reveal that introduction of price information feedback implies a significant change of individual behavior. Without price information feedback, the data support the risk neutral Nash equilibrium prediction; with price information feedback, on the other hand, subjects overbid the risk neutral Nash equilibrium significantly. The constant relative risk aversion model is rejected since it predicts overbidding for both feedback conditions.

***Keywords*: Experimental Economics, First-price Sealed-bid Auctions, Independent Private Value Model, Bidding Theory, Risk Aversion**

***JEL Classifications:* C12, C13, C72, C92, D44**

I Introduction

There is an ongoing debate whether the constant relative risk aversion model (hereafter CRRAM) of Cox, Smith and Roberson [4] can explain the overbidding pattern observed in repeated experimental markets of first-price sealed-bid auctions (hereafter FPA). Harrison's [18] methodological critique set off the controversy, which Friedman [17, p. 1374] coined the "loudest debate amongst experimentalists ever heard," involving five publications in September 1992 [13], [17], [19], [21], [23].

Recently, Neugebauer and Selten [25] reported that information feedback has a crucial impact on behavior in experimental FPA markets with computerized competitors. In two of their three treatments, underbidding was more frequently observed than overbidding, violating the predictions of CRRAM. Ockenfels and Selten [26] and Isaac and Walker [20] reported also treatment effects due to variation in the information feedback conditions, though they did not find underbidding.

In this article, we report the outcomes of an interactive experimental FPA market designed to show that due to changes in the information feedback conditions both underbidding and overbidding can emerge. The experiment applies a within-subjects variation and involves markets with and without price information feedback. According to CRRAM, a change of information feedback should not cause any behavioral change. In marked contrast to this, the data document a significant structural change of bidding behavior: Without information feedback, subjects may not overbid relative to the risk neutral equilibrium, but the same subjects overbid if they receive information feedback about the high bid in the market.

The bottom line to this evidence is that behavior in repeated experiments is adaptive to feedback conditions. Hence, all equilibrium concepts which do not take the information feedback conditions into account are necessarily violated. We conclude that theoretical behavioral theories of finitely repeated games are needed that adapt to information and presentation effects.

The paper is organized as follows: the next sections review the risk neutral model, CRRAM and the related literature. Thereafter, the experimental design is outlined and the results are reported. The last section concludes.

II Risk Neutral Nash Equilibrium

Assume $N>2$ bidders attend a market in which a single object is auctioned. Every bidder i, $i=1,..,N$, has a private valuation which is represented in the resale value denoted by $x_i \geq 0$. Resale values are independently drawn from a uniform distribution over the unit interval. Assume the first-price sealed-bid auction rule is applied such that every bidder submits a sealed-bid and the high bidder wins the auction and pays his bid. Vickrey [30] showed that, if bidders are risk neutral, there exists a unique symmetric Nash equilibrium (hereafter RNNE), in which bidders bid a constant fraction of their value, such that

$$b^*(x_i) = \frac{N-1}{N} x_i, \forall i = 1,..,N. \qquad (1)$$

The RNNE strategy can be interpreted as the bid which is equal to the bidder's expectation about the second highest resale value given that this value is

smaller than his own. The strategy constitutes a best response only if all other market participants use the same strategy.

A first experimental test of the RNNE was conducted by Coppinger, Smith and Titus [3]. One of their main findings was that subjects overbid the RNNE in repeated first-price sealed-bid auctions. Since, this observation has been replicated in various other experimental markets.

III Constant Relative Risk Aversion Model

In response to the observed "overbidding" regularity, Cox et al. [4] offered the explanation that subjects bid more aggressively than predicted by the RNNE because they are risk averse. In particular they proposed that individuals face risk preference parameters independently drawn from the unit interval. Given that all risk preference parameters are drawn from the same distribution and each agent *i* knows her own risk preference parameter, denoted by r_i ($(1-r_i)$ being her Arrow-Pratt constant relative risk aversion), the equilibrium bidding strategy of the constant relative risk aversion model (hereafter CRRAM) writes as

$$b(x_i) = \frac{N-1}{N-1+r_i} x_i, \forall i = 1,..,N. \qquad (2)$$

IV Related Literature

From CRRAM stems a huge literature: To start with, Cox et al. [4], [5], [6], [7], [8], [9], [10], [11], [12], [13] tested CRRAM and refined the model. Other studies provided some support for the constant relative risk aversion hypothesis, e.g., Chen and Holt [14] in an experiment with non-uniform resale values,[1] Goeree,

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[1] Chen and Plott [14] tested several models and reported that their sophisticated ad hoc model fits the data better than the CRRAM.

Holt and Palfrey [15] applied the quantal response equilibrium model to the data and reported significant constant relative risk aversion.

Violations of CRRAM were reported in Selten and Buchta [28] who found that subjects do not use constant bid functions but change their behavior in an adaptive way. Neugebauer and Selten [25] provided further evidence for the impact of price information feedback on learning and behavior of experimental markets. Facing a value of 100, their subjects competed in a transformed auction game with *N*-1 computerized competitors whose bids were randomly drawn from the interval [0,100]. Subjects who received price information feedback overbid the RNNE, whereas underbidding occurred in the other two experimental treatments. In one of them, feedback was limited to qualitative information about winning the auction or not. In the other one, both the price and the competitors' high bid were always revealed. These findings contradict to CRRAM, since it predicts the same outcome for either feedback condition. Also, the data of Isaac and Walker [20] and Ockenfels and Selten [26] suggest an impact of information feedback on behavior. Both studies involved treatments in which high-bid information feedback and all-bids information feedback were contrasted. The latter treatments induced significantly lower bids.

The experimental task presented in Neugebauer and Selten [25] is individual choice only, since the other bidders are robots. In this paper, we present a study of interactive play and check for the robustness of the observed information effect in a more natural setting. The experiment has been designed to show that subjects in FPA markets may not necessarily bid above the RNNE if they do not receive price information, but that the very same subjects overbid when price information feedback is given.

V Experimental Design

We ran a computerized experiment at the Centre for Experimental Economics (EXEC) at the University of York in November 2001.[2] A total of 28 subjects participated in one of the two sessions of the experiment. They were first year students from different fields and had never participated in any auction experiment before. The recruitment procedure followed standard announcement by mail shot and subjects enrolled themselves electronically over the Internet.

At the beginning of the experiment, subjects were given written instructions and time to read them carefully; then the experimenter read it to them. Eventual questions were answered by re-reading the corresponding sentences in the instructions. Afterwards, participants were introduced to the simple interface on their computer-monitors.

At the beginning of the experiment, the computer assigned participants randomly to one of two experimental auction markets. Each market consisted thus of a given set of seven subjects who competed in 100 auction rounds with one another. At the beginning of each of these auction rounds private values were independently drawn from a uniform distribution over the interval from 0 to 100 and were rounded to the next integer. Given their value, subjects had to submit a bid that could be a positive integer at or below their value.[3] According to the first-price auction rule, the high bidder paid a price equal to

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[2] The software was produced by means of Fischbacher's [16] z-tree.

[3] This limitation was introduced to omit the implementation of bankruptcy rules. However, eventual bidding above the resale value is of no interest in this study.

her bid. In case of a tie, the winner of the auction was selected at random among the high bidders.

[INSERT FIGURE 1 ABOUT HERE]

We used within-subject variation (see Figure 1). The treatment variable was information feedback, in particular, price and payoff information (denoted by p_t and π_{it}, t = 51, 52, .., 100 and i= 1, 2,..., 7, respectively). In the first 50 auction rounds, subjects did not receive any information feedback. Only in the second 50 auction rounds, price and payoff were revealed to subjects after each round. All past observations, including bids and values, and prices and payoffs (from round 51 on) were recorded in a table on a subject's monitor. At the end of the experiment, subjects were asked to write a recommendation of how to bid in the auction. Thereafter they had to tick one of seven boxes in a row to self-assess their inclination towards risk (from "risk averse" labeled at the utter left to "risk loving" at the utter right). Finally they filled out a questionnaire providing their personal data. Each of these queries was made successively on a different screen. Afterwards they were paid in private their cumulative payoff plus an additional show up fee of 3£.[4]

VI Experimental Results

In what follows we report the results from our experimental study. We first give an overview over the data in Table 1 and report non-parametric tests. Thereafter, we estimate bid functions using standard econometric techniques and test for a structural change of behavior when price information feedback is introduced.

[4] The average payoff was £9 Sterling; the experiment was completed within an hour.

In the RNNE, subjects bid a fixed share of their resale value, in particular $b^*(x) = 6x/7 \approx 0.857\ x$. Table 1 records the deviations of the individual (average) bid-value ratio from the RNNE prediction. For instance, subject 1's bid-value ratio exceeded the RNNE by 3.0% in the first period (column 1) since she bid 88.7% of her value. On average, her bid-value ratio was 0.6% below the RNNE in treatment T0 (column 2), and 7.9% below the RNNE in treatment T1 (column 3). Hence, her average bid-value ratio decreased from T0 to T1 by 7.3%; the negative sign in the fourth column of Table 1 reveals the decline. In the fifth column of Table 1, we report the results of the questionnaire in which subjects were asked to state their self-assessed risk preference. The scale of risk preference ranges from -3 (risk loving) to 3 (risk averse), zero representing risk neutrality.

From the Wilcoxon signed ranks test, reported in the lowest row of Table 1, we deduce the following: First, overbidding is not supported by the data from T0, neither in the first period of the experiment (first column) nor on average (second column). On average, the bid-value ratio is 3.0% below the RNNE, the 95% confidence bands extend from -5.7% to -0.2% relative to the RNNE indicating underbidding rather than overbidding. Second, observed bidding exceeds the RNNE significantly in T1 (third column).[5] In T1, 71.4% of subjects' average bids exceed the RNNE, contrasting with 32.1% in T0. Finally, as recorded in the fourth column of Table 1, subjects did significantly increase their bid (relatively to their value) from treatment T0 to T1.

[INSERT TABLE 1 ABOUT HERE]

[5] However, in the first period of T1 overbidding is not supported; the bid-to-value ratio in period 51 averaged 0.7 percent below the RNNE.

The result on non-overbidding in T0 is corroborated by examining the dynamics of the average difference between the bid-value ratio and the RNNE. In Figure 2 these deviations are plotted on time. In T0 we observe for the first 22 periods underbidding and thereafter we observe 14 times over- and underbidding. The sequence of under- and overbidding over the last 28 periods is non-systematic as a runs test indicates (p>.5) suggesting that subjects bid as if risk neutral up to an error term in these periods. In contrast to this, overbidding is four times as likely as underbidding in T1. We summarize our findings as follows.

Observation 1: Subjects overbid the RNNE in a market with seven bidders significantly only if information feedback is supplied.

The reported evidence may be also tested by implementing regression techniques which exploit efficiently the panel structure of the data provided by the experiment. Figures 3A and 3B depict the RNNE bid (dashed lines) and the fitted bid functions (continuous lines) for both treatments, i.e. T0 and T1. The bid functions were estimated by Generalized Least Squares and under the standard assumptions of the random effects model. The fitted bid functions for the treatments T0 and T1 are given in equations (3A) and (3B) respectively. The standard errors for both the slope and the intercept are given in parentheses and the asterisk indicates that the corresponding parameter is significantly different from zero at 1% confidence level.

$$\hat{b}_{it} = -1.320 + 0.874\, x_{it},\ t \in \{1,50\},\ i = 1, 2, \ldots, 28,\ R^2 = 0.921$$

$$\quad (.846) \qquad (.006)^{*} \qquad\qquad \text{(std. deviation)} \qquad (3A)$$

$$\hat{b}_{it} = -0.783 + 0.926\, x_{it},\ t \in \{51,100\},\ i = 1, 2, \ldots, 28,\ R^2 = 0.967$$

$$\underset{(.501)}{}\quad \underset{(.004)^*}{} \qquad \text{(std. deviation)} \qquad (3B)$$

[INSERT FIGURES 3A AND 3B ABOUT HERE]

These estimates confirm once again different behavioral patterns for both treatments, since the slope of the bid function for treatment T1 is greater than the one for treatment T0. In order to test this potential structural change we rewrite the bid functions for both treatments by using a treatment dummy variable, D_{1t}, such that $D_{1t} = 1$ if $t \in \{51, 100\}$ and $D_{1t} = 0$, otherwise. The estimates for the resulting model are embodied in the Eq. (4).

$$\hat{b}_{it} = -1.397 + 0.510\, D_{1t} + 0.875\, x_{it} + 0.053\, D_{1t}\, x_{it},\ t \in \{1,100\},\ R^2 = 0.921$$

$$\underset{(.632)}{}\quad \underset{(.435)}{}\quad \underset{(.005)^*}{}\quad \underset{(.008)^*}{} \text{(std. deviation)} \qquad (4)$$

Note that the coefficient of the product of dummy variable and value, $D_{1t}\, x_{it}$, indicates a significant change in the slope of the bidding function from treatment T0 to T1. Hence, the data support the following statement.

Observation 2: A significant structural change of bidding behavior is observed when information feedback is introduced.

This observation confirms that subjects take reference in the observed high bid.[6] In fact, Figure 2 suggests that an introduction of information feedback

[6] Selten and Buchta [28] and Neugebauer and Selten [25] found support for such a causal relationship via learning direction theory – a qualitative learning theory which goes back to Selten and Stoecker [29].

has an immediate effect, since in T1 overbidding is predominant from the second period on.[7]

VII Conclusion

In this paper we have tested the conjecture that subjects in first-price sealed-bid auctions behave according to CRRAM of Cox et al. [4]. We have reported the results of a laboratory study which uses within-subjects variation in an experimental market with seven bidders. Information feedback conditions varied between two treatments and caused a significant behavioral change. Without price information feedback, we observed no overbidding relative to the risk neutral equilibrium prediction. When information feedback was introduced, a significant structural change of bidding behavior occurred resulting in significant overbidding. Since the theoretical Nash equilibrium prediction remains unchanged, our data do not support CRRAM. Whether the same results can be obtained for markets with more or less bidders remains an open research question.[8]

[7] Interestingly, subjects' statements in their ex-post experimental questionnaire are to some degree in line with this conjecture: significantly more subjects than expected by chance evaluated the introduction of price information feedback as positive. Regarding the remaining data gathered by means of the questionnaire, the following remarks can be made: 1) subjects' stated average self-assessment of risk aversion was in support of risk neutrality ($p>.05$). 2) No significant correlation between the stated self-assessment of risk aversion and the individual average bid could be observed in either treatment; in marked contrast to this, the CRRAM assumes bidders to be risk averse and to know their risk preference parameter ($p>.1$). 3) No significant correlation of overbidding and gender or age could be found, either ($p>.1$). However, no salient rewards were linked to these answers and, thus, truthful response cannot be taken for granted.

[8] The data of Neugebauer and Selten [25] insinuate that subjects' bids could be above or below the RNNE depending on the number of market participants. Bidding behavior in their study appeared to be guided to some extent by focal points, such that for smaller markets subjects rather overbid while for greater market sizes underbidding was more frequent.

The lesson learned from our study is that feedback conditions can have a crucial impact on behavior in the laboratory. This must be taken into account by experimentalists and by theorists. Experimentalists are asked to study information feedback conditions systematically. Theories which take information variation into account must be developed in order to survive the laboratory test in the repeated setting. However, it is not the objective of the present work to propose a new theory. In fact, Selten's [27] impulse balance theory (see also [25] and [26]) is a recent approach of an information feedback oriented equilibrium concept as predictions change when information conditions are varied.[9] **Impulse balance theory makes quantitative predictions on the long run behavior of learning dynamics. The understanding on the impact of information feedback might be relevant also for the behavior in empirical markets. For instance, identical lots are frequently knocked down at the same price in real world sequential auction markets (see [1]).**[10] **Standard theory cannot explain this incident.**

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[9] Theoretical approaches which incorporate different information presentations might be relevant also. For instance, several theories have recently emerged in the context of individual decision making that take presentation effects into account ([2] and [22]). Birnbaum [2] reports that these theories have been the only ones that survived experimental testing.

[10] Ashenfelter [1] was rather concerned with the frequency of price declines compared to increases in sequential auctions. Nevertheless, more than 60% of consecutive lots in his sample were sold at the same price. The independent private value model predicts that prices follow a martingale and thus does not explain this observation. Experimental studies on sequential first-price sealed-bid auctions are reported in Neugebauer [24].

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Table 1. Differences of Individual Bid-Value Ratios from the RNNE

Market	ID	1. First period-RNNE	2. Average T0-RNNE	3. Average T1-RNNE	4. Average T1-Average T0	5. Risk-aversion
		$\frac{b_1}{x_1}-\frac{b^*}{x}$	$\frac{\bar{b}}{x}(T0)-\frac{b^*}{x}$	$\frac{\bar{b}}{x}(T1)-\frac{b^*}{x}$	$\frac{\bar{b}}{x}(T1)-\frac{\bar{b}}{x}(T0)$	Subjects' self-assessment c)
1	1	0.030	-0.006	-0.079	-	3
	2	-0.133	0.005	-0.014	-	0
	3	0.066	0.055	0.018	-	1
	4	-0.657	-0.156	0.082	+	1
	5	-0.368	-0.196	-0.125	+	-2
	6	-0.048	-0.013	-0.021	-	-1
	7	0.029	-0.003	-0.047	-	-3
2	8	-0.357	-0.049	-0.073	-	0
	9	-0.057	-0.074	-0.095	-	-1
	10	0.020	-0.081	0.026	+	-2
	11	-0.024	0.046	0.097	+	-2
	12	-0.168	0.034	0.092	+	1
	13	-0.835	0.041	0.013	-	-1
	14	0.119	0.060	0.072	+	-1
3	15	-0.064	-0.116	0.029	+	-2
	16	-0.190	-0.003	0.052	+	1
	17	-0.006	-0.057	0.088	+	1
	18	-0.087	0.018	0.062	+	-1
	19	-0.237	-0.018	0.064	+	-2
	20	-0.116	0.067	0.100	+	-1
	21	-0.024	0.049	0.085	+	1
4	22	-0.374	-0.171	0.118	+	-2
	23	-0.289	-0.066	-0.029	+	-3
	24	-0.151	-0.023	0.073	+	1
	25	0.106	-0.062	0.017	+	-2
	26	-0.075	-0.026	0.001	+	-1
	27	-0.143	-0.095	0.036	+	1
	28	0.143	0.014	0.007	-	1
average		-0.139	-0.030	0.023	0.053	-0.536
confidence		-0.225	-0.057	-0.002	0.020	-1.128
Band 95%		-0.052	-0.002	0.048	0.085	0.056
Z		-3.063	-1.844	1.867	3.029	-1.938
p-value		0.999 a)	0.967 a)	0.031 a)	0.002 b)	0.053

Note: a) Asymptotic result of a one-tailed Wilcoxon signed ranks test; H_0: $b/x \leq b^*/x$, H_1: $b/x > b^*/x$. Positive values indicate overbidding, negative ones indicate underbidding. b) Asymptotic result of a two-tailed Wilcoxon signed ranks test. c) Subjects' stated self-assessment of risk aversion scaled from -3 (extremely risk loving) to 3 (extremely risk averse); zero implies stated risk neutrality.

Figure 1. Treatment Overview

	T0	T1
Information feedback	-	p_t, π_{it}
Period	1 – 50	51 – 100

Figure 2. Deviations from the RNNE on time

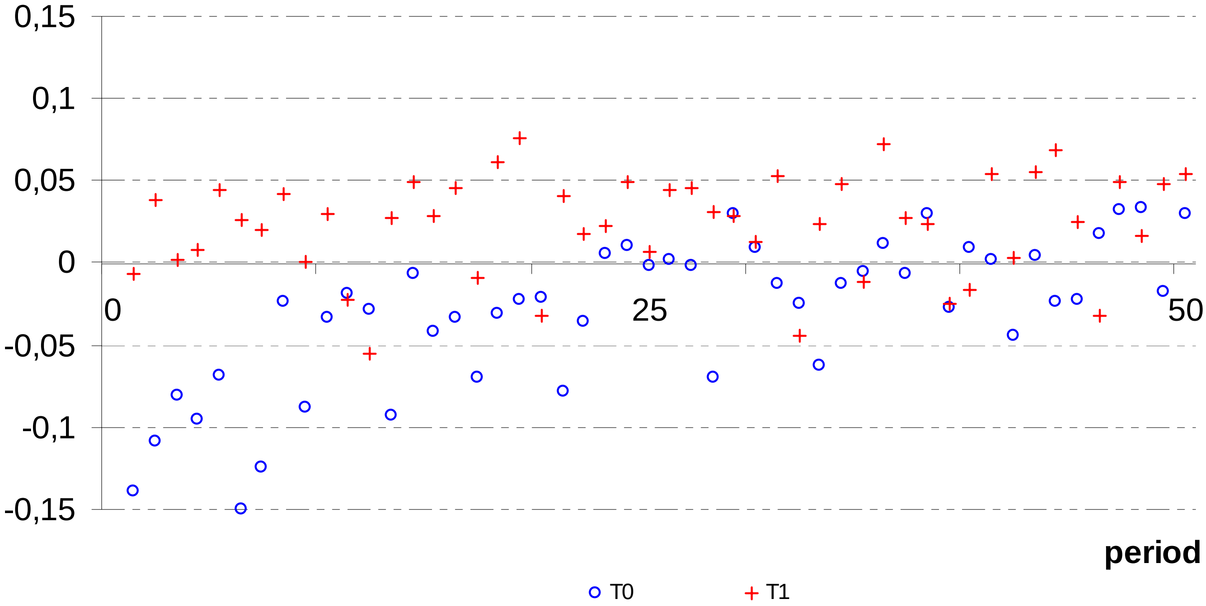


Figure 3A. Random Effect Model: Bid Function Estimate Treatment T0

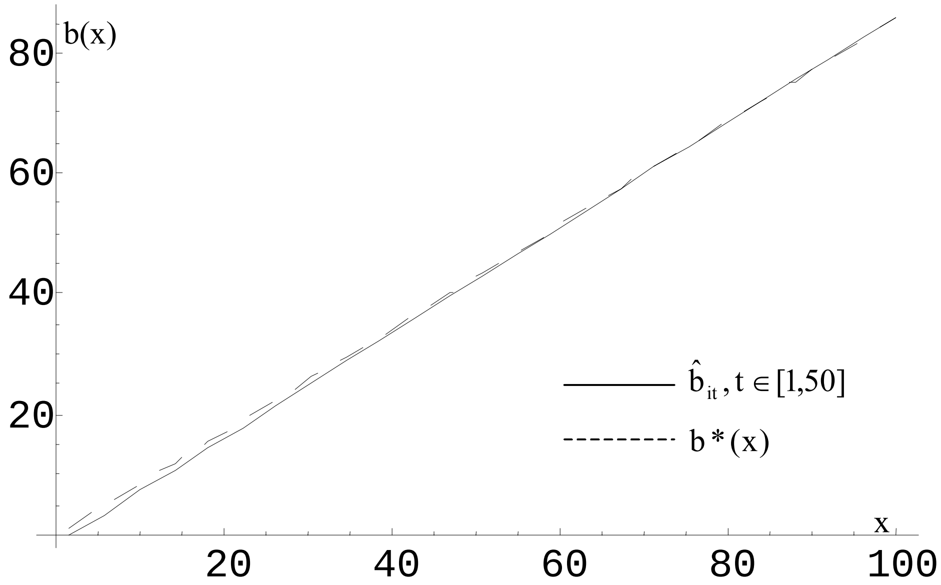
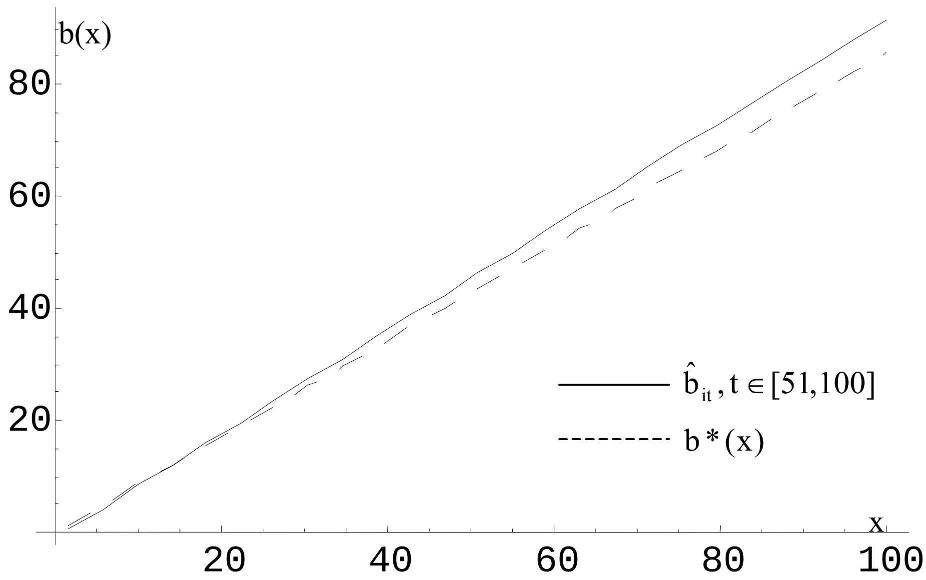


Figure 3B. Random Effect Model: Bid Function Estimate Treatment T1



Instructions

General Information

1. You are about to participate in 2 x 50 rounds of an auction experiment. In each of these rounds, you will be assigned to a group of 7 bidders: yourself and 6 other participants. Your group will stay the same throughout the experiment. However, you will not receive any information about the identity of the other group members.

2. In each of the 100 rounds, 1 fictitious item will be sold and you have to submit a bid for it. A *bid* consists in proposing a price of purchase (i.e., an integer number between 0 and 100).

The Auction Rule

3. In each auction round, the bidder who submitted the highest bid wins the auction.

4. If ever the highest bid is submitted by more than one bidder, the winner will be determined randomly. (There will be an equal chance for each of them to be selected as the winner).

5. The winner of the auction round is awarded the item and pays a *price* equal to her/his bid.

Your Payoff in the Auction Round

5. At the outset of each auction round, the computer draws integer numbers between 0 and 100 at random, one for each bidder. (These numbers are independent of each other.)

6. One of these numbers will be assigned to you. The number represents your resale value for the item for sale.

7. The *resale value* determines the amount the experimenter is going to pay you if you win the item in the auction round.

8. Therefore, if you win the item, your *round payoff* will be equal to the difference between your resale value and your bid. If you don't win the item your round payoff will be zero.

9. Note: In order to prevent negative payoffs, you will NOT be allowed to submit a bid above your resale value.

Your Payoff in the Experiment

10. Round payoffs, bids, prices and resale values will be expressed in the Experimental Currency Unit ECU.

11. At the end of the experiment you will be paid your accumulated payoff of the experiment privately in the adjacent office. The exchange rate will be 1 ECU = £0.06.

Information Feedback

12. In the first 50 auction rounds: you will not receive any information about prices or payoffs.

13. In the second 50 auction rounds: you will be informed about the price of the item, your payoff, and your accumulated payoff at the end of each auction round.

14. Throughout the experiment you will be given on-screen a record of all information you have received in the previous auction rounds (including values, bids, etc.).