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European University Institute, Florence

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# Experimental Results in Asymmetric Auctions — The 'Low-Ball' Effect —

Paul Pezanis-Christou*

November 15, 1994

**Abstract**

Maskin and Riley [1993] showed that Vickrey's well known Revenue Equivalence Theorem no longer holds in private - independent value auctions when bidders are assumed to be *asymmetric* and provided sufficient conditions on the buyers' distributions of values for the ranking of First- and Second-Price auctions in terms of the seller's expected revenue. The purpose of the present paper is to check whether theoretical predictions concerning the dominance of second-price over first-price auctions are verified in a laboratory experiment. Results show that the suggested ranking is not verified on either a full-sample basis or, once a learning activity has been detected, on a sub-sample basis.

*I wish to thank Reinhard Selten and Ronald Harstad for helpful suggestions on the running of the experiment and John Riley for providing numerical simulations of the equilibrium bidding strategies in First-Price auctions. I am also indebted to Klaus Abbink and Abdolkarim Sadrieh for their comments and time spent on the programming of the experiment. Finally, I wish to thank Alan Kirman, my thesis advisor, and Louis Phlips for their guidance. Financial support from the European University Institute and from the Deutsche Forschungsgemeinschaft through SFB 303 is gratefully aknowledged. Remaining errors are my own.

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# 1 Introduction

In this paper we present a laboratory analysis of some results recently reported in the literature on auction theory. This literature is usually thought of as stemming from Vickrey's [1961] seminal paper where attention was focused on four single unit auction institutions: the English, the Dutch, the First-Price Sealed Bid (FP) and the Second-Price Sealed Bid (SP) auctions. By considering these auctions as bidding games and by analysing their *strategic* forms, he stated the Revenue Equivalence Theorem (RET): these four auction institutions yield the same expected revenue to the seller. This result holds under a set of assumptions that are still considered as a benchmark in auction theory. These assumptions are:

1. The number of bidders participating in the auction is common knowledge,

2. Bidders are *risk neutral*,

3. Bidders are *symmetric* in the sense that they all draw their valuations from the same distribution which is common knowledge,

4. Any one bidder's valuation is statistically independent of any other bidder's valuation. Valuations are then said to be *private - independent.*

Part of subsequent research in auction theory focused on the implications of relaxing one or more of these assumptions on the seller's revenue and on bidders' bidding behaviour (Matthews [1987], Cox et al. [1982][1985]and [1988], Milgrom and Weber [1982]). In this vein, Maskin and Riley [1993] — referred to as MR henceforth — relaxed the 'symmetric-bidders' assumption and determined sufficient conditions on bidders' distributions of valuations for the ranking of FP and SP auctions in terms of the seller's expected revenue. In fact, recalling that the dominant strategy in a SP auction (i.e.: to bid one's valuation) is independent of bidder's distribution of values, the ranking of these auctions

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relies on two possible strategic behaviours that a bidder should adopt in FP auctions when facing a particular type of opponent (the opponent's type being defined by his distribution of valuations).

On one hand, when the asymmetry results because one buyer has a much higher probability of not bidding at all, it is the SP auction which dominates. This is due to the *low-ball* effect inherent to FP auctions: knowing that his opponent will not bid with a sufficiently high probability, a bidder should then submit a very low bid. On the other hand, when the asymmetry results because one buyer places sufficiently higher probability on high valuations then it is the FP auction that dominates. This is due to the *sure thing* effect or equivalently to the reluctance of the optimistic bidder (the one who has higher probability on high valuations) to take on risk by submitting lower bids.

Although both effects are readily perceived in a simple example involving atomic distributions, the predictions derived for continuous distributions are less intuitive. These theoretical insights remain nonetheless of considerable importance since they tackle one of the most realistic working assumptions and may to this extent explain why some auction formats are actually prefered by sellers to others.

Most of the auction literature that dealt with this assumption considered common-value auctions with, at the exception of Hausch [1987], the particular type of asymmetry resulting from the presence of some proprietary information in a symmetric setting[1]. In such a framework, a bidder is said to have proprietary information when he detains additional private information (such as on the true value of the item). Ortega-Reichert [1968] and Engelbrecht-Wiggans et al. [1983] analysed the consequences of this pattern in a one-period FP auction and Engelbrecht-Wiggans and Weber [1983] in sequential FP auctions.

[1] In common value auction models, bidders need to guess the true value ($V$) of the item to be sold. $V$ is assumed to be drawn from a known probability distribution and bidders receive private signals that are independent and identically distributed, conditional on $V$. In this respect, Hausch [1987] examines FP and SP auctions where bidders are asymmetric in that their private signals are drawn from different point distributions.



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The present paper reports on a series of experiments that reproduces MR's conditions to observe the *low-ball* effect in FP auctions and the resulting theoretical dominance of SP auctions in terms of the seller's expected revenue. Results show first that subjects did adopt significantly different strategies in SP auctions as they changed of competition environment and second, while they did realize the strategic implications of asymmetric preferences in FP auctions, the expected dominance outcome was not observed. This being understood when the equilibrium bidding strategies in FP auctions are reconsidered from a feasibility point of view.

The following section spells out the theoretical framework and the assumptions underlying MR's predictions. Section 3 describes the experimental design. Results are given in Section 4 and Section 5 concludes the paper.

# 2 Theoretical framework

There are 2 risk neutral buyers ($i=1,2$) competing for the purchase of a single item to be auctioned off. Each buyer $i$ has private information concerning his own valuation $v_i$ for the item, which is independently drawn from a non-degenerated c.d.f. $F_i \in C^1$ with support $[0; \bar{v}_i]$. Both supports and distribution functions are common knowledge.

## 2.1 Equilibrium bidding strategies

Under the above assumptions, Vickrey's [1961] well-known result with regards to the outcomes of SP and English auctions still remains valid. Indeed, despite the presence of asymmetries in bidders' distributions of values, it is still a dominant strategy to submit bids equal to one's valuation in SP auctions or to remain in the rising bidding process of an English auction until the last offer equals one's valuation. In both auction institutions, if bidders play their dominant strategies, the winning bidder will be awarded the item for a price equal to the second highest valuation .



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In FP auctions, the buyer who submitted the highest bid is awarded the item for a price equal to his bid. A buyer $i$ with valuation $v_i$ who obtains the item with a bid $b$ earns a profit of $v_i - b$. A pair of bid functions

$$b = B_i(v) \qquad \text{and} \qquad B_i'(\cdot) > 0, \qquad \text{for } i = 1, 2 \tag{1}$$

is then said to be an equilibrium if, for all feasible $v$, it is a best response for buyer $i$ to adopt $B_i(v)$ as his bidding strategy given that buyer $j$ $(j \neq i)$ bids $B_j(v)$. Let $v = \phi_i(b)$ denote the inverse function of $B_i(\cdot)$. That is, player $i$ bids $b$ when his valuation is $\phi_i(b)$ and wins if the other buyer bids less, that is if $v_j < \phi_j(b)$. Therefore, buyer $i$'s expected profit can be expressed as

$$U_i(v, b) = (v - b)F_j(\phi_j(b)), \qquad \text{for } i \neq j = 1, 2 \tag{2}$$

For both bidders, since it is not worth bidding more then one's competitor's maximum possible bid, there must exist some common maximum bid $\bar{b}$. On the other hand, a buyer with a zero valuation will not submit a positive bid since if he did so and won the auction, he would incur a loss. Hence, the equilibrium inverse bid functions must satisfy

$$\phi_i(0) = 0 \qquad \text{and} \qquad F_i(\phi_i(\bar{b})) = 1, \qquad \text{for } i = 1, 2 \tag{3}$$

$\phi_i(b)$ and $\phi_j(b)$ can now be defined as being the solution of the following system of differential equations

$$\phi_1(b)F'(\phi_2)\phi_2' - F_2(\phi_2)\phi_2' - F_2(\phi_2) = 0$$

$$\phi_2(b)F'(\phi_1)\phi_1' - F_1(\phi_1)\phi_1' - F_1(\phi_1) = 0$$

satisfying the boundary conditions (3).

In what follows, buyer 1 will be assumed to be the more optimistic buyer in the sense that his distribution of values, $F_1(v)$ dominates stochastically that of his competitor, that is $F_1(v) \leq F_2(v)$ so that $\bar{v}_1 \leq \bar{v}_2$.



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## 2.2 Expected revenue for the seller from SP auctions

Since it is a dominant strategy for both bidders to bid their own value, the theoretical expected revenue for the seller may be expressed as follows — Proposition 3.4 in MR —:

$$R_{SP} = \int_0^{\bar{v}_2} [1 - F_1(x)] \frac{d}{dx}[x(1 - F_2(x))]dx + \int_0^{\bar{v}_2} [1 - F_1(x)]xdF_2(x)$$

and has a distribution defined by

$$G(b) = 1 - [1 - F_1(b)][1 - F_2(b)], \qquad \text{for } b \in [0; \bar{v}_2] \tag{4}$$

## 2.3 Behavioural lemmas

Most of theoretical insights provided in MR rely on two behavioural lemmas which both require the following assumption on the buyers' distributions of valuations.

**Assumption A:** For all $v$, $\quad \frac{\partial}{\partial v}\left[\frac{F_1(v)}{F_2(v)}\right] > 0.$

L1: *Under Assumption A the more optimistic buyer bids less aggressively* — Lemma 3.1 in MR —.

L2: *Under Assumption A the equilibrium bid distribution of the more optimistic buyer exhibits first order stochastic dominance over the bid distribution of the more pessimistic buyer* — Lemma 3.2 in MR —.

## 2.4 Sufficient conditions for the ranking of auction institutions in terms of seller's expected revenue

The suggested ranking of auction institutions in terms of seller's expected revenue requires this last hypothesis:



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**Assumption B:** For $v \in [0; \bar{v}_2]$, $$\frac{\partial}{\partial v}\left[\frac{1-F_1(v)}{1-F_2(v)}\right] < 0.$$

SC1: *If Assumption A holds and if for all $v$ and $w$ such that for $w > v$*

$$F_1(w) < F_2(v) \Rightarrow F_1'(w) < F_2'(v)$$

*then expected revenue is higher in FP auctions than in SP* auctions — Proposition 3.6 in MR —

SC2: *If Assumption A and B hold, if $F_1(\cdot)$ is concave and if $\dfrac{F_2'(v)}{1-F_2(v)}$ is nondecreasing, then expected revenue is higher in the SP auctions than in FP auctions.*

# 3 Experimental design

The experiment consisted of four sessions in each of which 12 subjects participated. All subjects were recruited from populations of undergraduate students by means of public advertisement at the University of Bonn and were required to be inexperienced (i.e.: no previous participation in auction market experiments).

For all sessions, subjects reported to the experimental laboratory where written instructions were distributed and reviewed (see Appendix A). Once the key properties of the auction institution were explained and an example given, an introduction to the computer program and terminals' features was provided. Subjects were then randomly assigned to a computer terminal. The experimental setting can be summarised as follows:

*1. The distributions of valuations:* The unique requirement on bidders' distributions to observe *low-balling* (Assumption A) can be satisfied with an appropriate set of uniform distributions. Since for FP auctions, both the equilibrium bidding strategies and the seller's expected revenue have no analytical expressions, Maskin and Riley evaluated numerically the differences in seller's expected revenues from FP and SP auctions in



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various asymmetric configurations. Two of these configurations, henceforth labelled Case 1 and Case 2, will be considered. In Case 1, a subject with values drawn from U[0;100] (henceforth called a subject of type 1) will compete with a subject of type 2, that is with values drawn from U[-100;100]. In Case 2, a subject of type 1 will compete with a bidder of type 3 whose values are drawn from U[-300;100].

*2. The matching procedure:* Without further precisions, subjects were told that in each round they would be randomly matched with another participant. The cohort of 12 subjects in a given session was actually partitioned into 3 groups of 4 subjects from which the pairs of competitors were randomly drawn. Such a precaution allowed three statistically independent sets of observations to be obtained per session instead of only one. Also, for ease of comparison between FP and SP auction outcomes and in order to avoid sampling errors, both the matching of participants and the samples of valuations were kept constant across auction institutions.

*3. The sequencing of competition environments:* Subjects' attention was drawn to the fact that each of them would alternatively and deterministically change type or competition environment in each trading period of the session. Due to the implicit presence of some learning-by-doing, this option was preferred to swapping bidders' types after they had played in the same configuration for more then one round, in which case they would transfer their knowledge to the new competition environment and thereby biasing the data. The other alternative would have been to keep bidders' types constant during the whole session, in which case the resulting disparities in subjects' profits could yield some of them to adopt odd end-of-session behaviours. To prevent subjects possibly being confused by the constant change of bidding configuration, types were assimilated to colors and in each round, both subjects' ranges of valuations were displayed.

*4. The starting capital balance (SCB):* Since subjects were allowed to submit any integer bid between 0 and 100, they were permitted to bid above their valuation. For inexperienced subjects, bidding above one's value may seem a reasonable strategy in SP auctions since the dominant



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strategy to bid exactly one's valuation is not necessarily (or at least immediately) perceived. A drawback of allowing subjects to do so is that they may incur losses if they win. Each subject was therefore granted a small initial capital balance in order to permit him to suffer losses in one or two rounds and told that if his net balance dropped below zero at any time during the experiment, he was no longer permitted to participate.

*5. The information feedback:* At the end of each trading period, all terminal screens displayed the outcome of that particular round. Each subject was privately informed whether he had won or lost, the profit made in that round, the opponent's bid as well as both players' types. This information was then appended to a 'history window' that could be retrieved at any time during the session. The alternative of providing subjects with full information feedback (i.e.: opponent's value, bid, profit and identity) could have yielded undesirable supergame effects and/or mimicking of opponent's strategy and was therefore discarded here.

# 4 Experimental results

## 4.1 Expected revenue and efficiency comparisons

Tables 1 and 2 report some statistics describing the observed expected revenues for the seller in FP and SP auctions for the 6 groups of subjects and both competition environments. Although the expected selling prices from SP auctions are slightly above their theoretical predictions (i.e.: 16.66 for Case 1 and 8.33 for Case 2), they all remain close to the sample average of the second highest valuation $E(X_{(2)})$. In order to check whether the observed and theoretical distributions of prices in SP auctions agree or not, Tables 1 and 2 show the results of a two-tailed Kolmogorov-Smirnov test (K-S). The null hypothesis that the observed distribution of expected revenue $R_{SP}(b)$ is equal to Eq. 4 was accepted for all groups and in both asymmetric cases[2].

[2]It is worth noting that most sample distributions of selling prices and bids exhibit significant skewness, kurtosis and rejected the $\chi^2(2)$-test of normality, thereby



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Table 1: Expected Revenues Comparisons (Case 1).

| | SPSB | | | | FPSB | | | |
|---|---|---|---|---|---|---|---|---|
| Group (# Obs) | Mean (s.d.)[a] | Med.[a] | $E(X_{(2)})$ | $D_{Th}$[b] | Mean (s.d.) | Med. | $z^c$ $D^d$ | $\bar{\delta}^e$ (s.d.) |
| 1 (72) | 20.68 (25.2) | 9.5 | 17.39 | 0.09 | 17.17 (13.8) | 15 | 1.18 0.36* | 3.51 (22.75) |
| 2 (72) | 20.29 (27.2) | 5 | 18.33 | 0.07 | 25.86 (12.94) | 25 | 3.54* 0.47* | — |
| 3 (72) | 18.78 (24.38) | 1 | 16.32 | 0.06 | 26.74 (16.52) | 29 | 3.71* 0.49* | -7.96⁻ (21.4) |
| 4 (60) | 17.97 (26.7) | 4.5 | 19.8 | 0.07 | 21.9 (11.54) | 24.5 | 3.38* 0.4* | — |
| 5 (60) | 17.65 (27.17) | 0 | 17.43 | 0.08 | 16 (10.71) | 17.5 | 2.85* 0.47* | — |
| 6 (60) | 26.12 (28.06) | 17.5 | 24.53 | 0.17 | 17.4 (13.05) | 16.5 | -0.23 0.32° | 8.72⁺ (24.73) |
| All (396) | 20.22 (26.38) | 5 | 18.82 | 0.06 | 21.06 (13.95) | 21 | 5.79* 0.41* | — |

[a]: (s.d.): Standard deviation of expected revenue. Med.: Median

[b]: Two-tailed K-S test.
$H_0 : R_{SP}(b) = R_{SP}^{Th}(b)$ against $H_1 : R_{SP}(b) \neq R_{SP}^{Th}(b)$.

[c]: One-tailed M-W test ($z$: unit normal deviate).
$H_0 : R_{FP}(b) = R_{SP}(b)$ against $H_1 : R_{FP}(b) \leq R_{SP}(b)$.

[d]: One-tailed *two-sample* K-S test.
$H_0 : R_{FP}(b) = R_{SP}(b)$ against $H_1 : R_{FP}(b) \leq R_{SP}(b)$.

[e]: Average difference between observed prices in SP and FP auctions:
$\bar{\delta} = p_{sp} - p_{fp}$.

*: Reject $H_0$ at significance level: $p < 0.05$.

°: Reject $H_0$ against $H_1 : R_{FP}(b) \geq R_{SP}(b)$ at significance level: $p < 0.05$.

$^+$: Reject $H_0 : \bar{\delta} = 0$ against $H_1 : \bar{\delta} > 0$ at significance level: $p < 0.05$.

$^-$: Reject $H_0 : \bar{\delta} = 0$ against $H_1 : \bar{\delta} < 0$ at significance level: $p < 0.05$.



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Table 2: Expected Revenues Comparisons (Case 2).

| | SPSB | | | | FPSB | | | |
|---|---|---|---|---|---|---|---|---|
| Group (# Obs) | Mean (s.d.) | Med. | $E(X_{(2)})$ | $D_{Th}$ | Mean (s.d.) | Med. | $z$ $D$ | $\bar{\delta}$ (s.d.) |
| 1 (72) | 8.14 (17.23) | 0 | 7.22 | 0.03 | 11.9 (14.05) | 6 | 5.23* 0.63* | — |
| 2 (72) | 7.21 (19.55) | 0 | 7.82 | 0.06 | 12.81 (11.48) | 10 | 6.61* 0.72* | — |
| 3 (72) | 5.53 (14.07) | 0 | 4.9 | 0.07 | 16.19 (17.23) | 11 | 6.94* 0.72* | — |
| 4 (60) | 7.82 (15.44) | 0 | 10.25 | 0.07 | 15.06 (11.39) | 17 | 4.28* 0.47* | — |
| 5 (60) | 10.72 (23.32) | 0 | 9.43 | 0.03 | 9.68 (9.04) | 8 | 4.2* 0.57* | — |
| 6 (60) | 15.4 (23.69) | 0 | 14.1 | 0.14 | 8.6 (7.75) | 6 | 2.26* 0.52* | — |
| All (396) | 8.94 (19.25) | 0 | 8.74 | 0.03 | 12.49 (12.65) | 10 | 12.09* 0.61* | — |

To proceed with a ranking of auction institutions in terms of expected selling prices it may first be observed that there is no evidence that these are smaller in FP auctions than in SP auctions. By means of a one-tailed Mann-Whitney (M-W) test of the hypothesis that price series obtained from FP and SP auctions are stochastically equivalent, the null hypothesis can be rejected in favour of the alternative that selling prices are stochastically larger in FP than in SP auctions for most groups and in the aggregate. Results of a similar one-tailed *two-sample* K-S test cross-check and confirm this tendency.

Hence, on the basis of 396 observations per case, our data rejected MR's theoretical predictions that FP auctions yield smaller expected revenues to the seller than SP auctions[3]. Table 3 displays two measures of

proscribing the usual battery of parametric tests. Appropriate $t$-tests will however be performed and reported when samples have Gaussian distributions.

[3]Numerical simulations revealed that expected revenues were 13% smaller in FP auctions than in SP auctions in Case 1, and 34% smaller in Case 2.



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Table 3: Pareto-Optimality of Allocations

| | Case 1 | | | | Case 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | SPSB | | FPSB | | SPSB | | FPSB | |
| Group | M.E.[a] | %[$POA$][b] | M.E. | %[$POA$] | M.E. | %[$POA$] | M.E. | %[$POA$] |
| 1 | 96 | 90.3 | 94 | 84.7 | 100 | 100 | 96.1 | 93.1 |
| 2 | 98.4 | 91.7 | 96.2 | 90.3 | 99.3 | 97.2 | 97.7 | 93.1 |
| 3 | 97.1 | 93.1 | 95.8 | 87.5 | 98.7 | 98.6 | 96.5 | 94.4 |
| 4 | 97.9 | 88.3 | 91.4 | 80 | 94.7 | 90 | 96 | 93.3 |
| 5 | 97.2 | 90 | 94.9 | 85 | 99.8 | 98.3 | 95.5 | 90 |
| 6 | 99.7 | 95 | 93.5 | 78.3 | 100 | 100 | 94.2 | 81.7 |
| All | 97.7 | 91.4 | 94.4 | 84.6 | 98.8 | 97.5 | 96.1 | 91.2 |

[a]: Mean Efficiency.
[b]: Percentage of Pareto-Optimal Allocations.

efficiency of allocations in SP and FP auctions. If $W$ stands for the winner's valuation and if $V$ represents the highest value between the two competitors, Cox et al. [1982] measure the efficiency of an allocation by the ratio $\frac{100.W}{V}$. An allocation is said to be Pareto-optimal if the ratio equals 100. Any efficiency level below 100 characterizes unrealized gains from trade. Table 3 reports the mean efficiency for each group of subjects as well as the percentage of Pareto-optimal allocations among all auctions. As always observed in previous symmetric auction experiments (Cox et al. [1982], Harstad [1993] and Kagel [1993]), the SP institution appeared to be more efficient than the FP one, and this for both asymmetric settings.

## 4.2 Cumulative distributions of bids in FP auctions

According to Lemma L1, it should be observed that for equal valuations, subjects of type 1 in Case 1 submit lower bids than those of type 2 (and similarly for subjects of type 1 and 3 in Case 2). For each group and type $i$ of subjects, Table 4 shows the average relative difference $\bar{\delta}_i$ between subjects' valuations and bids. As implicitly postulated in L1, we



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Table 4: Comparisons of Cumulative Distribution of Bids in FP auctions.

| | Case 1 | | | | Case 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Group | $\Gamma^a$ | Type 1 $\bar{\delta_1}$ (s.d.)[b] | Type 2 $\bar{\delta_2}$ (s.d.) | $t_{12}$[c] $D_{12}$[d] (#)[e] | $\Gamma$ | Type 1 $\bar{\delta_1}$ (s.d.) | Type 3 $\bar{\delta_3}$ (s.d.) | $t_{13}$ $D_{13}$ (#) | $t_{11}$ $D_{11}$ | $t_{23}$ $D_{23}$ |
| 1 | 0.28* | 0.77 | 0.62 | — | 0.54* | 0.83 | 0.71 | — | — | — |
| | | (0.19) | (0.19) | 0.4* | | (0.22) | (0.15) | 0.56* | 0.24* | 0.3 |
| | | | | (40) | | | | (18) | | |
| 2 | 0.46* | 0.61 | 0.45 | — | 0.69* | 0.78 | 0.56 | — | — | — |
| | | (0.21) | (0.15) | 0.45* | | (0.18) | (0.18) | 0.64* | 0.51* | 0.37* |
| | | | | (38) | | | | (18) | | |
| 3 | 0.43* | 0.62 | 0.4 | 5.4* | 0.69* | 0.73 | 0.51 | — | — | — |
| | | (0.22) | (0.17) | 0.55* | | (0.24) | (0.17) | 0.57* | 0.34* | 0.3 |
| | | | | (37) | | | | (16) | | |
| 4 | 0.25* | 0.7 | 0.52 | — | 0.42* | 0.75 | 0.53 | — | — | — |
| | | (0.22) | (0.17) | 0.39* | | (0.24) | (0.17) | 0.61* | 0.25* | 0.19 |
| | | | | (34) | | | | (19) | | |
| 5 | 0.42* | 0.8 | 0.63 | 4.74* | 0.47* | 0.89 | 0.7 | — | — | — |
| | | (0.13) | (0.17) | 0.49* | | (0.09) | (0.16) | 0.6* | 0.43* | 0.27 |
| | | | | (29) | | | | (18) | | |
| 6 | 0.2 | 0.77 | 0.68 | — | 0.42* | 0.88 | 0.79 | — | — | — |
| | | (0.21) | (0.16) | 0.35* | | (0.11) | (0.12) | 0.39* | 0.29* | 0.39* |
| | | | | (36) | | | | (23) | | |
| All | 0.34* | 0.71 | 0.55 | — | 0.54* | 0.81 | 0.64 | — | — | — |
| | | (0.21) | (0.2) | 0.33* | | (0.2) | (0.19) | 0.43* | 0.27* | 0.26* |
| | | | | (214) | | | | (112) | | |

[a]: One-tailed K-S test. $H_0 : G_1(b) = G_2(b)$ against $H_1 : G_1(b) \leq G_2(b)$.

[b]: Standard deviation of $\delta_i = (v_i - b_i)/v_i$.

[c]: One-tailed $t$-test. $H_0 : \bar{\delta_1} = \bar{\delta_2}$ against $H_1 : \bar{\delta_1} > \bar{\delta_2}$.

[d]: One-tailed K-S test. $H_0 : J_{11}(\delta) = J_{21}(\delta)$ against $H_1 : J_{11}(\delta) \leq J_{21}(\delta)$.

[e]: Number of trading periods where subjects of type $\neq 1$ received positive values.

*: Reject $H_0$ at significance level: $p < 0.05$.



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observe that $\bar{\delta}_1 > \bar{\delta}_2$ in Case 1 and $\bar{\delta}_1 > \bar{\delta}_3$ in Case 2. This is confirmed by means of a K-S test ($D$) on the distributions $J_{ij}(\delta)$ of $\delta_i$ in Case $j$ which shows that $J_{11}(\delta) \leq J_{21}(\delta)$ and $J_{12}(\delta) \leq J_{32}(\delta)$ at both aggregate and group levels.
Furthermore, since subjects of type 1 (type 2) in Case 1 are in a clearly different competition environment than those of type 1 (type 3) in Case 2, distinct bidding behaviours should then be observed. From the plots of theoretical bidding functions in Figure 1 we see that for equal values *i*) subjects of type 1 submit lower bids when they are in Case 2 than when being in Case 1 and *ii*) subjects of type 3 submit lower bids than those of type 2. Hence we should observe that $\bar{\delta}_1$ in Case 1 is greater than $\bar{\delta}_1$ in Case 2 or equivalently that $J_{11}(\delta) \geq J_{12}(\delta)$ and that $\bar{\delta}_2 < \bar{\delta}_3$ or $J_{21}(\delta) \geq J_{32}(\delta)$. Results of a K-S test performed on the observed distributions indicates that subjects did adopt distinct bidding behaviours and in accordance with MR's theoretical predictions.

From Lemma L2, in each asymmetric case the bid distributions of subjects of type 1, $G_1(b)$, stochastically dominate those of their competitors: $G_2(b)$ in Case 1 or $G_3(b)$ in Case 2. Table 4 shows the results of a one-tailed K-S test ($\Gamma$). The null hypothesis that $G_1(b) = G_2(b)$ in Case 1 and $G_1(b) = G_3(b)$ in Case 2 can be rejected in favour of the alternative that bids submitted by subjects of type 1 are stochastically larger than those submitted by their respective competitor (type 2 or 3).

## 4.3 Bidding behaviours in SP and FP auctions

### 4.3.1 Second-Price auctions

As often observed in SP auction experiments (Harstad[1993], Kagel [1993] Kagel et al. [1987] and Kagel and Levin [1993]), subjects did not necessarily adopt the dominant strategy when bidding. Only about 50% of all bids were equal to subjects' valuations (and about 40% were above). This figure is relatively large when compared to the 30% reported by Kagel and Levin [1993] for a set of symmetric SP private-independent values auction experiments with 5 and 10 bidders. Although the auction



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Table 5: Relative Deviations from Dominant Strategy in SP auctions.

| | Case 1 | | Case 2 | | K-S | | | |
|---|---|---|---|---|---|---|---|---|
| | Type 1 | Type 2 | Type 1 | Type 3 | | | | |
| Group | $\bar{d}^a$ (s.d.) [Med.] | $\bar{d}$ (s.d.) [Med.] | $\bar{d}$ (s.d.) [Med.] | $\bar{d}$ (s.d.) [Med.] | $D_{12}{}^b$ $[D'_{12}]^c$ $(\#)^d$ | $D_{13}$ $[D'_{13}]$ (#) | $D_{11}$ $[D'_{11}]$ | $D_{23}$ $[D'_{23}]$ |
| 1 | 1.12• (5.25) [0.03] | 0.83• (2.85) [0.02] | 0.16• (0.77) [0] | 0.15• (0.35) [0.03] | 0.11 (40) | 0.31 (18) | 0.18 | 0.22 |
| 2 | 0.36• (1.88) [0] | 0.1• (0.31) [0] | 0.31• (1.57) [0] | -0.04 (0.2) [0] | 0.31* (38) | 0.53* (18) | 0.11 | 0.39* |
| 3 | 0.36• (1.04) [0] | 0.05 (0.25) [0] | 0.34• (1.69) [0] | 0.73• (2.87) [0] | 0.44* (37) | 0.62* (16) | 0.14 | 0.38** |
| 4 | -0.03• (0.45) [0] | 0.08• (0.32) [0.02] | 0• (0.47) [0] | -0.13 (0.37) [0] | 0.16 (34) | 0.29 (19) | 0.08 | 0.3 |
| 5 | 0.19 (0.61) [0] | 0.13 (0.65) [0] | 0.07 (0.31) [0] | 0.1 (0.31) [0] | 0.15 (29) | 0.28 (18) | 0.1 | 0.2 |
| 6 | 0.16• (0.57) [0] | 0.07• (0.11) [0] | 0.06• (0.12) [0] | 0.44• (1.53) [0] | 0.22 (36) | 0.32** (23) | 0.08 | 0.21 |
| All | 0.38• (2.46) [0] | 0.22• (1.29) [0] | 0.17• (1.06) [0] | 0.2• (1.31) [0] | 0.21* [0.1] (214) | 0.33* [0.09] (112) | 0.08 [0.11] | 0.26* [0.11] |

[a]: Mean of relative deviations from dominant strategy: $d = (b_i - v_i)/v_i$.

[b]: Two-tailed *two-sample* K-S test.
$H_0 : \Psi_1(d) = \Psi_2(d)$ against $H_1 : \Psi_1(d) \neq \Psi_2(d)$.

[c]: Two-tailed *two-sample* K-S test on non-zero deviations ($d \neq 0$).
$H_0 : \Psi_1^*(d) = \Psi_2^*(d)$ against $H_1 : \Psi_1^*(d) \neq \Psi_2^*(d)$.

[d]: Number of trading periods where subjects of type $i \neq 1$ received positive values.

•: Reject the null hypothesis that $\bar{d} < 0$ in favour of the alternative that $\bar{d} > 0$. (binomial test on non-zero deviations)

*: Reject $H_0$ at significance level: $p < 0.05$. [**: $p < 0.1$]



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game is considerably simplified when there are only 2 competitors, there is an important difference in the experimental designs that strengthens the appearance that the dominant strategy is more easily adopted when there are only 2 competitors (even though these are *asymmetric)*: subjects in this experiment were not provided with full information feedback as they were in Kagel and Levin [1993] (i.e.: all competitors' bids and valuations), so that no mimicking of opponent's bidding strategy was possible.

For each group and asymmetric setting, Table 5 displays some statistics on the relative deviations from the dominant strategy,

$$d = \frac{\text{[bid]-[valuation]}}{\text{[valuation]}}$$

Since optimal bidding in SP auctions is insensible to asymmetries in bidders' distributions of valuations, these relative deviations should thus theoretically be equal to 0 and remain constant through competition environments.

A binomial test on non-zero deviations ($d \neq 0$) shows that should a bidder deviate from his dominant strategy he is more likely to bid above his valuation than below. For symmetric SP auctions, Harstad [1993] attributes the presence of overbidding to the combined effects of subjects' misunderstanding of the selling procedure and the weakness of learning feedback mecanisms that would correct for this pattern. Both of these effects were readily perceived in this experiment. First, from informal discussions with participants at the end of SP sessions, it appeared that most of them established a trade-off between $i$) increasing the probability of winning by overbidding and $ii$) decreasing the probability of losing money by submitting bids not too much above their values. This trade-off in terms of probabilities seemed to be preferred to the straightforward questioning of what is the gain from overbidding and winning the auction as compared to bidding one's valuation. Second, an analysis of the overbidding pattern illustrates well the weakness of learning feedback mechanisms in this auction institution: when bidding above ones valuation, the probability of incurring a loss is far smaller then that of earning



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a positive profit (respectively, 0.107 and 0.648 in Case 1 and 0.037 and 0.775 in Case 2).

A set of K-S *two-sample* tests — $D_{ij}$ in Table 5 — checks furthermore whether the distribution of relative deviations for subjects of type $i$, $\Psi_i(d)$, differs or not from $\Psi_j(d)$. Since in the aggregate, the null hypothesis that (according to theory) $\Psi_i(d) = \Psi_j(d)$ has only been accepted when $\Psi_1(d)$ in Case 1 was compared with $\Psi_1(d)$ in Case 2, it appears that the observed distributions of relative deviations did significantly change as bidders swapped types. Results of similar K-S *2-sample* tests — $D'_{ij}$ — on the aggregate distributions of non-zero deviations, $\Psi_1^*(d)$, also indicate that there are no significant changes in subjects' *out-of-equilibrium* behaviours when they change type. The discrepancies in terms of significance between $D_{ij}$ and $D'_{ij}$ are then due to various proportions of zero deviations in $\Psi_i(d)$ and $\Psi_j(d)$[4]. Despite the relatively higher rate of equilibrium bids reported here, these deviations are not as well organized as those observed in Kagel and Levin [1993] where a significant decrease in overbids occurred as the number of bidders increased from 5 to 10 in symmetric SP experiments. These misbehaviours illustrate well participants' difficulties in understanding SP auction selling rules.

Convergence to the dominant strategy across trading periods has however been observed. A core of 5 subjects adopted the dominant strategy within ten rounds and 6 others did so within forty. No particular bidding behaviour has further been observed: some of the remaining participants converged to the dominant strategy only by the end of the session while others continued to overbid.

[4]Among all bids, 50% of those submitted by subjects of type 2 or 3 were equal to subject's valuation and for subjects of type 1 in Case 1 and in Case 2, these percentages were respectively equal to 46.2% and 47.5%. Also, since most rejections of the null hypothesis that $\Psi_i(d) = \Psi_j(d)$ were observed in Groups 2 and 3, K-S tests were performed on the aggregate data of Groups 1, 4, 5 and 6. We observed: $D_{12} = 0.13$, $D_{13} = 0.22^*$, $D_{11} = 0.08$ and $D_{23} = 0.22^*$.



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Table 6: Relative Deviations from Equilibrium in FP auctions.

| | Case 1 | | Case 2 | | K-S | | | |
|---|---|---|---|---|---|---|---|---|
| | Type 1 | Type 2 | Type 1 | Type 3 | Case 1 | | Case 2 | |
| Group | $\bar{d}^a$ (s.d.) [Med.] | $\bar{d}$ (s.d.) [Med.] | $\bar{d}$ (s.d.) [Med.] | $\bar{d}$ (s.d.) [Med.] | $D_1^{-\,b}$ | $D_2^-$ | $D_1^-$ | $D_3^-$ |
| 1 | 0.09 (0.2) [0.02] | 0.09 (0.2) [0.05] | 0.12• (0.23) [0.03] | 0.11•‡ (0.16) [0.07] | 0.1 | 0.08 | 0.32* | 0.03 |
| 2 | 0.24• (0.25) [0.21] | 0.25•‡ (0.16) [0.2] | 0.17• (0.19) [0.14] | 0.26•‡ (0.18) [0.21] | 0.36* | 0.21* | 0.47* | 0.11 |
| 3 | 0.24• (0.24) [0.23] | 0.3•‡ (0.19) [0.25] | 0.23• (0.24) [0.19] | 0.32•‡ (0.17) [0.34] | 0.24* | 0.19* | 0.44* | 0.08 |
| 4 | 0.14• (0.24) [0.08] | 0.17• (0.19) [0.13] | 0.19• (0.26) [0.17] | 0.26•‡ (0.19) [0.26] | 0.26* | 0.14 | 0.46* | 0.17* |
| 5 | 0.05 (0.12) [0.04] | 0.06 (0.2) [0.03] | 0.05• (0.08) [0.04] | 0.12•‡ (0.16) [0.09] | 0.06 | 0.04 | 0.28* | 0.08 |
| 6 | 0.06 (0.23) [0] | 0.01 (0.16) [0] | 0.06 (0.12) [0.04] | 0.03 (0.13) [0] | 0.15 | 0.13 | 0.29 | 0.15 |
| All | 0.14• (0.23) [0.09] | 0.15• (0.21) [0.14] | 0.14• (0.21) [0.08] | 0.18•‡ (0.19) [0.13] | 0.18* | 0.12* | 0.35* | 0.1 |

[a]: Mean of relative deviations from the equilibrium strategy $b^*(.)$: $d = (b_i - b^*(v_i))/v_i$.

[b]: One-tailed K-S test. $H_0 : G_1(b) = G_1^{Th}(b)$ against $H_1 : G_1(b) \leq G_1^{Th}(b)$.

•: Reject $H_0 : \bar{d} \leq 0$ against $H_1 : \bar{d} > 0$. (binomial test).

‡: Reject $H_0 : \bar{d} = 0$ against $H_1 : \bar{d} > 0$. ($t$-test).



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### 4.3.2 First-Price auctions

As Table 5, Table 6 reports statistics on subjects' relative deviations from their respective equilibrium bidding strategy $b^*(.)$

$$d = \frac{[\text{bid}] - b^*(v)}{[\text{valuation}]}$$

As mentioned earlier, optimal bidding strategies in these FP auctions represent the backbone of the revenue ranking suggested in MR so that special attention is focused on them.

Results of a binomial test show that these deviations are significantly positive for both cases in the aggregate. At the group level, significant overbidding (i.e.: bidding above $b^*(.)$) appears to be more present in Case 2 than in Case 1. Since the binomial test does not take into account the deviations' magnitudes in its statistic, a one-tailed K-S test on the observed distributions of bids when subjects are of type $i$, $G_i(.)$ would shed additional light on the subjects' behaviour. The results of this test indicate first that if not equal to their theoretical distributions $G_i^{Th}(.)$, empirical distributions are stochastically greater and second, that overbidding was relatively more present when subjects were of type 1 in either asymmetric case[5].

Tables 7 and 8 report a non-parametric (Spearman) correlation analysis between *absolute* relative deviations from equilibrium — $|d|$ — and valuations. A negative correlation coefficient — $\rho_v$ — indicates that the higher a subject's valuation the less important is his absolute relative deviation from equilibrium. Since overbidding has been observed, most of these absolute deviations will thus be positive so that a significant $\rho_v$ would actually reveal whether *low-balling* is lacking when subjects have high valuations ($\rho_v > 0$) or low valuations ($\rho_v < 0$)[6].

[5]One exception occurred for Group 5 in Case 1, where the opposite has been observed: $D^+ = 0.17$; so that $G_1^{Th}(b) \leq G_1(b)$.

[6]Over all bids, 67.2% in Case 1 and 74% in Case 2 were above their theoretical predictions. Similarly, 29% in Case 1 and 25% in Case 2 were below theoretical predictions.



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Table 7: Spearman's Correlation Analysis of Deviations: Valuations. — Case 1 —

| | Type 1 | | | Type 2 | | |
|---|---|---|---|---|---|---|
| Group | $\rho_v$ | #[< 0][a] (#)[b] | #[> 0] (#) | $\rho_v$ | #[< 0] (#) | #[> 0] (#) |
| 1 | 0.01 | 2 (1) | 2 (1) | -0.28** | 2 (1) | 2 |
| 2 | -0.59* | 4 (3)‡ | | -0.42* | 4 | |
| 3 | 0.03 | 2 (2)‡ | 2 | -0.61* | 3 (2) | 1 |
| 4 | -0.17 | 3 (1) | 1 | -0.38* | 3 (1) | |
| 5 | -0.13 | 3 | 1 (1)‡ | -0.39* | 4 (2)‡ | |
| 6 | 0.09 | 2 (1)‡ | 2 (1) | 0.04 | 3 | 1 |
| All | 0.02 | | | -0.34* | | |

[a]: Number of subjects who displayed a negative $\rho_v$.

[b]: Number of subjects with negative $\rho_v$ at significance level $p < 0.05$. A ‡ indicates that exactly one of them had a negative coefficient significant at $p < 0.1$.

*: Significant at $p < 0.05$. [**: $p < 0.1$]



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Table 8: Spearman's Correlation Analysis of Deviations: Valuations. — Case 2 —

| | Type 1 | | | Type 3 | | |
|---|---|---|---|---|---|---|
| Group | $\rho_v$ | #[< 0] (#) | #[> 0] (#) | $\rho_v$ | #[< 0] (#) | #[> 0] (#) |
| 1 | 0.17 | 1 (1) | 3 (1) | -0.17 | 2 (1)‡ | 1 |
| 2 | -0.28* | 4 (1) | | -0.33 | 4 (1) | |
| 3 | 0.07 | 2 (1)‡ | 2 (2) | -0.25 | 1 | 2 |
| 4 | -0.18 | 2 (1) | 2 (1)‡ | -0.33 | 2 | 1 |
| 5 | 0.19 | 3 | 1 (1) | -0.39 | 1 | 2 |
| 6 | 0.02 | 2 (1) | 2 (2) | 0.26 | 1 | 3 |
| All | 0.02 | | | -0.31* | | |

We observe that all groups with significant correlations display negative coefficients and that these are mainly observed when subjects are of type 2 (or 3 in the aggregate).

Although coefficients are not significant when subjects are of type 1 at the group level, individuals with a significant coefficient are more frequent when they are of type 1 than 2 or 3. We further note a clear tendency for bidders in Case 1 to deviate from equilibrium when valuations are low. On the other hand, subjects of type 1 in Case 2 are equally likely to have positive or negative significant correlation coefficients which is not surprising given that both the non-linearity and the support of their optimal bidding function are more demanding in terms of subject's expected behaviour in Case 2 than in Case 1, and this for both high and low valuations.

The presence of overbidding in FP auction experiments has often been attributed to subjects' risk aversion and consequent models, and ex-



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Table 9: Spearman's Correlation Analysis of Deviations: Trading Periods.

| | Case 1 | | | | Case 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Type 1 | | Type 2 | | Type 1 | | Type 3 | |
| Group | $\rho_r$ | #[< 0] (#) | $\rho_r$ | #[< 0] (#) | $\rho_r$ | #[< 0] (#) | $\rho_r$ | #[< 0] (#) |
| 1 | -0.24* | 4 (2)‡ | -0.34* | 3 (2)‡ | -0.04 | 2 (1) | -0.45** | 3 (1)‡ |
| 2 | -0.14 | 3 (1) | -0.25 | 3 (1) | -0.29* | 4 (2) | -0.17 | 2 (1) |
| 3 | -0.35* | 4 (1) | -0.49* | 4 (2)‡ | -0.33* | 4 (2) | 0.1 | 1 |
| 4 | -0.12 | 2 (1) | -0.18 | 3 | -0.22** | 3 (1)‡ | -0.04 | 2 |
| 5 | -0.17 | 2 (1)‡ | -0.34** | 3 (1) | 0.04 | 2 | -0.11 | 1 |
| 6 | 0.08 | 2 | 0.23 | 1 | -0.31 | 4 | 0.29 | 1 |
| All | -0.09** | | -0.2 | | -0.04 | | -0.09 | |

*Note*: Though not reported here, four subjects (one of type 1 in Case 1 and three of type 2) had positive correlation coefficients at significance level $p < 0.05$.

perimental designs have been developed to explain this pattern (Cox et al. [1982][1985] and [1988]). Sharing straigthforwardly this risk aversion interpretation of overbids implicitly yields to assume that participants (even though 'inexperienced') act at equilibrium from the first trading period onwards or equivalently that there is no learning activity. Table 9 shows the results of a correlation analysis between $|d|$ and *active* trading periods (i.e.: periods where a subject had a positive valuation). A significant negative coefficient $\rho_r$ indicates that deviations from equilibrium become smaller as experience grows[7].

[7] It is worth noting here the importance of using non-parametric correlation coefficients when looking for relationships between variables that are *a priori* unknown: these coefficients depict both linear and non-linear types of correlation. Cox et al.



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It is notable that all significant coefficients are negative and are observed essentially in Case 1 at both individual and aggregate levels and for some subjects of type 1 in Case 2. For subjects of type 3, the overwhelming acceptance of the null hypothesis that *observed* and *theoretical* distributions of bids agree — see the statistics $D_3^-$ in Table 6 — explain the scarcity of significant correlation coefficients $\rho_r$.

### 4.3.3 Implications of learning on MR's revenue ranking

Having detected learning trends in both SP and FP auctions, we now reconsider expected revenues outcomes in Tables 10 and 11 when omitting the thirty earliest trading periods in each session.

According to the high rejection rate of the null hypothesis that the price series obtained from SP and FP auctions are identically distributed in favour of the alternative that those coming from FP auctions are stochastically greater than those from SP auctions, there is no evidence of the superiority of SP auctions on FP auctions in terms of expected revenues as postulated in MR.

## 5 Concluding remarks

This paper reports on a series of laboratory experiments designed to check whether MR's theoretical predictions concerning a specific type of asymmetry among bidders in private-independent values auctions were verified. We see that the ranking in terms of the seller's expected revenue of SP and FP auctions suggested by the authors is not verified on either a full-sample basis (i.e.: 396 observations) or, once a learning activity has been detected, on a sub-sample basis (i.e.: 216 observations).

In previous SP symmetric auction experiments, significant modifications in bidding behaviour occurred as the number of bidders increased from 5 to 10. The outcomes of our SP auction sessions revealed

[1988], for example, looked for learning trends partially (i.e.: on a subset of all subjects and by means of a linear regression estimate).



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Table 10: Expected Revenues Comparisons for rounds > 30 (Case 1).

| | SPSB | | | | FPSB | | | |
|---|---|---|---|---|---|---|---|---|
| Group (# Obs) | Mean (s.d.)[a] | Med. | $E(X_{(2)})$ | $D_{Th}$[b] | Mean (s.d.) | Med. | $z^c$ $D^d$ | $\bar{\delta}$ (s.d.) |
| 1 (42) | 24.21 (25.01) | 17.5 | 20.85 | 0.17 | 16.35 (11.25) | 20 | -0.44 0.36° | — |
| 2 (42) | 20.31 (26.78) | 4 | 19.42 | 0.08 | 23.29 (13.2) | 22 | 2.34* 0.48* | — |
| 3 (42) | 16.86 (24.06) | 0 | 16.05 | 0.08 | 23.31 (14.91) | 25 | 3.01* 0.52* | -6.42⁻ (21.83) |
| 4 (30) | 18.7 (26.23) | 8.5 | 20.07 | 0.13 | 21 (11.87) | 24.5 | 2.37* 0.33 | — |
| 5 (30) | 10.5 (20.92) | 0 | 12.13 | 0.19 | 15.5 (11.5) | 16.5 | 3.22* 0.53* | — |
| 6 (30) | 25.97 (27.4) | 21 | 25.2 | 0.19 | 19.6 (12.2) | 19 | -0.16 0.3°° | 6.33 (25.3) |
| All (216) | 19.6 (25.35) | 3.5 | 18.93 | 0.05 | 20.04 (12.9) | 21 | 3.9* 0.37* | — |

[a]: (s.d.): Standard deviation of expected revenue. Med.: Median

[b]: Two-tailed K-S test.
$H_0 : R_{SP}(b) = R_{SP}^{Th}(b)$ against $H_1 : R_{SP}(b) \neq R_{SP}^{Th}(b)$.

[c]: One-tailed M-W test ($z$: unit normal deviate).
$H_0 : R_{FP}(b) = R_{SP}(b)$ against $H_1 : R_{FP}(b) \leq R_{SP}(b)$.

[d]: One-tailed *two-sample* K-S test.
$H_0 : R_{FP}(b) = R_{SP}(b)$ against $H_1 : R_{FP}(b) \leq R_{SP}(b)$.

[e]: Average difference between observed prices in SP and FP auctions:
$\bar{\delta} = p_{sp} - p_{fp}$.

*: Reject $H_0$ at significance level: $p < 0.05$.

°: Reject $H_0$ against $H_1 : R_{FP}(b) \geq R_{SP}(b)$ at significance level: $p < 0.05$.

°°: Reject $H_0$ against $H_1 : R_{FP}(b) \geq R_{SP}(b)$ at significance level: $p < 0.1$.

+: Reject $H_0 : \bar{\delta} = 0$ against $H_1 : \bar{\delta} > 0$ at significance level: $p < 0.05$.

−: Reject $H_0 : \bar{\delta} = 0$ against $H_1 : \bar{\delta} < 0$ at significance level: $p < 0.05$.



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Table 11: Expected Revenues Comparisons for rounds > 30 (Case 2).

| | SPSB | | | | FPSB | | | |
|---|---|---|---|---|---|---|---|---|
| Group (# Obs) | Mean (s.d.) | Med. | $E(X_{(2)})$ | $D_{Th}$ | Mean (s.d.) | Med. | $z$ $D$ | $\bar{\delta}$ (s.d.) |
| 1 (42) | 10.81 (19.85) | 0 | 10.43 | 0.06 | 11.37 (10.86) | 6 | 3.05* 0.55* | — |
| 2 (42) | 4.36 (13.67) | 0 | 4.26 | 0.11 | 8.48 (7.45) | 6 | 5.1* 0.71* | — |
| 3 (42) | 5.83 (14.71) | 0 | 5.83 | 0.09 | 12.29 (13.34) | 6 | 4.7* 0.67* | — |
| 4 (30) | 5.77 (12.54) | 0 | 6.97 | 0.09 | 12.87 (10.14) | 14.5 | 2.94* 0.47* | — |
| 5 (30) | 11.9 (21.52) | 0 | 11.43 | 0.08 | 10.37 (9.55) | 9 | 2.39* 0.53* | — |
| 6 (30) | 18.6 (25.19) | 0 | 17.9 | 0.22 | 8.73 (7.07) | 7 | 0.81 0.47* | — |
| All (216) | 9.12 (18.54) | 0 | 9.03 | 0.04 | 10.65 (10.13) | 7 | 8.02* 0.57* | — |

that *asymmetric* subjects also significantly changed their strategies as their competitive environment varied. Given the relatively higher rate of equilibrium bids observed here (≃50% instead of 30% in the above mentioned experiments), these variations in strategic behaviours show clear evidence of subjects' difficulties in understanding the SP auction selling procedure.

Rejection of the dominance of the SP auction institution which theory suggests is due to the weakness of observed *low-balling* in FP auctions. This lack of *low-balling* occurred mainly when subjects received low values and persisted as their experience of the game grew. This can be understood as follows. What MR's predictions are based on is a characterization of equilibrium. The difficulty here seems to have been for the subjects to 'learn their way' to such an equilibrium, this is to a situation in which they are all reacting optimally to each other.

However, we did first see that bidders' behaviours in FP auctions



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were consistent with results of Lemmas L1 and L2, thereby showing that subjects did realize the strategic implications of this asymmetric setting.

Second, it is worth noting that MR obtained optimal strategies numerically by means of a 'tatonnement' process aimed to define a maximum bid to be submitted by both competitors ($\bar{b}$ in Eq. 3) such that equilibrium bidding functions exist. If one were then to observe experimental subjects acting and remaining at equilibrium, one might expect them to perceive the existence of that common ceiling on bids. From informal end-of-session discussions with participants, it appeared on one the hand that most comments were related to the implication of Lemma L1 but none of them mentioned the problem of a common ceiling. On the other hand, it should be pointed that even if they had noticed this common maximum bid subtlety, subjects' task of submitting equilibrium bids would then be considerably more difficult since they would then need to learn to agree on an unknown parameter. At this point, it has to be observed that the existing literature on interactive learning shows there is a fundamental problem with learning to coordinate on an equilibrium in non-cooperative games no matter how long a learning period allowed. Thus it is rather more likely that one will observe a variety of outcomes depending on subjects' aspirations than that one would see MR's exact predictions ever verified.



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# A Instructions for FP auctions

**Set Up**

Each of you will participate in 60 auctions.

In each auction you will be competing with one other participant for the purchase of a fictitious item.

In each auction, you will be randomly matched with another participant.

**Values**

At the outset of each auction, a value is randomly chosen for every bidder.

Each bidder will know his own value but not the value of his competitor.

The ranges from which values are drawn (with an equally likely chance) are known to both bidders.

**Types**

There are 3 different types of bidders: Red, Blue and Green.

1. Red-type bidders have their values drawn from the range [0;100],
2. Blue-type bidders have their values drawn from the range [-100;100],
3. Green-type bidders have their values drawn from the range [-300;100].

There are 2 possible matchings of bidders:

1. Red versus Blue,
2. Red versus Green.

Each of you will alternatively be in one of the 4 following situations:

1. You are Red and your competitor is Blue,
2. You are Blue and your competitor is Red,
3. You are Red and your competitor is Green,
4. You are Green and your competitor is Red.

**Bids**

If your value is negative, you are not allowed to submit a bid.



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If your value is positive, you will be asked to submit a bid.

Any integer bid that ranges from 0 to 100 will be accepted.

**Awards**

If only one of the bidders was allowed to submit a bid, he will be awarded the item.

If both bidders were allowed to submit bids, the bidder with the higher bid will be awarded the item.

If both bidders submitted the same bid, one of them will be randomly chosen (with probability of one half) to be awarded the item.

The bidder who is awarded the item will be called the buyer.

**Gains and Losses**

If you are the buyer, you will pay a price equal to your bid.

Only the buyer can make a gain or a loss.

The gain or loss of the buyer is equal to his value minus his bid.

**Payoffs**

All values, bids, prices, profits and losses refer to Crowns.

Each of you will be given an initial capital balance of 100 Crowns.

Your total profit of the game is equal to the sum of your gains and your capital balance minus your losses.

If ever your current total profit falls below zero during the experiment, you will no longer be allowed to participate in the game.

The exchange rate is 0.02 DM per Crown.



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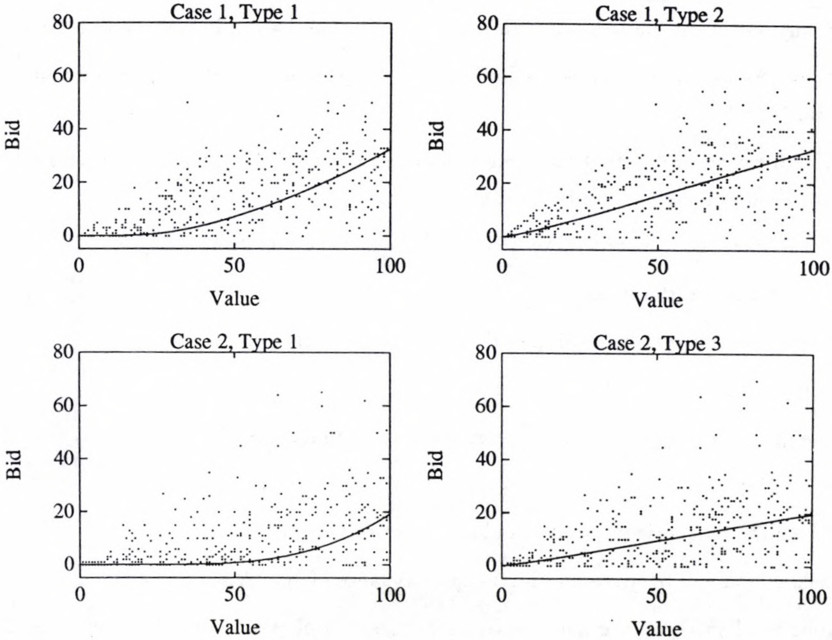


Figure 1: Observed and Theoretical Bids in FP Auctions.



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