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Varying the number of bidders in the first-price sealed-bid auction: experimental evidence for the one-shot game

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Abstract The paper reports experimental data on the behavior in the first-price sealed-bid auction for a varying number of bidders when values and bids are private information. This feedback-free design is proposed for the experimental test of the one-shot game situation. We consider both within-subjects and between-subjects variations. In line with the qualitative risk neutral Nash equilibrium prediction, the data show that bids increase in the number of bidders. However, in auctions involving a small number of bidders, average bids are above, and in auctions involving a larger number of bidders, average bids are below the risk neutral equilibrium prediction. The quartile analysis reveals that bidding behavior is not constant across the full value range for a given number of bidders. On the high value quartiles, however, the average bid–value ratio is not different from the risk neutral prediction. The behavior is different when the winning bid is revealed after each repetition.

Keywords First-price sealed-bid auction · Experiment · Within-subject variation · Between-subject variation · Feedback

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1 Introduction

Auction theory is an important area of game theoretic modeling.[1] Since the seminal paper by Vickrey (1961) much theoretical work has been contributed to the study of the *one-shot game* where a single object is auctioned to a known number of bidders who have private values for the object. The behavior of the other bidders is unknown, only the distribution from which values are independently drawn is known. Assuming that bidders are risk neutral and that their private values are independently and uniformly distributed over the unit interval, Vickrey proved the equilibrium's existence and uniqueness. In the *risk neutral Nash equilibrium* of the first-price sealed bid auction, the bid is a constant fraction of the value for a given number of bidders and increases with the number of bidders.[2]

We test the risk neutral Nash equilibrium predictions of the first-price sealed-bid auction theory using controlled laboratory experiments where no information is revealed on the other bidders' behavior. Our data show that the bid is increasing in the number of bidders, but less increasing than predicted by the risk neutral equilibrium. On average, we observe above-equilibrium bid–value ratios when the number of bidders is small and below-equilibrium bid–value ratios when the number of bidders is large. A quartile analysis reveals that the bid–value ratio is not constant across the full value range for a given number of bidders. Over the higher value quartiles, i.e., the *outcome-decisive* value range, the bid–value ratio is in line with the risk neutral Nash equilibrium for larger markets, $N > 3$. We tend to conclude that the equilibrium describes fairly well the average behavior in our data over the decisive value range.

We are not first to consider bidding behavior in the experimental first-price auction. A considerable body of experimental literature has been contributed to this topic for over three decades (see surveys by Kagel 1995; Kagel and Levin 2008). The most famous stylized fact of the literature on experimental first-price auctions is that average bids exceed the risk neutral Nash equilibrium prediction. Our results are in disagreement with the stylized fact, apparently because of the differences to the conventionally used design. Most experimental studies investigate small markets in a *repeated-game design* in which feedback is given on the high bid and the private profits after each repetition. We use a *feedback-free design* to study the behavior of the one-shot game,[3] and look at rather large markets compared to the literature.[4] Several

[1] Engelbrecht-Wiggans (1980) surveys the theoretical literature on bidding models.

[2] Grimm and Schmidt (2000) more generally show that fanning out or fanning in of bidding strategies can result from quasiconcave or quasiconvex preferences.

[3] There is evidence from various experimental environments that repeated interaction with feedback influences decision-making. The feedback-free approach is the state-of-the-art approach in the experimental literature on individual decision making under risk and uncertainty (Hey 1991; Camerer 1995). A treatment effect between feedback-free and repeated-game approach was reported for different experimental environments including public goods (Neugebauer et al. 2009), guessing games (Weber 2003; Grosskopf and Nagel 2008), sequential first-price auctions (Neugebauer 2004), and single-unit first-price auctions (Neugebauer and Perote 2008).

[4] One contribution of our study is that we consider comparatively large number of bidders, including $N = 14$ and $N = 21$. Most studies on the first-price auction focused on a rather small number of bidders, $N \leq 4$, exceptions are reported below.

studies have investigated the stylized fact suggesting that risk attitudes (Cox et al. 1982a,b, 1988; Chen and Plott 1998; Grimm and Schmidt 2000; Andreoni et al. 2007; Kirchkamp et al. 2008),[5] cognitive and probability misjudgment (Goeree et al. 2002; Dorsey and Razzolini 2003; Crawford and Iriberri 2007; Armantier and Treich 2009; Kirchkamp and Reiss 2011), and feedback-responsive learning dynamics (Selten and Buchta 1999; Dufwenberg and Gneezy 2002; Güth et al. 2003; Ockenfels and Selten 2005; Engelbrecht-Wiggans and Katok 2007; Neugebauer and Selten 2006) may be its drivers. This paper relates to the latter study as we disable feedback-responsive dynamics in the feedback-free design.

Neugebauer and Selten (2006) studied behavior of subjects who play against computerized competitors. They suggested that bidding above the risk neutral equilibrium is an adaptive response, highly influenced by the feedback on the others' bids.[6] On average they observed bid–value ratios below rather than above the risk neutral Nash equilibrium, thus also in disagreement with the aforementioned stylized fact. This observation is dominated by the behavior of larger market sizes, since average bids are frequently above the equilibrium prediction when $N = 3$. Neugebauer and Perote (2008) showed for the market with $N = 7$ bidders in the feedback-free human-competitors setting that average bids move towards the risk-neutral equilibrium prediction, whereas in the repeated-game design average bids exceed the risk-neutral level. In contrast to Neugebauer and Selten (2006) our design involves human competitors, uniformly distributed private values independently drawn from the unit interval, and no feedback on others' bids in any repetition. We thus extend the feedback-free approach, as used in Neugebauer and Perote, to the study of market-size effects,[7] and report quartile analyses for both between-subjects variation with $N = \{3, 5, 7, 9, 14\}$ and within-subjects variation with $N = \{3, 7, 14, 21\}$. Average bid–value ratios are generally not significantly different in between-subjects and within-subjects variations for given $N > 3$.[8]

Our experimental design relates also to early experimental work on the first-price sealed-bid auctions where the effect of increased competition was studied in the repeated-game design. Cox et al. (1982a, 1988), and Kagel and Levin (1993) studied the effects of varying number of bidders in a between-subjects design, and Dyer et al.

5 Under the assumption that the bidders exhibit constant relative risk aversion and the risk-aversion measures are independently drawn from a commonly known distribution, the existence of a Nash equilibrium has been shown (Cox et al. 1982a). In equilibrium, bids are above the risk neutral Nash equilibrium and are positively correlated with the degree of individual risk aversion.

6 In Neugebauer and Selten's work, the subject's value was fixed at unity and computerized competitors' bids were independently drawn from the uniform distribution over the unit interval. In between-subjects variation three feedback conditions were examined in different market sizes $N = \{3, 4, 5, 6, 9\}$; (1) winning bid and competitors' highest bid, (2) winning bid, (3) winning bid only if subject wins. Above-equilibrium bidding was the average action in condition (2) for all N, and in the conditions (1) and (3) for $N = 4$.

7 Related experimental studies of oligopolistic markets have also shown that competitive pressures increase with the number of oligopolists (Huck et al. 2000, 2004; Dufwenberg and Gneezy 2000; Abbink and Brandts 2008; Brandts and Guillen 2007). In a remotely related theoretical and now classical paper, Selten (1973) suggested that quite extreme competition-effects can occur in oligopolies.

8 For the high value quartile in the small market size, $N = 3$, the bid–value ratios are higher in within-subjects variation. This evidence seems to suggest that behavior in small markets is quite sensitive to variations.

(1989) and Battalio et al. (1990) used a within-subjects design, $N \leq 10$. The results reported in the literature suggest that the tendency of above-equilibrium bidding may be less intense for a larger number of bidders even in the repeated-game design. We present also some data on the repeated-game design for $N = \{7, 10\}$ that point to similar effects. The quartile analysis applied to the repeated-game design shows in agreement with the stylized fact that bids exceed the risk neutral equilibrium on the decisive value quartiles. We conclude that the stylized fact of bidding above equilibrium describes well the average behavior of the repeated-game design, and that bidding at equilibrium describes well the average behavior of the feedback-free design, $N > 3$. With or without feedback the qualitative result of a *positive relationship between bids and the number of bidders* seems to be supported for a broad range of market sizes.

The paper is organized as follows. The second section presents the testable hypotheses implied by the risk neutral Nash equilibrium. Sections three and four inform on our experiments in the feedback-free design with between-subjects and within-subjects variation, respectively. The fifth section reports the repeated-game design control experiment. The sixth section summarizes the results and concludes the paper.

2 Testable hypotheses: the equilibrium bid–value ratio

Assume N bidders participate in a first-price sealed-bid auction for which all of the individual private values (v_i) are independently drawn from a rectangular distribution over the unit interval, $v_i \sim U[0; 1]$. Given each bidder i is *risk-neutral*, Vickrey (1961) showed existence and uniqueness of the *Nash equilibrium* (hereafter RNNE). Let (b_i) denote the individual bid, bidders homogeneously apply the following bid–value ratio in the RNNE.

$$\frac{b_i}{v_i} = \frac{N-1}{N} \tag{1}$$

The following testable hypotheses are immediately derived from the equilibrium prediction.

(H1) For any given N, the individual bid–value ratio is constant.
(H2) The bid–value ratio is increasing in N.
(H3) Observed bid–value ratios are equal to the RNNE.

Beyond that, we expect divergent results from those reported previously in the repeated-game design (Cox et al. 1982a, 1988; Dyer et al. 1989; Battalio et al. 1990; Kagel and Levin 1993). In particular, we expect that the bid–value ratio in the feedback-free design is lower than in the repeated-game design. The reason for our divergent expectation is that in the repeated-game design *ex post* best-reply dynamics (Selten and Buchta 1999) may account for the previous high bid of the others. These adaptive dynamics are shut off in the feedback-free approach enabling learning only by introspection (Weber 2003). Nonetheless, in line with the risk neutral equilibrium (1), where information revealed in hindsight on the behavior of the others has no relevance, we state our fourth hypothesis.

(H4) The bid–value ratio is the same in the between-subjects and within-subjects variations, and the same for the feedback-free design and the repeated-game design.

Besides referring to the results already reported in the literature, we evaluate this hypothesis also with some data from a control experiment with feedback on the high-bid after each repetition.

3 Experiment 1: between-subjects variation

3.1 Procedures

The first experiment involves between-subject variation. It is computerized conducted using zTree (Fischbacher 2007). Each subject is exposed to one treatment condition only. The treatment conditions are described by the number of bidders $N = \{3, 5, 7, 9, 14\}$. At the beginning of the experiment, the computer randomly assigns participants to an experimental auction market of size N. The subjects anonymously compete within the same market for 50 experimental auction periods. In each auction period, individual private values are independently and uniformly drawn from the interval [0, 1], multiplied by 100 and rounded to the next integer.[9] Given the value, the subject submits a non-negative integer bid at or below that value. According to the first-price auction rule, the winning bidder pays a price equal to her bid. In the case of a tie, the winner of the auction is randomly chosen among the high bidders. The bids, however, are private; subjects receive *no information feedback* on the winning bid or any other bid, and they are not informed about their payoff in any period. Only after the final period, that is, after 50 periods of bidding, are subjects posted their total payoff. During the experiment, each subject has an on-screen record of her own previous private values and bids.

The experimental sessions were conducted at the Centre for Experimental Economics EXEC (The University of York, UK), and at the Leibniz University of Hannover, Germany. At the beginning of the experiment, the subjects were given written instructions.[10] First subjects read the instructions themselves, thereafter, the experimenter read them aloud. Questions were answered. Finally, the participants were introduced to the simple interface on their computer screens. At the end of the experiment, subjects were privately paid their cumulative payoff plus a show-up fee of £3 sterling and €5, respectively. The average payoff was £9 and €13 (about the same amount), respectively; including instructional reading, the experiment was completed within an hour and a quarter.[11]

[9] This way of presenting the problem is theoretically equivalent to having values and bids over the unit interval rounded to the second decimal. As reported below, a finer scale has been applied in the experiment for within-subjects variation.

[10] The instructions are appended to the paper.

[11] The reported task was the first one of several tasks in an experimental session.

Table 1 Average and RNNE bid–value ratio overall values

N	Number of observations	RNNE ratio	Bid–value ratio (SD)	Bid–value ratio minus RNNE ratio
3	12	0.667	0.755 (0.145)	0.088*
5	15	0.800	0.809 (0.137)	0.009
7	28	0.857	0.827 (0.071)	−0.030*
9	27	0.889	0.832 (0.101)	−0.057***
14	28	0.929	0.842 (0.100)	−0.087***

Asterisks indicate results of the two-tailed Wilcoxon signed ranks tests; H_0: (b/v) = RNNE ratio; H_1: $(b/v) \neq$ RNNE ratio

* Significant at 10 %, ** significant at 5 %, *** significant at 1 %

3.2 Results

In total, 110 first-year students participated in the experiment; 12, 15, 28, 27, and 28 subjects participated in the market of size $N = \{3, 5, 7, 9, 14\}$, respectively. Since there was no information flow between the subjects, the data of each subject are treated as an independent observation. The number of participants therefore indicates the number of independent observations per treatment.[12]

The treatment averages of the individual bid–value ratio are recorded in Table 1; zero values are treated as missing observations.[13] The first and second columns in the table record the number of bidders N and the number of independent observations, respectively; the third column records the RNNE bid–value ratio; and the fourth one the observed average bid–value ratio. The fifth column records the differences between the observed and the predicted bid–value ratios, where the attached asterisk indicates significance of these differences according to the two-tailed Wilcoxon signed ranks test. The test results are summarized as follows.

Observation 1

(a) The data indicate bidding both above and below the RNNE.
(b) The bid–value ratio increases with N.
(c) The difference between the bid–value ratio and the RNNE is decreasing in N.

[12] The experiment conducted in York involved market size $N = 7$ only. In York, the participants were from different fields of study, while in Hannover all participants were economics students. For the market size $N = 7$ (the data including some replies to the debriefings are detailed in Neugebauer and Perote 2008), there were no significant behavioral differences between the samples from Hannover and York. Therefore, we include the data from York in the sample. As a matter of fact, the stated observations do not change if these data are excluded.

[13] In experiment 1, in 58 of 5,500 random draws the outcome was a zero private value; in experiment 2: we had 4 zero draws of 12,600 draws. In experiment 3, the private value was always positive.

Support:

(a) The positive and negative signs in the last column of Table 1 indicate bidding above (for $N = 3$) and below ($N \geq 7$) the RNNE, respectively. The recorded p values show that the differences are significant at the 10 % level for $N \neq 5$.[14]

(b) The one-tailed Jonckheere–Terpstra test for ordered alternatives (see e.g., Conover 1999) rejects the null hypothesis that all samples come from the same distribution in favor of the alternative hypothesis (H2) that the bid–value ratio weakly increases with N; the p value is 0.033.[15]

(c) As shown in Table 1 the difference of the observed bid–value ratio and the RNNE prediction is positive for $N = 3$ and smaller for larger N. The two-tailed Jonckheere–Terpstra test supports the alternative hypothesis that the differences are significantly increasing in N at any conventional significance level; the p value is 0.000. The propensity for bidding above the RNNE thus decreases when N increases.

Observation 1(b) agrees with earlier results of increasing bid–value ratios, and supports the theoretical predictions, as hypothesized in (H2). Observations 1(a) and 1(c) challenge hypothesis (H3). Observation 1(c) is in line with previous results on the repeated game design (Battalio et al. 1990). Observation 1(a), in contrast, is disagreeing with the results of the literature on the repeated-game design for $N > 3$, where above-equilibrium bidding is the stylized fact (Kagel 1995).[16] According to our observation, the stylized fact of the repeated-game design does not describe the behavior of the first-price sealed-bid auction in the feedback-free experiment. Already, for a rather small N (e.g., $N = 5$), the average bid–value ratio is not significantly above the RNNE.

3.3 Value-quartiles analysis

The experimental literature on the first-price auction has suggested for the repeated game design that subjects' bids exceed the RNNE if they have a high probability of winning, but they may not necessarily do so if they have a low probability of winning (Cox et al. 1988; Neugebauer and Pezanis-Christou 2007; Kirchkamp et al. 2008; Kirchkamp and Reiss 2011). To check the robustness of observation 1, therefore, the average bid–value ratio in the data of the present study is re-examined in conditions of a high probability of winning.

To investigate the robustness of observation 1, therefore, we segment the value range into quartiles, and report the bid–value ratio for each of the value quartiles $\{1,\ldots,25\}$, $\{26,\ldots,50\}$, $\{51,\ldots,75\}$, and $\{76,\ldots,100\}$. Corresponding to the last column of Table 1,

14 Exact p values are 0.071, 0.211, 0.065, 0.005, and 0.000, for $N = \{3, 5, 7, 9, 14\}$ respectively.

15 The null hypothesis that all samples come from the same distribution is tested against the ordered alternative that bids weakly increase with N with at least one inequality. The test is conducted one-tailed as the prediction of the risk-neutral Nash equilibrium indicates an increase of the bid–value ratio with N.

16 In the repeated first-price auction experimental design that reveals at least the winning bid after each period, average bidding above the RNNE results for all market sizes $N \leq 10$. Experimental markets with more than 10 participants have not been investigated before.

Table 2 Difference of average and RNNE bid–value ratio by quartiles

N	Number of observations	Value segment {1,…,25}	Value segment {26,…,50}	Value segment {51,…,75}	Value segment {76,…,100}
3	12	0.065 (0.167)	0.106** (0.137)	0.109** (0.159)	0.088* (0.141)
5	15	−0.018 (0.154)	0.030 (0.145)	0.031 (0.119)	0.005 (0.162)
7	28	−0.091*** (0.092)	−0.034 (0.098)	−0.001 (0.090)	0.003 (0.082)
9	27	−0.130*** (0.156)	−0.056* (0.117)	−0.024 (0.117)	−0.019 (0.095)
14	28	−0.192*** (0.109)	−0.075*** (0.139)	−0.039 (0.111)	−0.040 (0.101)

Asterisks indicate results of the two-tailed Wilcoxon signed ranks tests; H_0: (b/v) = RNNE ratio; H_1: $(b/v) \neq$ RNNE ratio

* Significant at 10 %, ** significant at 5 %, *** significant at 1 % (standard deviations in parentheses)

Table 2 displays the average difference between the observed bid–value ratio and the RNNE bid–value ratio for each quartile.[17]

Observation 2

(a) For given N, the bid–value ratio is constant only for the two high value quartiles.
(b) For the high value quartiles, the bid–value ratio is different from the RNNE for $N = 3$ only.
(c) For the three high value quartiles, the bid–value ratio increases with N.
(d) For each value quartile, the difference between observed and RNNE bid–value ratio is decreasing in N.

Support:

(a) The pairwise two-sided Wilcoxon signed ranks test rejects the null-hypothesis of no differences in favor of the alternative hypothesis that the bid–value ratio is different on the lower three quartiles; the p values are below 0.001, pooling all the observations ($n = 110$).[18] The bid–value ratio is not significantly different across the two high value quartiles ($p = 0.3863$), and the statistical power of this result is 0.653.
(b) The asterisks in Table 2 indicate significant differences between the bid–value ratio and the RNNE ratio according to the Wilcoxon signed ranks test. For the

[17] The individual average bid–value ratios are recorded in Table 5 in Appendix for each quartile and overall. Confirmatory results to the reported ones are obtained if one examines the behavior conditional on being assigned the high value that is expected to win in an efficient market (see Neugebauer 2007), or if one considers only bids of values equal or above 90, or if one considers only values that in the RNNE have at least a probability of winning of 0.25 (this would involve values of at least 50 in the market with $N = 3$; it would involve values of at least 71 in the market with $N = 5$; etc.).

[18] Splitting the data by group size yields significant differences between the first and the second quartile for $N > 3$ ($p < 0.015$), and between the second and the third quartile for $N > 5$ ($p < 0.015$). None of the sessions shows a significant effect on the 5 % significant level between the third and the fourth quartile.

two high value quartiles, the difference between the observed and the RNNE bid–value ratios is statistically significant only in the case of $N = 3$.

(c) The one-tailed Jonckheere–Terpstra test for ordered alternatives supports the alternative hypothesis that the bid–value ratio is increasing in N for each but the low value quartile.[19]

(d) The two-tailed Jonckheere–Terpstra test supports for each value segment the alternative hypothesis that the differences between the observed and the RNNE bid–value ratio change with increasing N at any conventional significance level; the p value is 0.000.

According to observation 2(a) the hypothesis of a constant bid–value ratio (H1) must be generally rejected, however, it is supported for the two high value quartiles. The test also suggest that the bidding below the RNNE in observation 1(a) is influenced by the bid–value ratio over the low value quartiles. For the high value quartiles, the average bid–value ratio is not significantly different from the RNNE. In general, neglecting the low value quartile, the reported results (observations 2c and 2d) agree with observation 1. Thus, we conclude that generally, and in particular as N increases, observation 2 suggests that the evidence against the RNNE looks weak for on the outcome-decisive value segment. Compared with the stylized fact of the repeated-game design of above-equilibrium bidding, the RNNE describes better the behavior of the feedback-free design.

4 Experiment 2: within-subjects variation

4.1 Procedures

In each period of the within-subjects experiment, subjects receive one private value independently and uniformly drawn from the unit interval, multiplied by 10,000 and rounded to the next integer. Subjects simultaneously submit non-negative integer bids to four auctions. In contrast to the between-subjects experiment, subjects are permitted to submit bids above their value.[20] However, we observe *no bid above value* in the experiment.

Each experimental session involves 21 subjects who simultaneously bid in four markets with the following number of bidders; $N = \{3, 7, 14, 21\}$. The composition of each market is determined at the beginning, and does not change during the experiment.[21] To avoid diversification effects, one of the four markets is decisive for the

[19] p values are 0.722, 0.017, 0.000, and 0.000, for $N = \{3, 5, 7, 9, 14\}$, respectively.

[20] To avoid unintended bidding above value, each such bid requires an extra confirmation by the subject.

[21] The software implemented the following matching protocol which was not explained in detail to subjects. Subjects are randomly assigned numbers $\{1, 2, \ldots, 21\}$. The subjects of the first three numbers are matched in the first market of size $N = 3$, the second three numbers are assigned to the second market, etc. Similarly, for the market size $N = 7$; the first seven numbers are assigned to the first market, etc. For market size $N = 14$, the first fourteen numbers are assigned to the first market. The numbers $\{15, \ldots, 21\}$ are assigned to the second. This market of size $N = 14$ is completed with the bids of the subjects numbered $\{8, \ldots, 14\}$, whose bids are relevant for the price determination in that second market, but whose payoffs are exclusively

period-gain of the subject. The payoff-decisive market is randomly determined in each period.

The within-subjects design involves the feedback-free approach, too. Only individual values and the bids are recorded after each period. The price in the payoff-relevant market and the generated period-gains are disclosed only at the end of the experiment after 50 periods. The corresponding cumulated payoffs are paid out privately.

The experiment was computerized (Fischbacher 2007), conducted at the EconLab, Unversity of Bonn. Two conditions were considered. In the *constant-pay* condition, the unit payoff on the 10,000 scale is constant at 0.150 Eurocents. In the *increasing-pay* condition, the unit payoff increases in $N = \{3, 7, 14, 21\}$, yielding {0.050, 0.233, 0.875, 1.925} Eurocents, respectively. The expected payoff in the risk neutral Nash equilibrium is the same across treatment conditions (approximately €0.40 per period), and is also the same for each number of bidders in the increasing-pay condition. The per-unit payoffs were communicated to subjects in the experimental instructions (see Appendix). We expected opposite bidding biases in the two conditions. In the increasing-pay condition, we imagined that subjects would be biased towards increasing their bids in N, whereas in the constant-pay condition, they would be biased towards decreasing their bids in N. Therefore, we conducted both treatments, but found no treatment effect.[22]

4.2 Results

The data contain 42 independent observations. As we observe no treatment effect between the constant-pay condition and the increasing-pay condition, we report on the pooled data. Each independent observation involves 50 periods, for which we observe one private value and four bids, one for each $N = \{3, 7, 14, 21\}$. By participating to the experiment, subjects earned on average €13.38 including a show-up fee of €5. The session took 1 h and 15 min to complete.

The results of the within-subjects experiment confirm the two observations of the between-subjects design.

Observation 3

(a) For given N, the bid–value ratio is constant for the two high value quartiles.
(b) The individual bid–value ratio increases with N.
(c) The difference between observed and RNNE bid–value ratio is decreasing in N for each value quartile.

Footnote 21 continued
determined in the first market of size $N = 14$. Finally, each subject submits a bid to the market of size $N = 21$.

[22] Comparing the bid–value ratios for the within-subject experiment between conditions, we find that the increasing-pay treatment generates higher averages than the constant-pay treatment. However, only for the low-value quartile are these differences significant at the 5 % significance level. We conduct a two-tailed Mann–Whitney test for the comparison of the bid–value ratio across treatment conditions. The p values of the test conducted on the low value quartile are {0.046, 0.044, 0.024, 0.031} for $N = \{3, 7, 14, 21\}$.

(d) We generally find no treatment effect between our two feedback-free approaches, i.e., the within-subjects variation and the between-subjects variation. However, we find one difference for the high value quartile in the market of size $N = 3$.

Support:

(a) Table 3 records the average differences of the average bid–value ratio from the RNNE ratio for the varied number of bidders. For all group sizes, the Wilcoxon signed ranks test rejects the null hypothesis of equal bid–value ratios comparing the first and second quartile ($p < 0.001$), and comparing the second and third quartile ($p < 0.03$). However, the tests cannot reject the null hypothesis of equal bid–value ratios between the two high value quartiles ($p > 0.333$).
(b) Comparing bid–value ratios across group sizes the one-sided Wilcoxon signed ranks test accepts the alternative hypothesis that the bid–value ratio increases in N. The tests are conducted on the overall averages as well as on each quartile; the p values for each of the pairwise tests are below 0.002.
(c) The second column of Table 3 also reports the average differences by value quartile. As indicated by the asterisks in the first column, the two-sided Wilcoxon signed ranks test rejects the null hypothesis that the bid–value ratio is at the RNNE for all market sizes but $N = 7$. The bid–value ratio is significantly above the RNNE for $N = 3$ (p value is 0.000), and significantly below the RNNE for $N = 14$ (p value is 0.002), and $N = 21$ (p value is 0.003). However, the bid–value ratios for the two high value quartiles are not significantly different from the RNNE for $N \geq 14$.
(d) Comparing the bid–value ratio of the two experiments for market-sizes $\{3, 7, 14\}$, we find no significant differences of the between-subjects and within-subjects experiments for most value segments. Significant differences between pay conditions are observed for the high value quartile when $N = 3$.[23] The p value of the two-tailed Mann–Whitney test is 0.023.

5 Repeated-game design control experiment

As a control observation, we report some data on the conventional repeated-game design with large market sizes $N = \{7, 10\}$. The outcomes on smaller markets are well documented in the literature (e.g., Kagel 1995), and are not further detailed here. The report on $N = \{7, 10\}$ in the repeated-game design should give an idea about the behavioral differences from the feedback-free design. In the described experimental sessions, each subject participates in one market for 50 subsequent periods. After each period the subject receives feedback on the winning bid and on the personal period gain.

[23] The p values of the two-tailed Mann–Whitney test are $\{0.901, 0.349, 0.183, 0.023, 0.261\}$ for $N = 3$, $\{0.737, 0.240, 0.166, 0.401, 0.323\}$ for $N = 7$, and $\{0.068, 0.420, 0.590, 0.692, 0.181\}$ for $N = 14$, where the first p value in the curly brackets represents the first quartile, the second quartile, …, the fourth quartile; finally, the last p value represents the two sample test of bid–value ratios for the corresponding number of bidders.

Table 3 Difference of average and RNNE bid–value ratio by quartiles

N	Overall values {1,…,10,000}	Value segment {1,…,2,500}	Value segment {2,501,…,5,000}	Value segment {5,001,…,7,500}	Value segment {7,501,…,10,000}
3	0.138***	0.047**	0.147***	0.176***	0.178***
	(0.122)	(0.190)	(0.140)	(0.128)	(0.115)
7	−0.032	−0.117***	−0.035	0.010	0.005**
	(0.132)	(0.194)	(0.179)	(0.128)	(0.122)
14	−0.076***	−0.159***	−0.082***	−0.037	−0.036
	(0.129)	(0.197)	(0.183)	(0.113)	(0.115)
21	−0.074***	−0.156***	−0.079**	−0.039	−0.032
	(0.124)	(0.200)	(0.180)	(0.106)	(0.105)

Averages are computed on 42 independent observations (standard deviations in parentheses)
Asterisks indicate results of the two-tailed Wilcoxon signed ranks tests; H_0: (b/v) = RNNE ratio; H_1: $(b/v) \neq$ RNNE ratio
* Significant at 10 %, ** significant at 5 %, *** significant at 1 %

5.1 Procedures

The experiment of market size $N = 10$ was computerized (Fischbacher 2007), conducted at the NSM Decision Lab, Radboud University Nijmegen. In the session, there were two auction groups.[24]

In each period subjects' private values are independently and uniformly drawn from the unit interval multiplied by 10,000 and rounded to the next integer. Subjects are permitted to submit bids above their value. The cumulated payoffs are paid out in private at the end of the experiment. By participating, subjects earned on average €9 including show-up fee. The session took 1 h to complete.

The experimental data of market size $N = 7$ involves 8 groups. The data was collected in experiments at EXEC, University of York, and at the University of Hannover. It is identical to the data (INFO) reported in Neugebauer and Perote (2008). The value support was {0,…,100}, and bidding above value was inhibited.

5.2 Results

The data consist of 10 independent observations. The difference of the observed average from the RNNE bid–value ratios are recorded by quartile in Table 4 corresponding to the earlier tables. To test the effects for significance, however, we apply a one-tailed binomial sign test, the results of which are recorded in the bottom line of the table. Generally, the statistical power is limited due to the small number of independent observations in the repeated-game design. Still we think that the reported evidence correctly indicates the direction.

Observation 4

(a) For the high-value quartiles, the difference between the average observed bid–value ratio and the RNNE is different from zero.

[24] Unfortunately there was a high no-show rate, such that we were unable to obtain data from a third group. However, as the results are quite clear, we refrained from running a further session.

Table 4 Difference of average and RNNE bid–value ratio by quartiles

N (group ID)	Overall values {1,…,10,000}	Value segment {1,…,2,500}	Value segment {2,501,…,5,000}	Value segment {5,001,…,7,500}	Value segment {7,501,…,10,000}
10	−0.007	−0.094	−0.007	0.029	0.022
(1)	(0.062)	(0.201)	(0.083)	(0.040)	(0.041)
10	−0.028	−0.161	−0.004	0.036	0.008
(2)	(0.077)	(0.246)	(0.051)	(0.024)	(0.028)
7	−0.025	−0.233	−0.015	0.096	0.076
(3)	(0.141)	(0.309)	(0.227)	(0.021)	(0.017)
7	0.032	−0.065	0.047	0.080	0.073
(4)	(0.075)	(0.181)	(0.099)	(0.041)	(0.019)
7	0.047	−0.007	0.039	0.067	0.075
(5)	(0.085)	(0.123)	(0.113)	(0.075)	(0.037)
7	0.044	−0.054	0.060	0.081	0.077
(6)	(0.045)	(0.107)	(0.044)	(0.025)	(0.028)
7	−0.026	−0.193	−0.002	0.044	0.041
(7)	(0.067)	(0.158)	(0.062)	(0.075)	(0.047)
7	0.019	−0.043	0.029	0.048	0.041
(8)	(0.077)	(0.185)	(0.096)	(0.067)	(0.048)
7	0.069	0.018	0.088	0.095	0.074
(9)	(0.024)	(0.038)	(0.024)	(0.024)	(0.037)
7	0.032	−0.055	0.031	0.084	0.072
(10)	(0.049)	(0.128)	(0.061)	(0.040)	(0.052)
Pos./neg. deviations	6/4	1/9	6/4	10/0	10/0
Binomial test result p value	.172	.989	.172	.000***	.000***

Averages are computed on 10 and 7 observations for each group (standard deviations in parentheses)

Asterisks indicate results of the one-tailed binomial sign test; H_0: $\text{Prob}(b/v > \text{RNNE}) \leq \text{Prob}(b/v < \text{RNNE})$; H_1: $\text{Prob}(b/v > \text{RNNE}) > \text{Prob}(b/v < \text{RNNE})$

*** Significant at 1 %

(b) For the two high-value quartiles, i.e., the decisive value range, we find a treatment effect of the bid–value ratio between the repeated-game design and the feedback-free design.

Support:

(a) The fourth and fifth columns of Table 4 report the difference between the observed average bid–value ratio and the RNNE over the two high value quartiles. Note, that the bid–value deviations from the RNNE are positive for each session. The likelihood that this result is due to chance is 0.001. This result is reported on the bottom line of the table. Note that on the lower two quartiles and overall, the observed bid–value ratio is not significantly larger than the RNNE. The effect on the $N = 7$ sample, however, is significantly positive; in 6 of 8 sessions the average bid–value ratio exceeds the RNNE.[25]

(b) For the comparison between the feedback-free design and the repeated-game design we must look at comparable market sizes. Arguably the toughest test of our hypothesis compares the outcomes of the repeated-game design with the within-subject data for market size $N = 7$. The average bid–value ratio exceeds the RNNE 30 of 42 times on the high value quartile. According to the Fisher exact test, the difference to the repeated-game design where each of the 10 average bid–value ratios is above equilibrium is significant; the p value is 0.054. The p value for the second highest value quartile is 0.040. Compared to the between-subject data with comparable markets sizes $N = \{7, 9\}$ the p values are 0.026 and 0.059, respectively. On the overall-values sample with $N = \{7, 9\}$, we find no significant differences between the feedback-free and the repeated-game design as the p values are 0.525 and 0.582 on the within-subject and between-subjects sample, respectively. If we consider $N = 9$ only the difference, however, is significant on the overall-values sample ($p = 0.084$).[26]

6 Conclusions

We have proposed to test the risk neutral equilibrium theory for the one-shot game in the feedback-free experimental design. The feedback-free design shares similarities with the strategy method (Selten 1967; Selten et al. 1997),[27] but it aids introspective reasoning as the data contain repeated spontaneous choices rather than formulating predefined actions in all possible circumstances without even having gathered any kind of experience. In our opinion, this introspection agrees with the *ex ante* reasoning idea of the equilibrium concept, and it disables the frequently reported *ex post* adaptation of individual bids. To us, it appears difficult to control for the effects of

[25] In line with earlier results on the repeated-game design, this observation suggests that the difference of the average bid–value ratio from the RNNE may decrease with an increasing number of bidders.

[26] In between-subjects variation only four observations of market size $N = 7$ are independent from the feedback-free approach (INFO1). So, the Fisher test involves the first six observations of Table 4.

[27] The strategy method has been applied to repeated first-price auctions with feedback information in Selten and Buchta (1999), Güth et al. (2003), Pezanis-Christou and Sadrieh (2003), Kirchkamp et al. (2008), Kirchkamp et al. (2009), and Kirchkamp and Reiss (2011).

information revealed in hindsight without considering the feedback-free design when testing predictions for the one-shot game.

In contrast to the feedback-free approach, most contributions to the experimental literature on first-price sealed-bid auctions have applied the repeated-game design where feedback on outcomes is received after each repetition. The observed results between the approaches are strikingly different in relation to the risk neutral Nash equilibrium. The average bid–value ratios of the feedback-free approach are rather consistent with the risk neutral equilibrium over the decisive range of values when the number of bidders is sufficiently large. We thus provide a fresh perspective on risk neutral bidding in the laboratory when environmental influences that result from feedback on the behavior of the others are removed and introspective reasoning (Weber 2003) dominates *ex post* best-reply dynamics (e.g., Neugebauer and Selten 2006). In sharp contrast to this observation, the average bid–value ratios of the first-price auction experiment have been consistently reported above the risk neutral Nash equilibrium over a varied number of bidders (Cox et al. 1982a, 1988; Dyer et al. 1989; Battalio et al. 1990; Kagel and Levin 1993), and we have also provided some additional data to this end.

Comparing the results of the feedback-free and the repeated-game approach we can confirm qualitative findings of the experimental first-price sealed-bid auction literature. First, it has been observed that bids increase in value (Kagel 1995; Kagel and Levin 2008); second, bids do not increase with the number of bidders as fast as suggested by the RNNE; and third, bid–value ratios are frequently below the risk neutral benchmark on the low segment of the value distribution (Kirchkamp and Reiss 2011). Overall in the feedback-free design, the average bid–value ratio indicates below-equilibrium bidding when the number of bidders is increased. Apparently, this effect is to some extent a consequence of the behavior on the low value quartile.

For the small market size, in particular, the auction with three players, we have generated data for the feedback-free design only. Nonetheless, our feedback-free evidence and the stylized fact of the first-price auction literature suggest that above-equilibrium bids are representative of the behavior for both the feedback-free and the repeated-game design. Therefore, we think it would be worthwhile studying the models of behavioral biases regarding preferences (Cox et al. 1982a,b, 1988), cognition (Crawford and Iriberri 2007) and expectation formation and best replies (Armantier and Treich 2009; Kirchkamp and Reiss 2011; Neri 2012) in the feedback-free design approach as well.

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Appendix

Instructions (between-subjects experiment)

General information

1. You are about to participate in 50 rounds of an auction experiment. In each of these rounds, you will be assigned to a group of N bidders:[28] 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, one fictitious item will be sold for which you have to submit a bid. A *bid* consists in proposing a price of purchase (i.e., an integer number between 0 and 100).

The auction rule

3. Your bid must be always a number between 0 and 10,000. In each auction round, the bidder who submits 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 an auction round

5. At the outset of each auction round, the computer draws integer numbers between 0 and 10,000 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. Your *resale value* is 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 in the market to which you participate, 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 are 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

[28] In the sessions, N was substituted by the number of participants $N = \{3, 5, 7, 9, 14\}$.

= 0.0015 (*constant pay treatment*). The exchange rate differs between markets. In the 3-bidders market, 100 ECU = €0.05; in the 7-bidders market, 100 ECU = €0.233; in the 14-bidders market, 100 ECU = €0.875; and in the 21-bidders market, 100 ECU = €1.925.

Information feedback

12. You will not receive any information about prices or payoffs. Throughout the experiment you will be given an on-screen record of all information you have received in the previous auction rounds including values and bids.
13. After 50 rounds, you will receive full information on prices and payoffs per period and overall.

Instructions (within-subjects experiment)

General information

1. You are about to participate in 50 rounds of an auction experiment. In each of these rounds, you will simultaneously propose a price (submit a bid) in four auction markets. You participate to each of the four markets with equal probability, but the actual market to which you participate is revealed to you only in hindsight.
2. The four markets in which you simultaneously bid differ in the number of bidders. The first auction market has 3 participants (3-bidder market), the second has 7 participants (7-bidder market), the third 14 (14-bidder market), and the fourth 21 (21-bidder market). The participants in each of these groups stay the same. Unless you bid in the 21-bidder market, however, you will not know the identity of the other group members.
2. In each of the 100 rounds, one fictitious item will be sold for which you have to submit a bid. 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 submits 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 an 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. Your *resale value* is 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 should NOT submit a bid above your resale value.

Your payoff in the experiment

10. Round payoffs, bids, prices and resale values are 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 (UK, $N = 7$); 1 ECU = € {0.05, 0.05, 0.10, 0.10, 0.20} (Germany, $N = \{3, 5, 7, 9, 14\}$).

Information feedback

12. You will not receive any information about prices or payoffs.
13. Throughout the experiment you will be given an on-screen record of all information you have received in the previous auction rounds including values and bids.

Tables[29]

See Tables 5, 6, and 7.

Table 5 Individual average bid–value ratio by segment in between-subjects experiment

Subject ID	Overall value segment {1,…,100}	Value segment {1,…,25}	Value segment {26,…,50}	Value segment {51,…,75}	Value segment {76,…,100}
$n = 3$					
1	0.974	0.996	0.931	0.984	0.990
2	0.701	0.667	0.710	0.761	0.664
3	0.642	0.530	0.684	0.688	0.743
4	0.922	0.990	0.943	0.890	0.823
5	0.828	0.842	0.853	0.827	0.771
6	0.609	0.629	0.682	0.556	0.571
7	0.768	0.789	0.735	0.861	0.732
8	0.867	0.843	0.866	0.923	0.858
9	0.495	0.496	0.494	0.498	0.492

29 Data on the repeated game design are available upon request.

Table 5 continued

Subject ID	Overall value segment {1,…,100}	Value segment {1,…,25}	Value segment {26,…,50}	Value segment {51,…,75}	Value segment {76,…,100}
10	0.842	0.689	0.876	0.930	0.914
11	0.608	0.563	0.632	0.596	0.673
12	0.804	0.745	0.868	0.791	0.826
	0.755	0.732	0.773	0.775	0.755
$n = 5$					
13	0.914	0.892	0.923	0.928	0.906
14	0.879	0.797	0.891	0.911	0.885
15	0.935	0.951	0.938	0.929	0.917
16	0.835	0.851	0.852	0.826	0.812
17	0.898	0.757	0.940	0.958	0.975
18	0.468	0.409	0.460	0.573	0.466
19	0.876	0.892	0.890	0.865	0.851
20	0.750	0.857	0.873	0.623	0.553
21	0.780	0.746	0.757	0.814	0.823
22	0.738	0.690	0.730	0.794	0.824
23	0.852	0.754	0.933	0.869	0.936
24	0.542	0.493	0.561	0.669	0.497
25	0.881	0.888	0.899	0.881	0.845
26	0.919	0.939	0.886	0.927	0.909
27	0.870	0.812	0.924	0.900	0.881
	0.810	0.782	0.830	0.831	0.805
$n = 7$					
28	0.851	0.647	0.880	0.903	0.926
29	0.862	0.697	0.929	0.913	0.916
30	0.913	0.837	0.899	0.956	0.950
31	0.701	0.781	0.685	0.653	0.691
32	0.661	0.781	0.574	0.633	0.683
33	0.844	0.812	0.790	0.855	0.889
34	0.854	0.810	0.783	0.890	0.919
35	0.809	0.596	0.857	0.869	0.910
36	0.783	0.782	0.708	0.799	0.830
37	0.776	0.876	0.810	0.717	0.673
38	0.903	0.921	0.924	0.922	0.856
39	0.891	0.860	0.903	0.902	0.924
40	0.898	0.860	0.859	0.907	0.932
41	0.917	0.896	0.973	0.907	0.903
42	0.741	0.585	0.746	0.804	0.818
43	0.854	0.744	0.875	0.884	0.899

Table 5 continued

Subject ID	Overall value segment {1,…,100}	Value segment {1,…,25}	Value segment {26,…,50}	Value segment {51,…,75}	Value segment {76,…,100}
44	0.800	0.818	0.815	0.811	0.769
45	0.875	0.837	0.907	0.905	0.853
46	0.839	0.844	0.788	0.880	0.839
47	0.924	0.816	0.969	0.981	0.959
48	0.907	0.678	0.946	0.972	0.966
49	0.686	0.653	0.690	0.680	0.739
50	0.791	0.696	0.749	0.835	0.865
51	0.834	0.807	0.831	0.851	0.855
52	0.796	0.678	0.767	0.895	0.844
53	0.831	0.704	0.858	0.869	0.889
54	0.762	0.651	0.687	0.845	0.889
55	0.871	0.796	0.849	0.922	0.907
	0.827	0.767	0.823	0.856	0.860
$n = 9$					
56	0.891	0.814	0.905	0.928	0.929
57	0.894	0.932	0.875	0.899	0.841
58	0.886	0.768	0.898	0.954	0.958
59	0.882	0.887	0.927	0.916	0.826
60	0.844	0.781	0.853	0.862	0.873
61	0.768	0.714	0.686	0.833	0.807
62	0.786	0.684	0.752	0.858	0.818
63	0.838	0.646	0.854	0.926	0.937
64	0.829	0.602	0.796	0.909	0.920
65	0.514	0.561	0.507	0.523	0.471
66	0.910	0.826	0.930	0.963	0.957
67	0.781	0.737	0.777	0.798	0.811
68	0.693	0.577	0.635	0.764	0.851
69	0.854	0.812	0.838	0.867	0.901
70	0.882	0.895	0.871	0.913	0.830
71	0.890	0.860	0.894	0.920	0.874
72	0.580	0.205	0.601	0.510	0.904
73	0.753	0.763	0.703	0.743	0.823
74	0.934	0.861	0.964	0.963	0.960
75	0.909	0.841	0.927	0.934	0.916
76	0.827	0.697	0.866	0.917	0.899
77	0.908	0.839	0.960	0.959	0.945
78	0.960	0.967	0.960	0.966	0.944
79	0.849	0.837	0.862	0.853	0.832

Table 5 continued

Subject ID	Overall value segment {1,…,100}	Value segment {1,…,25}	Value segment {26,…,50}	Value segment {51,…,75}	Value segment {76,…,100}
80	0.874	0.709	0.940	0.948	0.945
81	0.874	0.959	0.841	0.820	0.820
82	0.849	0.723	0.878	0.896	0.885
	0.832	0.762	0.838	0.871	0.866
$n = 14$					
83	0.874	0.792	0.882	0.924	0.906
84	0.741	0.641	0.778	0.766	0.735
85	0.720	0.703	0.634	0.760	0.792
86	0.937	0.879	0.950	0.972	0.953
87	0.831	0.627	0.870	0.920	0.946
88	0.924	0.877	0.924	0.959	0.942
89	0.897	0.822	0.903	0.934	0.943
90	0.861	0.639	0.913	0.958	0.959
91	0.855	0.682	0.907	0.929	0.934
92	0.958	0.882	0.970	0.983	0.986
93	0.876	0.651	0.901	0.942	0.935
94	0.699	0.725	0.734	0.702	0.648
95	0.857	0.754	0.924	0.877	0.956
96	0.897	0.859	0.898	0.919	0.948
97	0.878	0.752	0.882	0.921	0.925
98	0.872	0.714	0.941	0.937	0.861
99	0.871	0.683	0.924	0.935	0.889
100	0.851	0.811	0.907	0.877	0.828
101	0.892	0.862	0.900	0.881	0.910
102	0.764	0.595	0.757	0.866	0.870
103	0.539	0.489	0.608	0.449	0.575
104	0.960	0.942	0.967	0.978	0.961
105	0.876	0.765	0.898	0.922	0.935
106	0.817	0.642	0.846	0.906	0.878
107	0.620	0.598	0.320	0.826	0.769
108	0.963	0.841	0.970	0.984	0.975
109	0.887	0.743	0.933	0.967	0.972
110	0.854	0.660	0.862	0.914	0.944
	0.842	0.737	0.854	0.890	0.888

Table 6 Individual average bid–value ratio by segment in within-subjects experiment—constant-pay condition

Subject ID	Overall value segment {1,…,10,000}				Value segment {1,…,2,500}				Value segment {2,501,…,5,000}			
	$n = 3$	$n = 7$	$n = 14$	$n = 21$	$n = 3$	$N = 7$	$n = 14$	$n = 21$	$n = 3$	$n = 7$	$n = 14$	$n = 21$
111	0.790	0.807	0.855	0.883	0.697	0.718	0.741	0.757	0.798	0.756	0.879	0.928
112	0.886	0.910	0.931	0.981	0.740	0.793	0.843	0.942	0.934	0.920	0.907	0.991
113	0.641	0.664	0.708	0.765	0.447	0.517	0.557	0.638	0.570	0.583	0.681	0.746
114	0.949	0.949	0.950	0.958	0.914	0.914	0.915	0.921	0.940	0.940	0.942	0.949
115	0.824	0.868	0.899	0.932	0.821	0.877	0.882	0.884	0.839	0.885	0.924	0.958
116	0.805	0.858	0.913	0.968	0.670	0.754	0.843	0.933	0.846	0.894	0.938	0.983
117	0.750	0.793	0.843	0.876	0.611	0.651	0.727	0.759	0.711	0.772	0.834	0.875
118	0.655	0.694	0.730	0.770	0.264	0.273	0.278	0.283	0.767	0.809	0.845	0.883
119	0.773	0.757	0.751	0.743	0.668	0.606	0.570	0.569	0.700	0.699	0.702	0.681
120	0.808	0.809	0.809	0.809	0.642	0.644	0.644	0.644	0.862	0.862	0.862	0.862
121	0.603	0.585	0.623	0.633	0.766	0.798	0.813	0.813	0.649	0.635	0.662	0.673
122	0.773	0.768	0.764	0.766	0.600	0.601	0.601	0.602	0.795	0.782	0.782	0.785
123	0.823	0.866	0.889	0.929	0.909	0.909	0.909	0.913	0.814	0.885	0.864	0.912
124	0.781	0.816	0.852	0.886	0.639	0.679	0.725	0.774	0.831	0.868	0.907	0.939
125	0.926	0.942	0.963	0.977	0.808	0.851	0.904	0.944	0.951	0.959	0.973	0.983
126	0.839	0.882	0.921	0.956	0.591	0.689	0.776	0.868	0.867	0.907	0.943	0.972
127	0.844	0.941	0.956	0.968	0.917	0.936	0.944	0.947	0.960	0.976	0.982	0.988
128	0.510	0.442	0.506	0.599	0.507	0.454	0.481	0.508	0.524	0.425	0.473	0.606
129	0.691	0.700	0.704	0.703	0.502	0.484	0.484	0.484	0.669	0.674	0.673	0.687
130	0.966	0.966	0.966	0.966	0.910	0.910	0.910	0.910	0.969	0.969	0.969	0.969
131	0.637	0.740	0.824	0.910	0.260	0.459	0.619	0.744	0.687	0.786	0.862	0.947
Average	0.775	0.798	0.827	0.856	0.661	0.691	0.722	0.754	0.795	0.809	0.838	0.872

Table 6 continued

Subject ID	Value segment {5,001,…,7,500}				Value segment {7,501,…,10,000}			
	$n = 3$	$n = 7$	$n = 14$	$n = 21$	$n = 3$	$n = 7$	$n = 14$	$n = 21$
111	0.836	0.878	0.912	0.936	0.846	0.883	0.914	0.946
112	0.953	0.972	0.986	0.994	0.872	0.912	0.947	0.989
113	0.770	0.758	0.775	0.822	0.859	0.870	0.905	0.928
114	0.963	0.963	0.963	0.972	0.975	0.975	0.975	0.985
115	0.803	0.862	0.912	0.959	0.831	0.846	0.865	0.906
116	0.891	0.924	0.958	0.992	0.920	0.943	0.970	0.993
117	0.832	0.871	0.904	0.930	0.870	0.893	0.919	0.946
118	0.742	0.802	0.855	0.900	0.739	0.776	0.828	0.900
119	0.814	0.805	0.816	0.805	0.860	0.852	0.845	0.846
120	0.847	0.847	0.847	0.847	0.922	0.924	0.924	0.924
121	0.495	0.569	0.618	0.634	0.615	0.421	0.470	0.476
122	0.860	0.861	0.848	0.849	0.786	0.771	0.776	0.785
123	0.830	0.886	0.928	0.966	0.734	0.780	0.868	0.938
124	0.878	0.912	0.936	0.961	0.887	0.914	0.940	0.962
125	0.959	0.971	0.979	0.986	0.966	0.973	0.983	0.990
126	0.921	0.946	0.967	0.983	0.940	0.958	0.976	0.988
127	0.791	0.947	0.967	0.981	0.747	0.917	0.944	0.965
128	0.498	0.404	0.526	0.639	0.503	0.505	0.598	0.690
129	0.757	0.781	0.801	0.778	0.824	0.840	0.827	0.842
130	0.982	0.982	0.982	0.982	0.989	0.989	0.989	0.989
131	0.742	0.815	0.895	0.969	0.827	0.877	0.901	0.968
Average	0.817	0.845	0.875	0.899	0.834	0.849	0.874	0.903

Table 7 Individual average bid–value ratio by segment in within-subjects experiment—increasing-pay condition

Subject ID	Overall value segment {1,…,10,000}				Value segment {1,…,2,500}				Value segment {2,501,…,5,000}			
	$n = 3$	$n = 7$	$n = 14$	$n = 21$	$n = 3$	$N = 7$	$n = 14$	$n = 21$	$n = 3$	$n = 7$	$n = 14$	$n = 21$
132	0.706	0.783	0.820	0.839	0.537	0.609	0.621	0.626	0.784	0.816	0.856	0.856
133	0.630	0.628	0.651	0.686	0.571	0.565	0.547	0.584	0.608	0.529	0.598	0.646
134	0.793	0.844	0.877	0.918	0.795	0.891	0.892	0.919	0.860	0.879	0.905	0.936
135	0.861	0.897	0.933	0.948	0.862	0.866	0.893	0.907	0.858	0.932	0.971	0.978
136	0.654	0.514	0.509	0.521	0.210	0.102	0.102	0.102	0.441	0.089	0.000	0.000
137	0.811	0.842	0.873	0.922	0.753	0.796	0.822	0.886	0.788	0.822	0.860	0.915
138	0.851	0.886	0.906	0.925	0.706	0.738	0.764	0.789	0.759	0.854	0.889	0.924
139	0.894	0.891	0.897	0.929	0.818	0.847	0.852	0.941	0.921	0.915	0.898	0.890
140	0.503	0.547	0.581	0.628	0.576	0.586	0.596	0.606	0.496	0.548	0.569	0.606
141	0.985	0.967	0.985	0.985	0.973	0.973	0.973	0.973	0.986	0.986	0.986	0.986
142	0.903	0.921	0.935	0.940	0.902	0.917	0.942	0.905	0.875	0.896	0.907	0.931
143	0.882	0.899	0.955	0.969	0.712	0.754	0.939	0.965	0.850	0.866	0.916	0.938
144	0.938	0.950	0.955	0.962	0.837	0.846	0.853	0.860	0.957	0.964	0.968	0.973
145	0.902	0.929	0.952	0.982	0.815	0.865	0.914	0.980	0.949	0.971	0.984	0.990
146	0.886	0.910	0.940	0.960	0.845	0.866	0.888	0.914	0.906	0.920	0.951	0.976
147	0.908	0.911	0.926	0.930	0.853	0.853	0.868	0.824	0.937	0.937	0.944	0.966
148	0.818	0.864	0.928	0.940	0.800	0.811	0.927	0.939	0.848	0.910	0.949	0.966
149	0.790	0.835	0.889	0.961	0.763	0.824	0.881	0.956	0.768	0.790	0.855	0.937
150	0.942	0.955	0.974	0.979	0.928	0.937	0.954	0.954	0.966	0.970	0.983	0.988
151	0.930	0.956	0.976	0.988	0.929	0.958	0.968	0.977	0.943	0.960	0.977	0.990
152	0.943	0.964	0.971	0.986	0.920	0.971	0.980	0.988	0.986	0.988	0.990	0.992
Average	0.835	0.852	0.878	0.900	0.767	0.789	0.818	0.838	0.833	0.835	0.855	0.875

Table 7 continued

Subject ID	Value segment {5,001,…,7,500}				Value segment {7,501,…,10,000}			
	$n=3$	$n=7$	$n=14$	$n=21$	$n=3$	$n=7$	$n=14$	$n=21$
132	0.748	0.853	0.889	0.943	0.755	0.871	0.926	0.958
133	0.632	0.714	0.774	0.744	0.708	0.688	0.663	0.762
134	0.755	0.812	0.856	0.893	0.749	0.796	0.851	0.914
135	0.876	0.921	0.960	0.974	0.849	0.878	0.920	0.944
136	0.874	0.698	0.711	0.716	0.856	0.888	0.923	0.959
137	0.872	0.882	0.903	0.931	0.849	0.879	0.916	0.955
138	0.906	0.922	0.937	0.954	0.934	0.944	0.953	0.960
139	0.907	0.914	0.930	0.948	0.935	0.891	0.907	0.929
140	0.476	0.524	0.566	0.625	0.503	0.555	0.606	0.669
141	0.988	0.988	0.988	0.988	0.995	0.866	0.995	0.995
142	0.933	0.955	0.952	0.977	0.911	0.923	0.945	0.948
143	0.942	0.954	0.977	0.987	0.946	0.954	0.978	0.981
144	0.951	0.970	0.975	0.985	0.964	0.975	0.979	0.984
145	0.958	0.964	0.969	0.981	0.964	0.975	0.977	0.980
146	0.901	0.923	0.953	0.980	0.875	0.912	0.946	0.950
147	0.946	0.951	0.960	0.974	0.904	0.907	0.933	0.962
148	0.873	0.925	0.928	0.943	0.742	0.819	0.898	0.902
149	0.816	0.867	0.901	0.970	0.820	0.864	0.921	0.983
150	0.939	0.960	0.975	0.984	0.924	0.944	0.977	0.984
151	0.951	0.973	0.983	0.991	0.879	0.927	0.974	0.992
152	0.972	0.976	0.978	0.980	0.906	0.923	0.938	0.984
Average	0.867	0.888	0.908	0.927	0.856	0.875	0.911	0.938

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