Exp Econ (2009) 12: 202–219
DOI 10.1007/s10683-008-9210-8

Uniform price auctions and fixed price offerings in IPOs: an experimental comparison

Ping Zhang

Received: 8 April 2007 / Revised: 14 August 2008 / Accepted: 6 October 2008 /
Published online: 30 October 2008

Abstract We compare uniform price auctions with fixed price offerings in Initial Public Offerings (IPO) using laboratory experiments. The experimental environment is based on the Biais and Faugeron-Grouzet (J. Financ. Intermed. 11:9–36, 2002) model. Standard predictions based on tacit collusion equilibria (TCE) suggest lower revenues in uniform price auctions, although alternative equilibria allow for higher revenues. In our experiment, there is no evidence that TCE are played. The experiment suggests that the uniform price auctions are superior to fixed price offerings in terms of raising revenues.

Keywords Experiment · IPO · Uniform price auction · Fixed price offering · Share auction

JEL Classification D44 · G12 · C91

1 Introduction

In this paper we compare, experimentally, two alternative IPO mechanisms, namely fixed price offerings (also known as public offers) and uniform price auctions. Fixed price offerings are the main format used in countries that rely on retail investors and in countries where IPOs are infrequent (Sherman 2002).[1] Uniform price auctions are

[1]Countries where the fixed price offering is the most popular IPO method include India, Mexico and Singapore.

Electronic supplementary material The online version of this article (http://dx.doi.org/10.1007/s10683-008-9210-8) contains supplementary material, which is available to authorized users.

P. Zhang (✉)
School of Economics, University of Nottingham, Nottingham NG7 2RD, UK
e-mail: ping.zhang@nottingham.ac.uk

used in Israel and are occasionally also used in Finland, U.K. U.S. and Hong Kong. After the Internet giant Google successfully conducted its IPO using a uniform price auction in 2004, this IPO mechanism has received particular attention. There is empirical evidence that unseasoned new issues are underpriced using all IPO methods. However, no strong conclusions have been drawn on revenue comparisons of various IPO mechanisms, whose performances vary greatly across countries.[2]

Theoretically, the revenue ranking between uniform price auctions and other IPO mechanisms crucially depends on equilibrium selection. An extensive literature on uniform price auctions has focused on tacit collusion equilibria, in which market prices can be as low as reservation prices, leading to low revenues for sellers (e.g. Wilson 1979; Back and Zender 1993; Wang and Zender 2002). In such equilibria, bidders place bids regardless of their expected market value and, therefore, market prices provide little information about market values. However, Zhang (2006) shows that there are other equilibria of uniform price IPO auctions with the property that bidders with higher expected valuations bid more aggressively, generating higher seller revenues. For a sufficiently low reservation price, fixed price offerings outperform uniform price auctions when the tacit collusion equilibrium is selected, but the outcome may be reversed when other equilibria are chosen.

Comparing performance on the basis of field data is problematic. It is hard to assess the extent to which observed differences in underpricng across various IPO mechanisms reflect differences in the mechanisms rather than other factors that vary across countries or sample periods.[3] The French stock market where three issuing mechanisms are used offers a unique arena to compare their performances.[4] Even in this case, it is difficult to adequately control for all factors that may affect underpricing, or selection effects arising when firms that choose one form of IPO mechanism systematically differ from those that choose another.

The objective of our paper is to use laboratory experiments to empirically examine the performances of two alternative IPO mechanisms: uniform price auctions and fixed price offerings. The framework of the experiment is based on the model by Biais and Faugeron-Grouzet (2002, noted as BF hereafter). They suggest that because of the winner's curse problem underpricing exists in fixed price auctions, but the underpricing may be even aggravated in uniform price auctions due to collusion.

The price in the fixed price treatment is set exogenously following the BF model, and implies that underpricing of some degree will usually occur. Whether underpricing in uniform price auctions will be aggravated depends on the behavior of our

[2]See Loughran et al. (1994) and Sherman (2002) for detailed international evidence. For research on revenue comparisons of IPO mechanisms, see, for example, Benveniste and Wilhelm (1990), Loughran et al. (1994), Derrien and Womack (2001), Sherman and Titman (2002), Chemmanur and Liu (2003).

[3]Koh and Walter (1989) report an average underpricing rate of 34.7% for fixed price offerings in Singapore according to the data from 38 issues that took place from 1973 to 1987. In contrast, underpricing appears to be lower in countries using uniform price auctions. For instance, in Israel the average underpricing level is 4.5% from 1993 to 1996 (Kandel et al. 1999), and in Argentina during the 1990's, the shares were even overpriced (Sherman 2002).

[4]For the French stock market where modified uniform price auctions, fixed price offerings and Bookbuilding are used, Derrien and Womack (2001) find that the auction mechanism is associated with lower underpricing and lower variance of underpricing. They also suggest that the auction procedure incorporates more information from recent market conditions into IPO prices.

experimental subjects. In fact, we found that underpricing in uniform price auctions was less frequent and less severe than in the fixed price treatment. We found no evidence that tacit collusion equilibria have been achieved, and the results suggest that uniform price auctions outperform fixed price offerings in terms of raising revenue. Subjects' behavior shares the same properties with the new set of equilibria characterized by Zhang (2006): a subject who has a higher expected market value bids for higher quantities at higher prices and obtains a greater allocation. As a consequence, market prices increase with market values in uniform price auctions.

The rest of the paper is organized as follows. In Sect. 2 we briefly review the related literature. Section 3 describes the experiment, and results are reported in Sect. 4. We summarize and conclude in Sect. 5.

2 Related literature

2.1 Uniform price auctions

In uniform price auctions, all bidders who win pay the same market-clearing price. In uniform price IPO auctions there are a large number of identical stocks for sale. In such auctions, if a bidder has a positive probability of influencing the price, in a situation where the bidder obtains some allocation, then she has an incentive to shade her bid (Ausubel and Cramton 2002). If each bidder shades her bid by submitting a steep demand function regardless of her expected market value, then it would take a big price increase to increase one's allocation. When the demand function is steep enough, nobody could profitably deviate and the auction ends up at a low market price. These are the tacit collusion equilibria (TCE) that have been the focus of most theoretical research (e.g. Wilson 1979; Back and Zender 1993; Wang and Zender 2002). However, with steep demand functions, if a bidder deviates from equilibrium by bidding for a higher quantity, it is very likely that all winning bidders suffer losses.[5] Thus there is a sense in which the tacit collusion equilibrium is risky. In the coordination game experiments run by Van Huyck et al. (1990), the payoff-dominant equilibrium is an extremely unlikely outcome either initially or in repeated play. Instead, subjects' behavior converges to a risk-dominant but payoff-dominated equilibrium. They conclude that the coordination failure results from the strategic uncertainty due to the riskiness of choosing the payoff-dominant action. Thus one might wonder whether the payoff dominant, but risky, tacit collusion equilibria would be observed in uniform price IPO auctions.

IPO auctions are multi-unit, asymmetric, and common value mechanisms. Most experiments with multi-unit auctions consider the case of *private* values, and in these the payoff-dominant collusive equilibria have not been frequently observed.[6]

[5] In markets outside the laboratory, this might be important because with a large number of investors especially many inexperienced retail investors, there is a high probability that some bidders will fail to follow the collusive strategy.

[6] For example, Engelmann and Grimm (2003) conducted an experiment where two bidders can bid for two units. In the payoff-dominant equilibrium, subjects bid their private values for the first unit and zero for the second unit, but this is rarely observed. See also Kagel and Levin (2001), Porter and Vragov (2003).

Sade et al. (2006) conducted an experiment to examine the performance of different auctions including uniform price auctions in a multiunit common value setting. They find little evidence of collusive behavior in the uniform price setting even when professionals are involved as subjects. Their experiment studies a quite different model from that of BF. For example they study auctions with five *symmetric* bidders.[7] Based on the theoretical model by Chemmanur and Liu (2003), Trauten and Langer (2008) experimentally analyze investors' behavior in fixed price offerings and auctions. They argue that auctions are not the preferable mechanism for young and risky firms because of the high cost of information production. Unlike BF in which issuers care only about the offering proceeds, in their model issuers also have a preference for information production by investors. This is a fundamentally different approach in IPO modelling.

2.2 Fixed price offerings

In fixed price offerings, market prices are determined before the sale of shares. Shares are randomly rationed or prorated among all bidders if the demand exceeds the quantity of offered shares. If there is not enough demand, an IPO fails or is postponed.

In financial markets, institutional investors have an informational advantage and more experience than retail investors. They increase their demands when they have higher expected valuations regarding the market value of shares. Retail investors, on the contrary, do not have such information and thus cannot submit their demand contingent on such a valuation. The absence of price adjustment with demand in fixed price offerings results in a *winner's curse problem*: retail investors as well as investors with low expectations regarding the value of shares obtain the largest allocation when the value is at the lowest level. Setting the fixed market price below the expected market value is then necessary in order to convince such investors to participate (Rock 1986).[8] By doing this shares have a higher probability to be fully subscribed and thus avoid the failure of an IPO. Test results from issues in Singapore's stock market are consistent with the theoretical implications of Rock's model (Koh and Walter 1989). The model by BF follows Rock (1986) and sets the fixed price equal to the highest price that guarantees full subscription in equilibrium.[9]

[7] Also, unlike our experiment, Sade et al. (2006) allow bidders to engage in nonbinding communication both before and during the conduct of the auctions (although actual bidding behavior remains private information). However, Goswami et al. (1996) show experimentally that communication may increase bidders' tendency to play collusive or collusive-looking strategies.

[8] The use of the term *winner's curse* in this paper follows BF in the sprit of Rock (1986). This differs from the traditional use of the term *winner's curse*, relating to the finding that the winner in a common value auction overpays the value of the purchased good (Kagel and Levin 2002).

[9] In practice the price is often fixed at a point where excess demand is most likely. "It may be surprisingly inexpensive for sellers to choose a rationing price in IPOs, making the practice sustainable even if it is not necessarily optimal" (Bulow and Klemperer 2002, p. 17).

3 The experiment

Our experimental environment is based on the model by BF. There are two treatments in our experiment: the uniform price auction treatment ("UNIFORM") and the fixed price offering treatment ("FIXED").[10]

In both treatments, there are three informed buyers and one uninformed buyer in each group.[11] Each informed buyer receives a signal that represents either a *high* value or a *low* value with equal probabilities. The uninformed buyers do not observe a signal. From now on we call bidders who receive high value signals "H bidders", those who receive low value signals "L bidders", and uninformed bidders "U bidders". The value of each unit of shares is set equal to one plus the number of high signals received by the group.[12] The shares are underpriced (overpriced) if the market price is lower (higher) than the resulting value. There are 100,000 units of shares for sale. Each informed buyer can bid for up to 150,000 units and needs to pay a cost of 5,000 points if her demand exceeds 100,000;[13] while each uninformed buyer can buy up to 80,000 units.[14] The increment of quantities is 1. The point earnings that each subject earns are equal to the market value minus the market price, times the number of units allocated, with a deduction of 5,000 points cost if applicable.

3.1 The UNIFORM treatment

In the UNIFORM treatment, subjects are asked to submit up to six bids, each of which is a price-quantity pair consisting of the price they would like to bid and the quantity they bid for at that price.[15] The prices range from 0 to 6 in increments of 0.01. We set an upper bound limit of six for the bidding price in order to prevent subjects

[10] The instructions are posted as supplementary materials.

[11] In BF informed investors represent institutional investors, while one uninformed investor represents a fringe of retail investors. In the experimental setting we stay close to BF by having three informed investors and one uninformed investor. Note, however, that BF analyzes the behavior of rational and risk-neutral investors, whereas in our experiment investors are played by human subjects.

[12] The market value can be seen as the price of shares in a secondary market, where according to the *Efficient Markets Hypothesis*, prices reveal all available information. In BF the market value is assumed to be increasing in the number of high signals, and thus our experiment implements this in a simple linear form.

[13] Although the bids that exceed the supply cannot be fully executed, they "can be optimal, however, to the extent that they enable the investor to obtain a larger share of underpriced and overbid issues"; the cost "can be thought of as the cost of immobilizing funds during the period of the IPO" (BF, p. 18). Technically, this cost is used to distinguish the equilibrium strategies between H bidders and L bidders in fixed price offerings.

[14] This follows the capacity constraint assumption made on retail investors by BF.

[15] It is impractical for bidders to submit demands in continuous prices. Previous research shows that even if they are allowed to submit as many pairs as they can, bidders seem to use a relatively small number of price-quantity pairs in bidding (Bikhchandani and Huang 1993; Wang and Zender 2002). To keep the balance between flexibility and simplicity, we chose six pairs of price and quantity: four for each possible market values (1, 2, 3, 4), one for the price predicted by the tacit collusion equilibrium (zero), and one for bids above 4. In fact, few bidders have used all six pairs to submit their bids. The percentages corresponding to the number of bids submitted by subjects (ranges from 1 to 6) are 22%, 28%, 27%, 12%, 5% and 6% respectively.

Fig. 1-a

	Price	Quantity(units)
bid 1:	6	25,000
bid 2:		

Fig. 1-b

	Price	Quantity(units)
bid 1:	2	50,000
bid 2:	6	25,000

Fig. 1-c

	Price	Quantity(units)
bid 1:	2	50,000
bid 2:	3	16,667
bid 3:	4	33,333

Fig. 1-d

	Price	Quantity(units)
bid 1:	1	25,000
bid 2:		
bid 3:		

Fig. 1

from submitting unreasonably high bids because of misunderstanding or mistakes, especially at the beginning of the experiment, which might have led them to bankruptcy.[16] The market price is determined at the highest price where demand exceeds supply. Bids placed above the market price are fully filled, and then the shares left are prorated among the bids placed at the market price. Bids placed below the market price are ignored. If demand is less than or equal to supply, the market price is zero and each bidder is allocated the quantity that she bids for.[17]

BF derives a tacit collusion demand function for uniform price auctions. The function is downward sloping with a sufficiently steep slope, such that a deviation by bidding more to obtain a higher allocation at a higher price is unprofitable. Under symmetric TCE each bidder obtains an equal proportion of the supply at the price of zero if no reservation price is set.

Nevertheless, as mentioned previously, it is not practical for investors to submit continuous demand functions. Thus TCE must be adjusted when price is discrete. For our UNIFORM treatment, there is a multiplicity of symmetric TCE where the market price can be any permissible price between zero and two (the expected value of an L bidder). To facilitate an understanding of equilibrium strategies in our discrete experimental setting, we provide some examples (Fig. 1-a to 1-d) to describe subjects' behavior (see Zhang (2006) for the complete characterization of equilibria). If each player demands 25,000 units at a price of 6 and places no other bids, they each obtain one quarter of the shares at a price of zero (Fig. 1-a shows this demand schedule in the experimental interface).[18] This results in the payoff-dominant TCE equilibrium

[16]The ceiling on bids is higher than the highest possible market value because bidders may bid at high prices to guarantee some allocation as they do not necessarily pay the price that they bid.

[17]In markets outside the laboratory, an IPO fails if offered shares exceed the demand. Compared with the allocation rule used in our experiment, using this rule would have made collusion among subjects in UNIFORM more difficult, and might have generated higher demand in FIXED. As we will show later, even with our allocation rule there is no evidence of collusion in UNIFORM and shares are oversubscribed in FIXED.

[18]The bidders should start bidding from a price no lower than 2.25 in symmetric TCE, otherwise a player could improve her expected payoff by bidding at a higher price and thus absorbing all the shares (Zhang 2006).

Table 1 Summary of equilibria (uniform treatment)

	Strategy	Price	Properties
TCE	Each informed bidder bids for at most 100,000 Symmetric TCE: each bidder bids for 25,000 above the TCE price and starts bidding from a price ≥ 2.25, bids can exceeds 25,000 at the TCE price; Asymmetric TCE: bids sum to 100,000 at a high price, and can exceed 100,000 at the TCE price	[0,2]	1. Bidders submit bids regardless of signals 2. Same price for different values 3. In symmetric TCE, each bidder obtains the same allocation
EH	H bids for 100,000/n above v_n, and up to 100,000/$(n-1)$ in $[v_{n-1}, v_n]$ L and U place no bids above price 1	$[v_{n-1}, v_n]$	1. H bids more aggressively than L 2. Price increases with values 3. H obtains a higher allocation than L 4. Bidders who are excluded from the market place no bids above 1 5. The market price is lower than the market value should L bidders obtain an allocation 6. The total demand above v_n is at most 100,000
EHL	H bids for less than under EH but more than L L places bids from a price above 1, U places no bids above price 1	$[v_{n-1}, v_n)$	
EHU	H bids for less than under EH L places no bids above price 1, U places bids from a price above 1	$[v_{n-1}, v_n]$	
EHLU	H bids for less than under EH but more than L L and U both place bids from a price above 1	$[0, v_n)$	

*The column of Price lists the price ranges when there are *n high* signals observed. Denote v_n the market value when there is *n high* signal(s). Let $v_{-1} = 0$

** We have described a particular case of EHLU in which all bidders bid for a positive amount, and an H bidder demands strictly higher than an L bidder. If we relax these restrictions, all the other equilibria can be nested in EHLU. Specifically, EHLU becomes TCE if H and L bidders bid symmetrically; becomes EH if both L and U bidders place no bids above 1; and becomes either EHU or EHL if either L or U bidders respectively place no bids above price 1

in the same spirit as BF. If each bidder follows the price-quantity schedule in Fig. 1-b, the market price is 2. There are also asymmetric TCE where bids sum to 100,000 at a high price, and exceed 100,000 at the TCE price. A common feature of TCE is that all investors receive an allocation irrespective of signals.

There are other pure strategy equilibria in uniform price IPO auctions characterized by Zhang (2006). In equilibria EH only H bidders obtain allocations given that there is at least one high value signal. For example, suppose each H bidder submits a demand schedule as shown in Fig. 1-c, while each L or U bidder follows the schedule in Fig. 1-d, the resulting market price will be 0, 1, 2 or 3 respectively when the market value is 1, 2, 3 or 4. L and U bidders only receive an allocation, at price zero, when there are no H bidders in the market. There are also sets of equilibria where H bidders demand less than under EH and share the market with L bidders (EHL), or with U bidders (EHU), or with both of them (EHLU). In these equilibria, bidders who are excluded from an allocation when H bidders exist place no bids above price 1 (Fig. 1-d provides an example). The equilibria for our parameter values as well as their expected price ranges and properties are summarized in Table 1. Except for TCE, where the market price remains constant and thus reveal little information about the market value, in all the other equilibria the market price increases with

the value, and H bidders bid for higher quantities at higher prices and obtain greater allocations.[19]

3.2 The FIXED treatment

In the FIXED treatment, subjects bid for shares at the predetermined market price 1.94. If demand exceeds supply, shares are prorated among winning buyers. Otherwise each bidder obtains the quantity that she bids for.[20]

The market price 1.94 is the highest possible price that guarantees full subscription for any possible valuations according to the theoretical solution provided by BF (p. 31). Since U investors are assumed not to be able to absorb all the shares, in order to guarantee full subscription even when high value signals are not observed, the market price has to be set such that an L bidder is willing to bid for the shares. Taking into account the winner's curse problem that an L bidder obtains the highest allocation when the market price is the lowest, the market price has to be set below the expected value of an L bidder. At 1.94 an L bidder gains a zero expected profit in equilibrium, where each H, L and U bidder bids for 150,000, 100,000 and 80,000 units respectively.[21]

In summary, for our experiment the theoretical revenue-ranking depends on equilibrium selection. For the TCE in BF fixed price offerings dominate uniform price auctions, although this may not be the case for other equilibria. Our experiment therefore provides a number of interesting testable hypotheses. First, using this design we can test whether the mechanisms are revenue equivalent or whether one out-performs the other. Second, for the UNIFORM treatment, we can compare prices with benchmarks (e.g. expected market values) and examine the properties of subjects' behavior, and in particular examine whether TCE can be achieved in a repeated-play environment. Third, we can test if subjects' behavior is consistent with BF's predictions in the FIXED treatment.

3.3 Conduct of the experiment

In both treatments, subjects are randomly divided into groups of four at the beginning of each session. The members of each group and the types of subjects (informed/uninformed) remain the same during the session. No information passes

[19] The symmetric TCE follow the spirit of BF. All the other equilibria follow Zhang (2006).

[20] Note that under the experimental settings the offering does not fail when under-subscription happens, see footnote 17 for the explanation.

[21] Under our experimental settings, both H and L bidders would bid 150,000 if the cost is set below 240 (then the gain from getting more allocation by bidding 150,000 is larger than the cost for both L and H bidders), or both bid 100,000 if the cost is higher than 8,212 (then the gain from getting more allocation by bidding 150,000 cannot offset the cost for both L and H bidders). If this is the case, as informed bidders behave the same regardless of signals, an L bidder obtains a same allocation regardless of the market value, and the fixed market price could be as high as the expected value of an L bidder, 2, and as high as the unconditional expected value 2.5 if additionally U investors could absorb the whole issue. In the next section, we will compare market prices in UNIFORM with 2 and 2.5 as well. Nevertheless, we keep our experimental settings consistent with BF. See p. 32 in BF for details.

across groups. Subjects are asked to repeat their choices 20 times (we call each repetition a *round*). Before the experiment the computer randomly generated the signals and thus market values. For each group in each treatment, there was a corresponding group in the other treatment with the same market values across rounds.

At the outset of the experiment, subjects are endowed with a quantity of points on their accounts. In the FIXED treatment, the predetermined market price is lower than the expected value of an L bidder, thus subjects have only a small chance to lose points. We decided to give subjects higher endowments in UNIFORM in order to avoid bankruptcies.[22] Even the high endowment used in the UNIFORM treatment does not completely eliminate the possibility of subjects losing money. If any subject went bankrupt they would be dismissed and paid £3, and if any subject earned less than £3 we would round up their earnings to £3.[23]

If all the subjects follow the equilibrium strategies described in BF, each buyer could earn up to £50 additionally in the UNIFORM treatment. Each informed and uninformed buyer would earn £10.66 and £6.77 respectively in the FIXED treatment on the top of the endowments. These earnings are considerable when compared with the endowments, and so we believe that subjects have sufficient motivation to take their decisions seriously. The actual additional earnings besides the endowments were £3.14 and £0.26 for the informed and the uninformed players respectively in UNIFORM, and the corresponding numbers were £12.30 and £5.56 in FIXED.[24] The endowments and average earnings of different player types are listed in Table 2.

To ensure that subjects understand the market rules, after reading instructions, subjects must pass a computerized test before the real experiment starts.[25] The questionnaires that subjects filled in after the experiment confirm that such a procedure was helpful for subjects to understand the experiment.

[22] In addition, since uninformed buyers have an information disadvantage in the experiment, and the quantity that they are allowed to bid for is less than the informed buyers, we compensate them by a higher endowment.

[23] At the time of experiment, the exchange rate was £1: $1.82. Policies to minimize the possibility of bankruptcy, and to deal with bankruptcy, involve difficult trade-offs. See Friedman and Sunder (1994), Hansen and Lott (1991), Kagel and Levin (1991), Lind and Plott (1991) for a discussion. In our case truncating earnings at £3 may affect theoretical results, and so high endowments were used to make it unlikely the rule would be necessary. In fact, two subjects (out of 116) made extreme and unexpected decisions and earned less than £3. One of these actually went bankrupt and was paid £3 and dismissed in round 15 (the rest of the group continued playing against the computer, which used a pre-determined strategy, and these subjects were paid their experimental earnings). Data from this group are excluded from our analysis. The other subject earned £1.18 and the figures given in the text are based on these earnings, even though that subject was paid £3. Since we have a complete 20 rounds of data for this group we include them in the analysis, although none of the results in the paper would be affected by excluding this group.

[24] The average earnings were £16.90 and £15.11 respectively in UNIFORM and FIXED. The standard deviation of earnings in the UNIFORM treatment was £7.99 (the highest and the lowest earnings were £45.34 and £1.18 respectively), much larger than £3.94 in the FIXED treatment (where the highest and the lowest earnings were £24.72 and £6 respectively).

[25] The example questions are posted as supplementary materials. When the answers are wrong, the correct answers are revealed on subjects' screens and then similar questions are repeated until they get them right. The numbers used in the test are different from those in the real experiment.

Table 2 Endowments and actual earnings

	Point endowments	Endowments in £'s	Average earnings
UNIFORM			
informed bidders	350,000	£14	£17.14
uninformed bidder	400,000	£16	£16.26
FIXED			
informed bidders	100,000	£4	£16.30
uninformed bidder	150,000	£6	£11.56

The experiment was conducted at the University of Nottingham in March 2004.[26] We recruited 116 subjects from a mailing directory that comprises of undergraduate students from the entire university, who have indicated their willingness to be paid volunteers. We exclude one group from the analysis (see footnote 23), leaving us with 28 valid groups in total, 14 groups for each treatment. The experiment lasted for about one and half hours for the UNIFORM treatment, and about one hour for the FIXED treatment, including both the time for reading instructions and the test phase.

4 Results

Since decisions of subjects within the same group are likely to be interdependent, statistical tests use the group results as the unit of observation; this is a simple and standard method for analyzing experimental data. We use the observations from the FIXED treatment as a comparison to the corresponding ones in the UNIFORM treatment because the same samples of market values have been used for both treatments. We also examine whether the tacit collusion equilibria, which have different properties from the other equilibria in Table 1, have been achieved.

4.1 Market price, seller's revenue and buyers' earnings

The average prices in the UNIFORM treatment lie above the predetermined market price in the FIXED treatment in all rounds (see Fig. 2).[27] Figure 3 displays the average price of each group in UNIFORM. In only 2 out of 14 groups, the average market price in UNIFORM falls below the fixed price, and only slightly. Thus the market prices in the two treatments are significantly different ($p = 0.001$).[28] Obviously, this is because the price in UNIFORM is higher.

[26] The experiment was computerized and conducted with the help of the software *Visual Basic 6*.

[27] The figure appears to show a negative trend in the market price, but in fact this almost exactly mirrors the trend in the market value. We examined how the frequency and level of underpricing towards the end of the experiment compares to that at the beginning of the UNIFORM treatment. We found no significant differences. For example, comparing the first and last ten rounds in the UNIFORM treatment, the p values are 0.502 and 0.903 respectively according to Wilcoxon signed-ranks tests. As we report later, we do find some changes in bidding behavior in the FIXED treatment.

[28] All tests reported in this paper are two-tailed Wilcoxon signed-ranks tests.

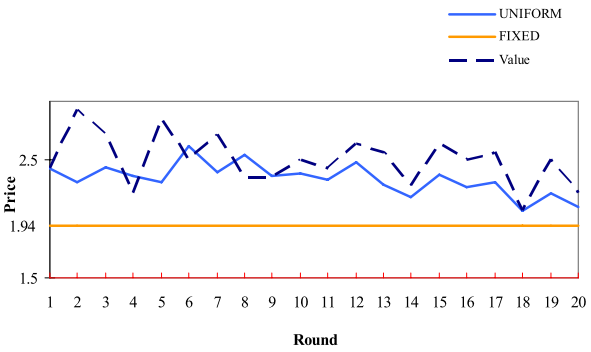

Fig. 2 Average market prices and values across rounds

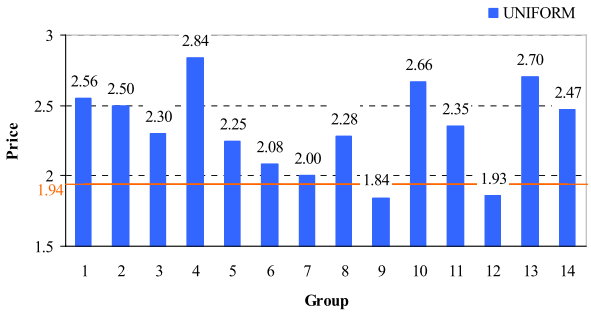

Fig. 3 Average prices across groups

As the market value is comparable for each pair of groups, bidders' payoffs are higher in the FIXED treatment. This holds for all types of bidders. In the FIXED treatment, in accordance with the theoretical prediction, L bidders gain profits statistically indistinguishable from zero ($p = 0.268$), while H and U bidders get positive payoffs in all groups.[29] In the UNIFORM treatment, the gain of U bidders is not significantly different from zero ($p = 0.626$); and the average payoff of L bidders is significantly negative ($p = 0.008$). H bidders also gain higher profits in FIXED than in UNIFORM ($p = 0.0002$). The overall subscription rate is 99.7% in UNIFORM and 98.3% in FIXED.[30] Demand exceeds supply in both treatments either across groups or across rounds, thus the higher price in UNIFORM also implies the higher seller's revenue. In 12 groups the revenue in UNIFORM is higher than that in FIXED ($p = 0.001$), and the average revenue is higher in UNIFORM in all rounds.

Result 1 *The average market price in the UNIFORM treatment is significantly higher than that in the FIXED treatment. Bidders obtain lower payoffs in the UNIFORM than in the FIXED treatment. The uniform price auction is superior to the fixed price offering in terms of raising revenues.*

[29] In one group, the U bidder bids for zero units throughout the session thus obtained zero additional earnings besides the endowment. All the other U bidders gained positive payoffs.

[30] The subscription rate simply refers to the proportion of shares sold.

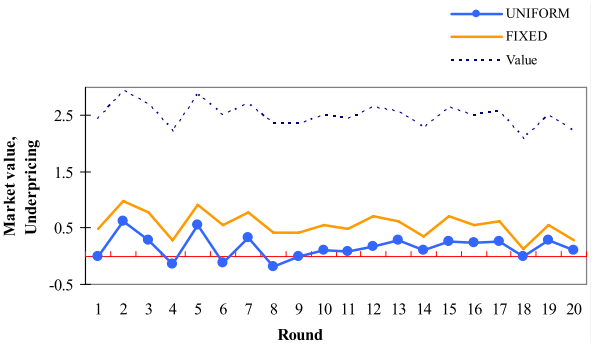

Fig. 4 Market values and underpricing across rounds. Underpricing = market value − market price. The series are averages over all the 14 groups in a given round

In UNIFORM, prices are below market values in 131 out of 280 rounds, and are equal to market values in 60 rounds. The average market price, which is 2.34 over all rounds, is not significantly different from the unconditional expected value of shares, 2.5 ($p = 0.080$). Though we did not set a reservation price, the resulting market price is higher than the highest possible reservation price suggested by TCE, 2 ($p = 0.002$).[31]

Result 2 *The average market price in the UNIFORM treatment is no higher than the unconditional expected market value but higher than an L bidder's expected value.*

Figure 4 shows the underpricing levels across rounds for both treatments and also shows the corresponding market values. In the UNIFORM treatment the level of underpricing is positively correlated with market value, i.e. higher market values are related to more severe underpricing.[32] This relationship is confirmed by the Spearman rank-order correlation coefficients between the market value and the underpricing level, which are positive for all 14 groups ($p = 0.0001$).[33] The standard deviations of underpricing levels across groups are not significantly different ($p = 0.194$) between the two treatments. This implies that while the levels of underpricing differ across treatments, the variability of underpricing does not.

[31] These results still hold even if we only look at the last ten rounds.

[32] In fact, there is no overpricing when all informed players receive high signals, and no underpricing when no one receives a high signal. In total, H bidders submitted 1181 bids, among them 31%, 18%, 51% are placed above, at and below the expected value given a high signal respectively. L bidders submitted 1097 bids, with 37%, 24% and 39% of bids are above, at and below the expected value given a low signal respectively. Among the 726 bids from U bidders, 51%, 3% and 46% are above, at and below the unconditional expected value respectively.

[33] To test for correlation between the two variables we use the following method. We first compute Spearman rank-order correlation coefficients between the two variables for each group separately. This gives a sample of independent observations, one for each group. We then apply the Wilcoxon signed-ranks test to check whether the coefficients are predominantly positive or negative. Notice that we do not examine the significance of the individual coefficients, as the Spearman test requires the coefficient to be based on independent paired observations. However, even if the paired observations within a group are dependent, if there is no relationship between the two tested variables the coefficient would be positive or negative with equal probability (H_0). In the current example the coefficients are positive for all 14 groups, thus we can reject the null hypothesis ($p = 0.0001$).

Result 3 *In the UNIFORM treatment, there is a positive relationship between the degree of underpricing and the market value. The standard deviations of underpricing levels are not significantly different between treatments.*

4.2 Strategies in the UNIFORM treatment

Result 1 is contrary to the revenue ranking prediction by BF. Their prediction is based on the assumption that players follow the payoff-dominant symmetric TCE. We thus check if there are individual subjects who follow this strategy. Among all 280 rounds the market price was zero in only four rounds. All of these happened in the first three rounds, and the total demands in these cases were less than the quantity for sale.[34] Looking at individual behavior, only 19 out of 1120 proposals (1.7%) demanded the symmetric collusive quantity 25,000. Only five subjects were responsible for these proposals, and none of them was from the same group. In no round did all bidders in a group obtain the same allocation. So the equilibrium provided by BF, where the price is zero and bidders behave symmetrically, was not followed in the experiment.

Symmetric TCE with market prices higher than zero also seem unlikely: there are 53 out of 1120 proposals (4.7%) where players demanded 25,000 units first and increased demands at prices at or below 2. Since in any TCE, the market price should be no higher than 2, we check if TCE with market prices higher than zero, or asymmetric TCE have been achieved by first selecting the rounds where the market prices are no higher than 2. We then take a closer look at bidder's behavior around these rounds when signals change. We find that subjects tend to change their behavior with a change in signals. In particular, they bid for higher quantities at higher prices when receiving high signals rather than low signals. In fact, among all 14 groups, the Spearman rank-order correlation coefficients between prices and values are negative in only one group. This suggests a positive correlation between the market price and the market value ($p = 0.003$). Looking at the aggregate demand curves of each type of bidders in each group, we see that in general H bidders' demand curve lies above that of L bidders.[35] This feature violates a key property of TCE, namely that bidders behave in the same way regardless their signals. The average demand at market prices of an H, an L or a U bidder is 50,476, 28,843 and 27,118 respectively. In 13 out of 14 groups the average demand of an H bidder is higher than that of an L bidder ($p = 0.000$).

Result 4 *There is no evidence that any of the tacit collusion equilibria has been achieved in the UNIFORM treatment.*

We also examined whether strategies led to outcomes conforming to properties of any of the other equilibria summarized in Table 1.

The equilibrium EH is risky for H bidders because they can easily suffer a loss if L or U investors place bids at high prices. Hence if TCE are not evident because of the riskiness, there should also be few cases that EH are achieved in the experiment.

[34] The highest demand among the four rounds is 84,000 units.

[35] Figures of aggregate demand curves of each group are posted as supplementary materials.

Consistent with this analysis, in the experiment few bids are placed in the range of this equilibria set. H bidders have to lose some shares to L and U bidders in order to avoid the market price being raised too high.

In 191 out of 280 rounds, the market price is no higher than the market value.[36] If an equilibrium characterized in Zhang (2006) has even been achieved, it should have the properties that the types of bidders who are excluded from the market place no bids above 1; and the market price is lower than the market value should L bidders obtain an allocation, given that at least one H bidder exists. Taking this into account, the numbers of rounds that an EH or EHL or EHU or EHLU equilibria might have been achieved are 10, 1, 29 and 78 (5.2%, 0.5%, 15.2% and 40.8%) respectively.[37] Hence the strategies followed by subjects are more likely to be those associated with EHLU.

The following result summarizes the analysis in this section so far.

Result 5 *Bidding in the UNIFORM treatment results all types of bidders obtain an allocation, H bidders bid more aggressively and obtain more allocation than L and U bidders, and the market price increases with the market value.*

These properties are consistent with those of EHLU characterized by Zhang (2006). EHLU are less risky compared with TCE. Unlike TCE where the demand at high prices remains high even if the market value is low, and thus a small deviation from equilibrium may cause a severe loss, in EHLU demand at high prices is high only if the market value is high, so the extent of possible loss in a deviation is lower.

4.3 Bidding behavior in the FIXED treatment

In the FIXED treatment, there is, on average, over-subscription both across groups and across rounds.[38] Even in the 31 rounds (out of 280) when no high signals were observed, the average group demand was 240,600 units. However, the average demand of each type of bidders falls below the equilibrium prediction in all groups even in later rounds. In Fig. 5 we plot the deviations from equilibrium, i.e., the differences between the average and the equilibrium demands, of each type of bidders across round. It shows that H and U bidders increase their demands over rounds especially at the beginning of the experiment. The demand of L bidders, however, remains stable during the experiment.[39] H bidders bid less than the equilibrium strategy (i.e.

[36] Among these 191 rounds, all types of bidders obtain allocations 63.4% of the time. In comparison only H, H and L, and H and U bidders obtain allocations 7.3%, 4.7% and 24.6% of the time respectively. When the market value is 4, the allocation to "L" bidders is automatically zero. Excluding these 32 cases, the percentages of rounds where only H bidders obtain an allocation is reduced to 3.1%, and where H and U bidders share the market is reduced to 15.1%.

[37] Excluding the cases when there are no L bidders in the group, the numbers of rounds that an EH or EHU might have been achieved are reduced to 1 and 6 respectively. Among all the bids submitted by U bidders, only 3.2% are placed at prices that are less than or equal to 1; the percentage for L bidders is 7.9%.

[38] There was one U bidder who always submitted a zero unit demand and this led to under-subscription in ten rounds. Only in three other rounds were the total demands below the supply.

[39] Comparing the average demands of the first and the last ten rounds, both the H and the U bidders increased their demands but the L bidders did not (the p-values are 0.001, 0.040 and 0.326 respectively).

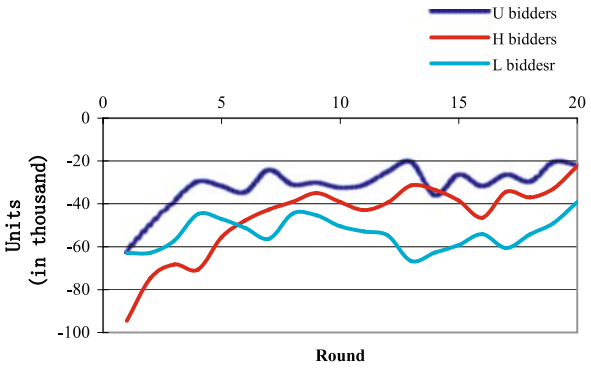

Fig. 5 Deviations from equilibrium across rounds (FIXED treatment)

bidding for 150,000 units) on average. This is not surprising since the prediction is to bid at the boundary of the strategy space. Thus any error or deviation from the prediction must bias the observation downwards. This may also lead L bidders to submit below-equilibrium bids.[40] Since the shares for sale were oversubscribed, this strategy variation did not make much difference for the seller. In fact, the demand in the FIXED treatment is greater than that in the UNIFORM treatment. In 13 out of 14 groups the demand in the FIXED treatment exceeds that in the UNIFORM treatment at price 1.94.[41] This suggests that because the amount of bidding influences both the allocation and the market price in the UNIFORM treatment, players tend to behave more conservatively.

Result 6 *In the FIXED treatment, shares are oversubscribed. However, on average all types of bidders bid less than the risk-neural equilibrium prediction.*

5 Summary and concluding remarks

We report an experiment that compares the performances of uniform price auctions and fixed price offerings. There are three main findings of this study.

Firstly, in our experiment, the market price in uniform price auctions is higher than the price used in fixed price offerings. As a result, compared to fixed price offerings, underpricing is less frequent and less severe and the seller receives more revenue in uniform price auctions. This might reflect the fact that in the fixed price offering price is set exogenously at a particularly low level. However, since the exogenous price is

[40] By definition of the market price, the equilibrium expected earnings of an L bidder are zero when bidding for 100,000 units. Bidding for other positive amounts would result in a negative expected payoff for an L bidder, given that the other bidders follow the equilibrium strategy. The actual average payoff of L bidders is not significantly different from zero although their demand is below the equilibrium strategy. This is because H and U bidders also bid less than the equilibrium strategy. H, L, and U bidders follow the equilibrium strategy 29%, 10% and 21% of the time respectively. L bidders bid for less than the equilibrium 87 % of the time.

[41] The average group demand and the demand of an H, an L or a U bidder at 1.94 are 269,280, 102,998, 46,605 and 44,875 in FIXED vs. 188,057, 66,547, 35,015 and 35,714 in UNIFORM. At 1.94, an H, an L or a U bidder demands more in the FIXED than in the UNIFORM in 13, 9 and 11 groups respectively.

based on the model this is a limitation of the theoretical model as much as it is a limitation of the experimental design. A richer model might consider alternative methods for setting the price in fixed price offerings. The market price in uniform price auctions lies between the unconditional expected value of shares and the expected value conditional on having a low signal. Increasing the fixed price above the latter would result in under-subscription if there are no high signals observed.[42]

Secondly, the tacit collusion equilibria (TCE) that have been the focus of Biais and Faugeron-Grouzet (2002) and many other researchers have not been achieved in the experiment, even though it is the most profitable outcome for subjects. Some experimental literature on collusion in laboratory multi-unit auctions suggests that collusion is only achievable if there are two bidders (Sherstyuk 2008), subjects have a coordination device (Brown et al. 2006), or anonymity is abandoned (Füllbrunn and Neugebauer 2007). From this perspective the present result of no-collusion in groups of four anonymous players is fully in line with the literature.[43]

Thirdly, the observed market outcomes have the following properties: all types of bidders participate in the market; compared with a bidder with a low signal, a bidder with a high signal bids for higher quantities at higher prices (thus the market price is positively related to the market value), and obtains a greater allocation.

The failure to achieve TCE may reflect strategic uncertainty in an environment with multiple equilibria. We noted that these equilibria are risky in the sense that a deviation from equilibrium by one bidder can cause large losses for other bidders. We also noted that there is another class of equilibria (in which bidders with high signals absorb all the shares, and uninformed bidders and bidders with low signals only obtain an allocation when there are no high signals) that are similarly risky, and are rarely observed. At the same time there is another class of equilibria, termed "EHLU equilibria" in Zhang (2006), that though payoff-dominated are less risky. EHLU equilibria have all the properties listed in the previous paragraph.

In summary, although TCE are theoretically interesting, they should not be overemphasized for practical purposes. However, the existence of multiple equilibria, including those with low revenues, implies a degree of uncertainty regarding the performance of uniform price auctions. Introducing rules to make it more difficult for investors to collude in circumstances where TCE are more likely to be achieved should be taken into account when designing auctions.

Acknowledgements I thank Klaus Abbink, Spiros Bougheas, Martin Sefton, the two anonymous referees and the editor for extremely valuable comments. I also thank Robin Cubitt, Saileshsingh Gunessee, Lars Moller, Maria Montero, Hans Normann, Henrik Orzen, Daniel Seidmann, Reinhard Selten, participants at the Economic Science Association 2004 International Meeting and the CREED-CeDEx 2005 Fall Event for comments. I am grateful for financial support from the University of Nottingham, the Leverhulme Trust (Program Grant F114/BF), the ESRC (PTA-026-27-1408), and the Centre for Decision Making and Experimental Research (CeDEx). Remaining errors are mine.

[42] In practice the choice of a mechanism is also situation-dependent. For a firm that has a good knowledge of its market value, fixed price offerings might be a better choice since it can set the price at a higher level than the theoretical prediction, without facing the risk of under-subscription.

[43] Thanks to an anonymous referee for pointing out this relation between the literature and results of our experiment.

References

Ausubel, L. M., & Cramton, P. (2002). *Demand reduction and inefficiency in multi-unit auctions*. Working paper of University of Maryland.

Back, K., & Zender, J. F. (1993). Auctions of divisible goods: on the rationale for the treasury experiment. *The Review of Financial Studies*, *6*, 733–764.

Benveniste, L. M., & Wilhelm, W. J. (1990). A comparative analysis of IPO proceeds under alternative regulatory environments. *Journal of Financial Economics*, *28*, 173–207.

Biais, B., & Faugeron-Grouzet, A. M. (2002). PO auction: English, Dutch, ... French, and Internet. *Journal of Financial Intermediation*, *11*, 9–36.

Bikhchandani, S., & Huang, C. F. (1993). The economics of Treasury securities markets. *Journal of Economic Perspectives*, *7*, 117–134.

Brown, A., Kamp, H., & Plott, C. (2006). *The nature of collusion facilitating and collusion breaking power of simultaneous ascending price and simultaneous Descending Price Auctions*. Caltech, Social Science Working Paper.

Bulow, J., & Klemperer, P. (2002). Price and the winner's curse. *The RAND Journal of Economics*, *33*, 1–21.

Chemmanur, T. J., & Liu, M. H. (2003). *How should a firm go public? A dynamic model of the choice between fixed-price offerings and auctions in IPOs and privatizations*. EFA 2003 Annual Conference Paper No. 366.

Derrien, F., & Womack, K. L. (2001). Auction vs. bookbuilding and the control of underpricing in hot IPO markets. *The Review of Financial Studies*, *16*, 31–61.

Engelmann, D., & Grimm, V. (2003). *Bidding behavior in multi-unit auctions: an experimental investigation and some theoretical insights*. Working paper, CERGE-EI 210.

Friedman, D., & Sunder, S. (1994). *Experimental methods, a primer for economists*. Cambridge: Cambridge University Press.

Füllbrunn, S., & Neugebauer, T. (2007). *Anonymity deters collusion in hard-close auctions: experimental evidence*. University of Luxembourg, Working Paper.

Goswami, G., Noe, T. H., & Rebello, M. J. (1996). Collusion in uniform-price auctions: experimental evidence and implication for treasury auctions. *The Review of Financial Studies*, *9*, 757–785.

Hansen, R. G., & Lott, J. R. Jr. (1991). The winner's curse and public information in common value auctions: comment. *The American Economic Review*, *81*, 347–361.

Kagel, J., & Levin, D. (1991). The winner's curse and public information in common value auctions: reply. *The American Economics Review*, *81*, 362–369.

Kagel, J. H., & Levin, D. (2001). Behavior in multi-unit demand auctions: experiments with uniform price and dynamic Vickrey auctions. *Econometrica*, *69*, 413–454.

Kagel, J. H., & Levin, D. (2002). *Common value auctions and the winner's curse*. NJ: Princeton University Press.

Kandel, S., Sarig, O., & Wohl, A. (1999). The demand for stocks: an analysis of IPO auctions. *The Review of Financial Studies*, *12*, 227–247.

Koh, F., & Walter, T. S. (1989). A direct test of Rock's model of the pricing of unseasoned issues. *Journal of Financial Economics*, *23*, 251–272.

Lind, B., & Plott, C. R. (1991). The winner's curse: experiments with buyers and with sellers. *The American Economic Review*, *81*, 335–346.

Loughran, T., Ritter, J. R., & Rydqvist, K. (1994). Initial public offerings: international insights. *Pacific-Basin Finance Journal*, *2*, 165–199.

Porter, D., & Vragov, R. (2003). *An experimental examination of demand reduction in multi-unit version of the uniform-price, Vickrey, and English auctions*. ICES Working Paper, George Mason University.

Rock, K. (1986). Why new issues are underpriced. *Journal of Financial Economics*, *15*, 197–212.

Sade, O., Schnitzlein, C., & Zender, J. F. (2006). Competition and cooperation in divisible good auctions: an experimental examination. *The Review of Financial Studies*, *19*, 195–235.

Sherman, A. E. (2002). *Global trends in IPO methods: book building vs. auctions*. Working paper, University of Notre Dame.

Sherman, A. E., & Titman, S. (2002). Building the IPO order book: underpricing and participation limits with costly information. *Journal of Financial Economics*, *65*, 3–29.

Sherstyuk, K. (2008) Some results on anti-competitive behavior in multi-unit ascending price auctions. In Plott, C., Smith, V. (Eds.), *Handbook of experimental economics results*. Amsterdam: Elsevier.

Trauten, A., & Langer, T. (2008). *Why the Google IPO might stay exotic–an experimental analysis of offering mechanisms.* Mimeo, University of Münster.

Van Huyck, J., Battalio, R., & Beil, R. (1990). Tacit coordination games, strategic uncertainty, and coordination failure. *American Economic Review*, *80*, 234–24.
Wang, J. D., & Zender, J. F. (2002). Auctioning divisible goods. *Economic Theory*, *19*, 673–705.
Wilson, R. (1979). Auctions of shares. *The Quarterly Journal of Economics*, *94*, 675–689.
Zhang, P. (2006). *A complete characterization of pure strategy equilibria in uniform price IPO auctions*. CeDEx discussion paper No. 2006-06.