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Bookbuilding with heterogeneous investors

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Abstract

Empirical evidence suggests that better-informed investors in bookbuilt IPOs submit more informative bids and receive better allocations than do investors with less precise information. While the traditional bookbuilding argument accounts for this evidence as better-informed investors being rewarded with more favorable allocations for providing more useful information, the present paper adopts the winner's curse argument and shows that better-informed investors get better allocations by being better able to pick underpriced issues, even though in equilibrium investors' bids fully reveal their information. The paper offers empirical implications that allow the two arguments to be separated.

JEL classification: G10; G32

Keywords: Bookbuilding; Investor heterogeneity; Winner's curse; Underpricing

1. Introduction

Do higher returns earned by better-informed investors in initial public offerings (IPOs) represent a reward for providing more valuable information as implied by the bookbuilding argument of Benveniste and Spindt (1989), or do they reflect a greater ability of better-informed investors to pick underpriced issues as implied by the winner's curse argument of Rock (1986)? The bookbuilding argument accounts for the empirical evidence of underpricing in IPOs as compensation to institutional investors for truthfully revealing their information. Its main empirical implication is that better-informed investors obtain more profitable allocations in exchange for providing more valuable information during the bookbuilding process. The winner's curse argu-

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ment, on the other hand, accounts for the underpricing in IPOs as compensation to uninformed investors for being allocated a disproportionately large share of overpriced issues, which implies that better-informed investors obtain better allocations by being better able to pick underpriced issues compared to investors with less precise information.

A common objection to the winner's curse argument, however, is that it implicitly assumes the fixed price method and hence the extent to which it has relevance in IPOs sold with bookbuilding is unclear. On a similar note, while the basic bookbuilding argument assumes that investors are identical in the precision of their information, its main empirical implication that better-informed investors are rewarded with better allocations implicitly assumes that investors differ in the precision of their information, and hence the extent to which (and indeed the way in which) that the main implication of the bookbuilding argument actually represents a formal prediction is unclear.

The present paper considers bookbuilding in a setting in which investors differ in the precision of their information. Consistent with the traditional bookbuilding argument, it is shown that investors' bids fully reveal their information. Moreover, consistent with the main—but inferred—implication of the traditional bookbuilding argument, better-informed investors submit more informative bids and get more profitable allocations compared to investors with less precise information. Nonetheless, underpricing is shown to represent compensation to less-informed investors for being allocated a disproportionately large fraction of overpriced issues rather than compensation to better-informed investors for providing more useful information. In other words, the analysis suggests that underpricing in bookbuilt issues represents a winner's curse premium even though the bids submitted by investors fully reveal their information.

The intuition for this result is as follows. Investors submit limit bids and are allocated shares at or below their bids. At the time that bids are submitted investors are incompletely informed about the demand for the issue. And although each investor makes a non-negative expected excess return in the issue, each investor faces a positive probability of being allocated overpriced shares. The possibility of being allocated overpriced shares implies in turn a winner's curse problem for less-informed investors, who respond by scaling down their bids, which leads to underpricing.

The model implies that investors who submit higher bids receive better allocations and make higher returns compared to investors who submit lower bids. This implication is consistent with empirical evidence of Cornelli and Goldreich (2001), as well as with inferred implications of the traditional bookbuilding argument. A second implication is that the allocation-weighted return to the marginal investor in the offering is zero. This implication is analogous to the main prediction of the basic winner's curse argument of a zero allocation-weighted return to uninformed investors. In the present model, however, the marginal investor is informed and the expected return to uninformed participation among bookbuilding investors is negative. In contrast, the traditional bookbuilding argument implies a positive expected excess return to uninformed participation, which follows from an assumption that the issuer commits not to overprice the issue given the information contained in investors' bids. This difference in predictions with respect to the return to uninformed participation among bookbuilding investors may help to distinguish the two arguments empirically.

Bookbuilding is modeled as a two-stage process. In stage one, investors reveal the realizations in their signals by indicating either a positive or a negative interest in the offering. In equilibrium, only investors with favorable signals will state a positive interest. These investors make up the potential demand for the issue and constitutes the set of investors who eventually may be allocated shares. In stage two, the issuer may set a fixed price based on the interest indicated from the first stage (equilibrium is partially revealing), or the issuer may price and allocate the issue so as to induce investors who indicate a positive interest in the first stage to reveal the precision in their signals by submitting limit bids (equilibrium is fully revealing).

This two-stage bookbuilding process may be viewed in terms of bookbuilding practices observed in most European IPO markets where the investment banking syndicate first solicits the opinions of institutional investors before setting the preliminary price range. Jenkinson et al. (2005) consider explicitly European bookbuilding and show that the incentives of investors to understate their beliefs initially are resolved by the issuer committing not to price the issue above the indicative price range, consistent with empirical evidence. In the present paper, the incentives of investors to understate their beliefs is resolved by the issuer committing to price the issue so that investors with unfavorable information will not find it profitable to ask for shares, which in turn requires the issuer to commit to withdraw the issue upon low interest in the initial stage. The present paper models the initial bookbuilding stage less explicitly compared to Jenkinson et al. (2005) and in this respect is more general than theirs. The idea is to capture in the simplest possible way a bookbuilding process in which investors update their bids over time and in which the issuer becomes informed in stages before pricing and allocating the issue. As such, the model applies to US bookbuilding as well as European bookbuilding.

By studying the role of adverse selection in bookbuilt IPOs, the paper is related to Benveniste and Wilhelm (1990) and Maksimovic and Pichler (2004) who examine the role of adverse selection in bookbuilt IPOs in settings where institutional investors are homogeneous in the precision of their information and retail investors are heterogeneous, being informed or uninformed. In these models, underpricing may come from adverse selection among retail investors but never from adverse selection among institutional investors, since institutional investors are assumed not to differ in the precision of their information. In contrast, the present paper considers information heterogeneity and adverse selection among institutional investors.

The paper is also related to Biais and Faugeron-Crouzet (2002) who consider a setting in which institutional investors are homogeneous in the precision of their information and retail investors are uninformed, with retail investors being allocated shares so as to reduce the incentives of institutional investors to understate their information. The issuer commits not to overprice the issue given the information observed by institutional investors and hence retail investors are not exposed to adverse selection risk from institutional investors. Finally, Malakhov (2004) develops a bookbuilding model where informed investors are perfectly informed about the true value of the IPO firm, and in the optimal mechanism implicitly reveal their information from the number of shares that they request. The presence of uninformed investors reduces the need for underpricing by reducing the bargaining power of informed investors. In the optimal mechanism uninformed investors free-ride on the underpricing that the issuer must offer informed investors to induce truthtelling. Uninformed investors therefore make positive excess returns despite potentially being exposed to adverse selection (by being uninformed). In the present paper, underpricing comes from adverse selection among informed (institutional) investors despite bookbuilding.

The rest of the paper is organized as follows. Section 2 presents the basic setup. Section 3 examines the bookbuilding process and derives the results. Section 4 discusses the main empirical implications of the model. Section 5 concludes the paper. All proofs in Appendix A.

2. The setup

A firm is to undertake an IPO. The underlying value of this firm equals v_H with probability α and v_L with probability $1-\alpha$, where $v_H > v_L = 0$. After the completion of the IPO, the firm's market value is established as an expectation over true value conditional on information observed by investors, as explained below. The number of shares that are sold in the offering is normalized to one, and investors are allocated fractions of this one share. All agents are risk neutral and the riskless interest rate is zero.

There are three investors in the offering, indexed $n = 1, 2, 3$. Each investor observes a private signal $s_n = \{b_n, g_n\}$, where b_n represents unfavorable information and g_n represents favorable information. The precision in s_n is given by $\gamma_n = p(g_n|v_H) = p(b_n|v_L)$, where $\gamma_3 \geqslant \gamma_2 \geqslant \gamma_1 \geqslant 1/2$. In other words, the signal observed by investor 3 is more precise than that of investor 2, whose signal is more precise than of investor 1. The firm's aftermarket value is denoted $v(s_1, s_2, s_3)$, which represents the expected value of the firm given the signals observed by investors. This specification implicitly assumes that trading in the aftermarket reveals the private information observed by investors, and in other words that trading in the aftermarket ensures informationally efficient market prices.

The bookbuilding process is conducted in two stages. In the first stage, investors indicate either a positive or a negative interest in the issue. Investors are informed about the total interest in the IPO before submitting their bids in the second stage. The issuer offers allocations only to investors who indicate a positive interest in the offering, and withdraws the issue if no investor indicates a positive interest in it.[1] This is optimal, for example, if the reservation value of the issuer is equal to or greater than $v(b_1, b_2, b_3)$. In equilibrium, only investors with favorable signals will indicate a positive interest in the offering. In the second stage, the issuer has a choice of setting a fixed price based on the interest indicated in the first stage, or pricing and allocating the issue so as to induce investors to reveal the precision in their signals. Investors who indicate a positive interest in the issue in stage one ask for allocations in the second stage by submitting limit bids.

This two-stage bookbuilding process captures an IPO process whereby investors are able to revise their bids over time as they become better informed about the value of the firm. In particular, investors become informed about the total demand for the issue as measured by the number of positive signals after the first stage, and then in the second stage reveal their types by submitting limit bids. This two-stage process is not strictly necessary to generate the main results of the paper, however. As an alternative, the issuer may offer a complete price and allocation schedule where prices and allocations are made contingent on the number of favorable signals and revealed type, but this will imply a higher level of abstraction and make the analysis needlessly complex.

No constraints are imposed on the size of the allocation to each investor, which implies that one investor may absorb the entire issue. Since the issuer withdraws the issue upon weak demand, the assumed absence of allocation constraints ensures that it will be costless to induce investors to reveal the realization in their signals, which allows a focus on the role of investor heterogeneity in the pricing and allocation of IPOs.

Investors are heterogeneously informed about the value of the IPO firm at the time that they submit their bids, and each investor is facing a positive probability of being allocated overpriced shares, which implies an adverse selection risk for less-informed investors. In the traditional bookbuilding argument, in contrast, the issuer commits not to overprice the issue given the information revealed by investors, and hence each investor gets a positive expected return in the issue. An exception is regular investors who are hypothesized to be allocated overpriced shares on the promise of favorable allocations in future (underpriced) issues. And although empirical

[1] For empirical evidence on withdrawal probability in IPOs see e.g. Dunbar (1998) and Busaba et al. (2001).

evidence[2] supports the idea that investment bankers favor regular investors in allocations, especially in heavily over-subscribed issues, presumably as a reward for accepting overpriced shares in under-subscribed issues, the same empirical evidence shows that both regular and occasional investors are allocated overpriced shares, consistent with the present argument.

Let N denote the number of investors who indicate a positive interest. The issuer observes N and passes this information on to investors. Although the issuer may have an incentive to overstate N to obtain a higher price, it is assumed that the issuer announces N truthfully. For example, the issuer (or the investment bank) may have reputational capital at stake. There are four possible states of demand: $N \in \{0, 1, 2, 3\}$. If $N = 0$, the issue is withdrawn. If $N = 3$, the interest indicated in the first stage fully reveals the firm's aftermarket value. If $N = 1$, then each investor will be able to infer true aftermarket value of the firm by combining $N = 1$ with her own signal. In cases $N = 1, 3$ there can be no adverse selection since investors are perfectly informed about the firm's true aftermarket value. Finally, if $N = 2$, then investors (as well as the issuer) are incompletely informed about the firm's aftermarket value, and hence less-informed investors face a potential adverse selection risk.

Case $N = 2$ is the interesting case for the present argument. Indeed, it may be viewed as the general case in the sense that adverse selection risk will be present with probability one as the number of investors in the offering becomes sufficiently large. To see this, suppose that the number of investors in the first stage is $M > 3$, then the possible states of demand are given by $N \in \{0, 1, 2, \ldots, M\}$. This set may be partitioned into subsets $\{0, 1, M\}$ and $\{2, \ldots, M - 1\}$, where the latter represents the states of demand for which there is adverse selection. Now to see that adverse selection must represent the general case, note that as M becomes large the probability that $N \in \{2, \ldots, M - 1\}$ will tend to one. To examine the simplest possible scenario, I assume that $M = 3$ and consider the case for which $N = 2$. (Cases $N = 1, 3$ are analyzed in Appendix B.)

3. Bookbuilding: second stage

The bookbuilding process is conducted in two stages. In stage one, investors reveal the realization in their signals by indicating either a positive or a negative interest in the offering. An investor who observes a favorable signal will have an incentive to indicate a positive interest so as to be able to ask for an allocation in the second stage. By the same token, an investor who observes an unfavorable signal will have no incentive to indicate a positive interest in the issue since, in equilibrium, such an investor will obtain a negative payoff if allocated shares.

The issuer has two alternatives when pricing and allocating the issue in stage two. She may set a fixed price based on the stated interest observed in the first stage, and then allocate the issue on a pro rata basis. Alternatively, investors submit limit bids, and the issuer prices and allocates the issue based on these bids. These two alternatives are analyzed next, in Sections 3.1 and 3.2.

3.1. Fixed price conditional on stated interest

The issuer observes the demand $N = 2$ for the issue from the first stage. In the present section, the issuer prices the issue by setting a fixed price P_0 conditional on $N = 2$ and then allocates it pro rata. In the next section, I consider the case in which investors submit bids according to their types and the issuer prices and allocates the issue based on these bids.

[2] See Cornelli and Goldreich (2001), Jenkinson and Jones (2004), and Boehmer and Fishe (2004).

Given $N = 2$, the issuer may price the issue such that only investor 3 is willing to submit a bid in the offering, provided her signal is favorable. In this case, there will be no underpricing, but the issue will fail with a positive probability since successful completion will require that investor 3 obtains a favorable signal. Alternatively, the issuer may price the issue with investor 2 as the marginal investor. In this case, there is adverse selection but the issue succeeds with probability one, since in this case the issue succeeds if either investor 2 or investor 3 obtains favorable signals.[3] Of interest is the case in which adverse selection may play a role in the pricing of the issue, and hence considered is the case in which the issuer prices the issue with investor 2 as the marginal investor.

Investor 2 knows that the total demand for the issue is $N = 2$ but is unable to observe the identity of the second investor. If the second investor is investor 1, then investor 2 will be allocated the entire issue, since investor 1 drops out. If the second investor is investor 3, then investor 2 is allocated half of the issue.

The issue is priced from the participation constraint of investor 2:

$$p_2\big[v(g_1, g_2, b_3) - P_0\big] + (1 - p_2)\frac{1}{2}\big[v(b_1, g_2, g_3) - P_0\big] = 0, \tag{1}$$

where

$$p_2 = \frac{p(g_1, g_2, b_3)}{p(g_1, g_2, b_3) + p(b_1, g_2, g_3)}. \tag{2}$$

The equilibrium IPO price P_0 is determined from (1) and equals:

$$P_0 = \frac{p_2 v(g_1, g_2, b_3) + (1 - p_2)\frac{1}{2} v(b_1, g_2, g_3)}{p_2 + (1 - p_2)\frac{1}{2}}. \tag{3}$$

Given this price, only investor 2 and investor 3 will ask for shares, if their respective signals are favorable. The expected aftermarket value of the issue, given $N = 2$, equals

$$\bar{v} = \frac{p(g_1, g_2, b_3)v(g_1, g_2, b_3) + p(g_1, b_2, g_3)v(g_1, b_2, g_3) + p(b_1, g_2, g_3)v(b_1, g_2, g_3)}{p(g_1, g_2, b_3) + p(g_1, b_2, g_3) + p(b_1, g_2, g_3)}. \tag{4}$$

The issue is underpriced if $P_0 \leqslant \bar{v}$ or, in other words, if its price is set below its expected aftermarket value.

Proposition 1. *The issue is underpriced in equilibrium*; *that is,* $P_0 \leqslant \bar{v}$.

The issue is priced so that it succeeds with probability one, given $N = 2$. Although investor 2, as the marginal investor, observes the total demand for the issue, she has incomplete information about the quality in this demand. The result is adverse selection in the allocation of shares for investor 2 and, therefore, underpricing.

Proposition 1 derives underpricing as compensation for adverse selection rather than for revealing valuable information, even though, in equilibrium, investors truthfully reveal the reali-

[3] A third alternative for the issuer is to price the issue sufficiently low to ensure that investor 1 submits a bid in the offering should he be among the (two) investors who indicated a favorable interest in the issue in the first stage. However, this would require a reduction in the IPO price without a corresponding increase in the success probability of the issue and hence would be wasteful from the point of view of the issuer.

zations in their signals. Truthtelling in the sense of investors revealing the realizations in their signals obtains, in other words, at zero cost.[4] This result allows a focus on the role of adverse selection in bookbuilt IPOs, as a complement to the pure information-revelation story, and follows from the assumption that the issuer will withdraw the issue if the stated interest for it is sufficiently weak. This assumption ensures that investors who fail to indicate a positive interest in the issue receive no allocations, which in turn ensures that the potential payoff from indicating a negative interest will be zero and hence that investors cannot expect to be compensated for merely stating a positive interest in the issue.[5]

3.2. *Price and allocations conditional on bids*

The previous section considered the case in which the issuer sets a fixed price conditional on stated interest. The present section considers the case in which the issuer prices and allocates the issue so as to induce investors to also reveal the precision in their signals. Investors who indicate a positive interest in the first stage submit bids in the second stage by using limit bids, or specifying a maximum price. In equilibrium, different investors submit different limit bids and hence reveal their types.

Let x_{nm} denote the fraction of the issue allocated to investor n, with the remaining fraction $x_{mn} = 1 - x_{nm}$ allocated to investor m, where $n, m = 1, 2, 3$, and $n \neq m$. Investors know the allocation policy of the issuer at the time that they submit their bids. In equilibrium, investors report their types truthfully by submitting bids that match their types. If, out-of-equilibrium, identical bids are observed, then bids are uninformative and the issuer prices the issue equal to the price submitted, and allocates the issue pro rata.

Let V_n denote the limit bid (or price) submitted by investor n. By submitting V_n investor n commits to accept any shares offered at or below this price. The issuer commits to price the issue at $\min[V_n, V_m]$ and to allocate it according to the pre-stated allocation policy (x_{nm}, x_{mn}).

Consider now investors' truthtelling and participation constraints.

Investor 1. In equilibrium, investor 1 submits a bid V_1 and obtains an expected payoff

$$U_1 = p_1 x_{12}\big[v(g_1, g_2, b_3) - V_1\big] + (1 - p_1)x_{13}\big[v(g_1, b_2, g_3) - V_1\big], \tag{5}$$

where

$$p_1 = \frac{p(g_1, g_2, b_3)}{p(g_1, g_2, b_3) + p(g_1, b_2, g_3)}. \tag{6}$$

It never pays to overstate signal precision, and hence investor 1 has no incentive to misrepresent her type. In equilibrium, the issuer must price and allocate the issue so that $U_1 \geqslant 0$ for investor 1 to submit a bid.

[4] There is a potential cost, though, since the issue is withdrawn in the event of weak demand. On the other hand, the issuer may have a reserve price that exceeds the value of the firm given zero interest, in which case the issuer will optimally withdraw the issue even if some investors indicate a positive interest.

[5] In Benveniste and Spindt (1989) this implication follows directly from investors' truthtelling constraints: if an investor by reporting unfavorable information is not allocated shares, then this investor has no incentive to (falsely) report unfavorable information and hence there will be no need for underpricing. Maksimovic and Pichler (2004) show more formally that "underpricing is not required to induce truthtelling … without allocation constraints." Relatedly, Busaba (2001) show theoretically and Busaba et al. (2001) empirically that the issuer's option to withdraw the issue upon weak demand reduces the amount of underpricing.

Investor 2. The expected payoff to investor 2 from submitting a limit bid V_2 is given by

$$U_2 = p_2(1 - x_{12})\big[v(g_1, g_2, b_3) - V_1\big] + (1 - p_2)x_{23}\big[v(b_1, g_2, g_3) - V_2\big]. \tag{7}$$

Alternatively, investor 2 may present himself as investor 1 by submitting a limit price of V_1. This gives an expected payoff

$$U_{21} = (1 - p_2)x_{13}\big[v(b_1, g_2, g_3) - V_1\big] + p_2\frac{1}{2}\big[v(g_1, g_2, b_3) - V_1\big]. \tag{8}$$

Participation and truthtelling for investor 2 require that $U_2 \geqslant 0$ and $U_2 \geqslant U_{21}$.

Investor 3. The expected payoff to investor 3 from submitting a limit bid V_3 is given by

$$U_3 = p_3(1 - x_{13})\big[v(g_1, b_2, g_3) - V_1\big] + (1 - p_3)(1 - x_{23})\big[v(b_1, g_2, g_3) - V_2\big], \tag{9}$$

where

$$p_3 = \frac{p(g_1, b_2, g_3)}{p(g_1, b_2, g_3) + p(b_1, g_2, g_3)}. \tag{10}$$

Investor 3 may present herself as a type-1 by submitting a limit bid of V_1 to obtain an expected payoff

$$U_{31} = (1 - p_3)x_{12}\big[v(b_1, g_2, g_3) - V_1\big] + p_3\frac{1}{2}\big[v(g_1, b_2, g_3) - V_1\big]. \tag{11}$$

Alternatively, investor 3 may submit a limit bid of V_2 to obtain an expected payoff

$$U_{32} = p_3(1 - x_{12})\big[v(g_1, b_2, g_3) - V_1\big] + (1 - p_3)\frac{1}{2}\big[v(b_1, g_2, g_3) - V_2\big]. \tag{12}$$

Participation and truthtelling for investor 3 requires that $U_3 \geqslant 0$ and $U_3 \geqslant \max[U_{31}, U_{32}]$.

Expected proceeds are given by

$$\pi = pV_1 + (1 - p)V_2, \tag{13}$$

where

$$p = \frac{p(g_1, g_2, b_3) + p(g_1, b_2, g_3)}{p(g_1, g_2, b_3) + p(g_1, b_2, g_3) + p(b_1, g_2, g_3)}. \tag{14}$$

The issuer prices and allocates the issue so as to maximize expected proceeds, subject to investors' participation and truthtelling constraints. More formally, the issuer solves

$$\max_{x_{13}, x_{12}, x_{23}, V_1, V_2} \pi \tag{15}$$

subject to

$$U_1, U_2, U_3 \geqslant 0, \tag{P}$$

$$U_2 \geqslant U_{21}, \tag{TT2}$$

$$U_3 \geqslant \max[U_{31}, U_{21}], \tag{TT3}$$

$$x_{nm} + x_{mn} = 1 \quad \text{and} \quad x_{nm} \in [0, 1]; \quad \text{where } n, m = 1, 2, 3 \text{ and } n \neq m.$$

The solution to the issuer's maximization problem has the following characteristics:

Proposition 2. (i) (*Fully revealing*) *If* $(1-\alpha)(1-\gamma_1) > \alpha\gamma_1$, *then*

$$V_1 = v(g_1, g_2, b_3) < P_0 < V_2 = v(b_1, g_2, g_3).$$

(ii) (*Partially revealing*) *If* $(1-\alpha)(1-\gamma_1) < \alpha\gamma_1$, *then*

$$V_1 = V_2 = P_0.$$

In both cases, the issue is allocated according to $x_{12} = x_{13} = 0$ *and* $x_{23} = 1/2$. *In case* (i), *investors' bids fully reveal their valuations, while in case* (ii) *bids are uninformative.*

The proposition gives a fully-revealing equilibrium ($V_1 < V_2$) in which investors' bid reveal both the realization and the precision in their signals, and a partially-revealing equilibrium ($V_1 = V_2 = P_0$) in which bids reveal only the realizations in their signals. In both equilibria, investor 1 is never allocated shares and the issue is priced along the participation constraint of investor 2. The fully-revealing equilibrium will be optimal relative to the partially-revealing equilibrium if the willingness of investor 2 to trade a higher V_2 for a lower V_1 is greater than that of investor 3, as measured by the relative slopes of their respective indifference curves. If this is the case, then increasing V_2 and decreasing V_1 along the participation constraint of investor 2 will lead to a decrease in the informational rent of investor 3 and therefore to an increase the expected proceeds for the issuer.

More formally, the fully-revealing equilibrium will be optimal if

$$\left.\frac{\mathrm{d}V_2}{\mathrm{d}V_1}\right|_{U_2} = -\frac{2p(g_1, g_2, b_3)}{p(b_1, g_2, g_3)} < \left.\frac{\mathrm{d}V_1}{\mathrm{d}V_2}\right|_{U_3} = -\frac{2p(g_1, b_2, g_3)}{p(b_1, g_2, g_3)}, \tag{16}$$

or if

$$p(g_1, g_2, b_3) \geqslant p(g_1, b_2, g_3). \tag{17}$$

Rearranging this condition gives

$$(1-\alpha)(1-\gamma_1) > \alpha\gamma_1, \tag{17$'$}$$

which is the parameter constraint stated in the proposition.

In both equilibria, it is the case that $U_1 \leqslant U_2 \leqslant U_3$, which says that better-informed investors make higher profits compared to less-informed investors. In the fully-revealing equilibrium, this implies that investors who submit higher and more informative bids get better allocations and make higher profits.[6] This prediction is consistent with empirical evidence by Cornelli and Goldreich (2001), who find that higher and more informative bids are awarded with more favorable allocations. They interpret their evidence in support of the traditional bookbuilding argument that the more favorable allocations associated with more informative bids represents an award to better-informed investors for providing more valuable information. The present model suggests an alternative explanation based on the winner's curse argument: the more favorable allocations associated with more informative bids represents an informational rent to better-informed investors based on their greater ability than less-informed investors to pick underpriced issues.

[6] Note also that higher limit bids are, on average, awarded with higher allocations, although this relation is weak. Investor 1 submits the lowest limit price, and receives a zero allocation. Investors 2 and 3 obtain equal allocations when both ask for shares, and each receives the entire issue when competing for allocations against investor 1.

In the fully-revealing equilibrium, the IPO price is always set below the limit price submitted by investor 3. This result is consistent with empirical evidence by Cornelli and Goldreich (2003) who report that "rather than setting the issue price at the point where demand equals supply the underwriter chooses a price at his discretion that is below the market clearing price." More generally, the pricing policy of the issuer implies that IPOs are priced (roughly) equal to the average of the limit prices submitted by investors, which is consistent empirical evidence by Cornelli and Goldreich (2003) who find that the investment banker in their sample adjusts the IPO price one-for-one with the average limit price submitted.

As implied by condition (17), the issuer may choose not to induce investors to fully reveal their information. The bid and allocation data collected by Cornelli and Goldreich (2001, 2003) and Jenkinson and Jones (2004) come from two separate investment banks. The two samples differ in the extent to which price sensitive bids are used. In particular, while Cornelli and Goldreich (2001, 2003) detect a high use of limit bids and find that higher limit bids receive more profitable allocations, Jenkinson and Jones (2004) find a more modest use of limit bids and in addition that limit bids do not receive better allocations than do strike bids. In terms of the present model, these observations suggest that the fully-revealing equilibrium conform to the investment bank of Cornelli and Goldreich, and the partially-revealing equilibrium to the investment bank of Jenkinson and Jones. An alternative view is offered by Ljungqvist (2004), who notes that "... Cornelli and Goldreich's bank is both more active and better connected and thus in a better position to extract pricing-relevant information from investors." However, if firms self-select into different investment banks according to their types along the lines of condition (17′) then the two views (firm versus bank) will be complementary.[7] A formal analysis of such a connection is beyond the scope of the paper, however.

4. Empirical implications

The model predicts a zero excess return to the marginal investor in the offering, analogous to the main prediction of the standard winner's curse argument of a zero allocation-weighted return to uninformed investors. If the marginal investor in the offering is informed, however, as hypothesized by the traditional bookbuilding argument, then the present argument implies a negative return to uninformed participation. In contrast, the traditional bookbuilding argument implies a positive return to uninformed participation, which follows from an assumption that the issuer commits not to overprice the issue given the information revealed in investors' bids.

To test the prediction of a negative return to uninformed participation in bookbuilt IPOs it is necessary to define the bid strategy associated with uninformed participation, and it is necessary to estimate the allocation probabilities associated with this strategy, which, in the case of bookbuilt IPOs, requires detailed bid and allocation data.[8] A natural candidate for the bid strategy associated with uninformed participation is one characterized by small strike bids submitted by non-regular investors, where the 'uninformed' part of this strategy is captured by assuming

[7] Condition (17′) suggests that riskier firms (in the sense of a lower α) will have stronger preference for price sensitive bids compared to less risky firms. However, the parameter restriction implied by this condition should not be taken too literally as it becomes significantly more complex as the number of investors is increased.

[8] If allocations are pro rata, then allocation probabilities are estimated directly from observing aggregate demand, as do Amihud et al. (2003) who find a negative allocation-weighted excess return to uninformed investors in a sample of fixed-price IPOs from Israel. Keloharju (1993) makes a similar finding in fixed-price IPOs in Finland (for large order sizes), although allocations in his sample are not strictly pro rata, which may bias his estimates.

that bids are placed indiscriminately in all IPOs, or a random subset. This choice of bid strategy is suggested by empirical evidence by Cornelli and Goldreich (2001, 2003) who find that small strike bids submitted by non-regular investors are the least favored in allocations. They do not estimate the returns associated with this strategy, however. And while the traditional bookbuilding argument implies a positive return to the proposed strategy, the bookbuilding argument presented in the present paper based on adverse selection predicts a negative return.

The present model addresses adverse selection among institutional investors in bookbuilt IPOs. However, its main prediction of a negative excess return to uninformed participation in bookbuilt IPOs applies to retail investors as well. After all, retail investors and institutional investors are both part of the bookbuilding process with the issuer observing, and presumably using, the demand reported in both investor groups before making the final pricing and allocation decisions. In the absence of a formal model that includes both investor groups, however, the prediction of a negative return to uninformed participation among retail investors in bookbuilt IPOs may be approached purely from an empirical point of view.[9]

5. Concluding remarks

This paper studies bookbuilding in a setting in which institutional investors are heterogeneous in the precision of their information, complementing the traditional approach which assumes that institutional investors are homogeneous in the precision of their information. A partially-revealing equilibrium is derived in which bookbuilding reveals the realizations in investors' signals but not the precision, along with a fully-revealing equilibrium in which both realization and precision are revealed. In both equilibria, the issue is underpriced, and in both equilibria underpricing represents compensation to less-informed investors for adverse selection risk in the allocation of shares rather than compensation to informed investors for revealing valuable information, as hypothesized by the traditional bookbuilding approach. As such, the paper addresses a common objection to the relevance of the winner's curse argument in bookbuilt IPOs.

The analysis implies that better-informed investors in bookbuilt IPOs submit higher and more informative bids and get better allocations than do less-informed investors. While these predictions are broadly consistent with empirical evidence on bids and allocations in bookbuilt IPOs, the fact that they are also consistent with the main (but inferred) implications of the traditional bookbuilding argument suggests that evidence on bids and allocations alone may not be sufficient to empirically distinguish the two arguments. To this end, the present argument predicts a negative return to uninformed participation among institutional investors in bookbuilt IPOs, in contrast to the traditional bookbuilding argument which implies a positive return.

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[9] An alternative view on adverse selection in bookbuilt issues is that retail investors are exposed to adverse selection from institutional investors. Consistent with this hypothesis, empirical evidence by Aggarwal et al. (2002) and Rocholl (2004) shows that the return to retail investors in bookbuilt issues are less than the return to institutional investors. However, their evidence also suggests that retail investors, as a group, make positive excess returns, which is inconsistent with the idea that retail investors, as a group, are exposed to adverse selection from institutional investors.

Appendix A. Proofs of Propositions 1 and 2

Proof of Proposition 1. The IPO price P_0 represents the reservation value of investor 2. Denote it by V_2. The corresponding reservation value for investor 3 is given by

$$V_3 = \frac{p_3 v(g_1, b_2, g_3) + \frac{1}{2}(1 - p_3) v(b_1, g_2, g_3)}{p_3 + \frac{1}{2}(1 - p_3)}, \tag{18}$$

where

$$p_3 = \frac{p(g_1, b_2, g_3)}{p(g_1, b_2, g_3) + p(b_1, g_2, g_3)}, \tag{19}$$

and $V_3 \geqslant V_2$ by $\gamma_3 \geqslant \gamma_2$. Expected aftermarket value may be expressed as follows:

$$\bar{v} = \Sigma V_2 + (1 - \Sigma) V_3, \tag{20}$$

where

$$\Sigma = \frac{p(g_1, g_2, b_3) + \frac{1}{2} p(b_1, g_2, g_3)}{p(g_1, g_2, b_3) + p(g_1, b_2, g_3) + p(b_1, g_2, g_3)}. \tag{21}$$

The issue is underpriced if $P_0 = V_2 \leqslant \bar{v}$, or if $V_2 \leqslant V_3$, which is the case since $\gamma_3 \geqslant \gamma_2$. □

Proof of Proposition 2. In the proposed equilibrium, an investor will indicate a positive interest in the issue in stage one only after observing a favorable signal. To prove the proposition I first analyze the second stage under the assumption that only investors with favorable information indicate a positive interest, and then prove later that this is consistent with equilibrium.

Second stage. I assume first that $x_{12} = x_{13} = 0$ and then show later that this is consistent with optimality. In equilibrium, investor n submits a limit price V_n; $n = 1, 2, 3$. Truthtelling requires that higher types submit higher limit prices, or $V_1 < V_2 < V_3$. Consider next the expected payoff to each investor.

Investor 1. With $x_{12} = x_{13} = 0$, investor 1 submitting a limit price V_1 receives a zero allocation and thus a zero payoff. Submitting a bid equal to V_2 or V_3 yields strictly negative expected payoffs, and hence investor 1 will prefer to be truthful by submitting a limit bid V_1.

Investor 2. Submitting a limit bid V_2 the expected payoff to investor 2 is given by

$$U_2 = p_2\big[v(g_1, g_2, b_3) - V_1\big] + (1 - p_2) x_{23}\big[v(b_1, g_2, g_3) - V_2\big]. \tag{22}$$

If, on the other hand, investor 2 submits a limit bid V_1 he obtains an expected payoff equal

$$U_{21} = p_2 \frac{1}{2}\big[v(g_1, g_2, b_3) - V_1\big]. \tag{23}$$

Participation by investor 2 requires $U_2 \geqslant 0$ and truthtelling requires that $U_2 \geqslant U_{21}$. If investor 2's participation condition is satisfied, then his truthtelling condition is satisfied as well, as long as

$$V_1 \geqslant v(g_1, g_2, b_3), \tag{24}$$

in which case $U_{21} \leqslant 0$ and hence $U_2 \geqslant U_{21}$. The issuer seeks to minimize the amount of money left on the table to investors and hence, in equilibrium, will price and allocate the issue such that

$$U_2 = 0 \tag{25}$$

and

$$U_{21} \leqslant 0. \tag{26}$$

Investor 3. The expected payoff to investor 3 from submitting a limit bid V_3 equals

$$U_3 = p_3\big[v(g_1, b_2, g_3) - V_1\big] + (1 - p_3)(1 - x_{23})\big[v(b_1, g_2, g_3) - V_2\big]. \tag{27}$$

Investor 3 may misrepresent his type by submitting a limit bid V_2 in which case his expected payoff equals

$$U_{32} = p_3\big[v(g_1, b_2, g_3) - V_1\big] + (1 - p_3)\frac{1}{2}\big[v(b_1, g_2, g_3) - V_2\big]. \tag{28}$$

Alternatively, he may submit a limit price V_1 to obtain an expected payoff

$$U_{31} = p_3\frac{1}{2}\big[v(g_1, b_2, g_3) - V_1\big]. \tag{29}$$

Participation requires $U_3 \geqslant 0$, and truthtelling requires $U_3 \geqslant \max[U_{31}, U_{32}]$. Equilibrium implies (as we shall see) that $\max[U_{31}, U_{32}] = U_{32}$ and hence the relevant truthtelling constraint for investor 3 is given by

$$U_3 \geqslant U_{32}, \tag{TT3}$$

which in equilibrium must hold as an equality to minimize the amount of money left on the table for investors. Constraint (TT3) may now be written

$$p(b_1, g_2 \mid g_3)(1 - x_{23})\big[v(b_1, g_2, g_3) - V_2\big] = p(b_1, g_2 \mid g_3)\frac{1}{2}\big[v(b_1, g_2, g_3) - V_2\big] \tag{30}$$

and hence

$$x_{23} = 1/2. \tag{31}$$

The binding constraint is now $U_2 = 0$ or

$$U_2 = p_2\big[v(g_1, g_2, b_3) - V_1\big] + (1 - p_2)x_{23}\big[v(b_1, g_2, g_3) - V_2\big] = 0 \tag{32}$$

from which prices V_1 and V_2 are determined.

The issuer now solves

$$\max_{V_1, V_2} \pi = pV_1 + (1 - p)V_2 \tag{33}$$

subject to

$$U_2 = 0. \tag{34}$$

The first order condition of the issuer's optimization problem is given by

$$\frac{\mathrm{d}\pi}{\mathrm{d}V_2} = -\frac{p(b_1, g_2, g_3)\frac{1}{2}}{p(g_1, b_2, g_3)}p + (1 - p), \tag{35}$$

and thus

$$\frac{\mathrm{d}\pi}{\mathrm{d}V_2} > (<)\ 0 \quad \text{if} \quad \frac{1 - p}{p} > (<)\ \frac{p(b_1, g_2, g_3)\frac{1}{2}}{p(g_1, g_2, b_3)} \tag{36}$$

or, in other words, if

$$p(g_1, g_2, b_3) < (>)\ p(g_1, b_2, g_3), \tag{37}$$

which is satisfied if

$$(1-\alpha)(1-\gamma_1) > (<)\ \alpha\gamma_1. \tag{38}$$

If now $(1-\alpha)(1-\gamma_1) > \alpha\gamma_1$, in which case optimality implies $V_1 < V_2$, it follows from $U_2 = 0$ and condition (24) that

$$V_1 = v(g_1, g_2, b_3) \quad \text{and} \quad V_2 = v(b_1, g_2, g_3). \tag{39}$$

If, on the other hand, $(1-\alpha)(1-\gamma_1) < \alpha\gamma_1$, in which case optimality implies $V_1 = V_2$, it follows from $U_2 = 0$ that $V_1 = V_2 = P_0$, since truthtelling requires that $V_1 < V_2$.

Now to see that $\max[U_{31}, U_{32}] = U_{32}$ note that

$$U_{32} - U_{31} = \big[p_3\big(v(g_1, b_2, g_3) - V_1\big) + (1-p_3)\big(v(b_1, g_2, g_3) - V_2\big)\big]\frac{1}{2}, \tag{40}$$

which is strictly positive for any pair $\{V_1, V_2\}$ determined along $U_2 = 0$.

First stage. Consider then the incentives of investors 1, 2, 3 to state a positive interest in the issue if and only if their private signals are favorable. Given the proposed equilibrium, an investor with favorable information will never have an interest in stating a negative interest in the issue, since such an investor will never be allocated shares and hence his expected payoff will be zero. Consider then the incentive of an investor with unfavorable information to state a positive interest in the issue in order to obtain an allocation. We need to show that the expected payoff to such an investor will be negative if allocated shares. Consider first case $N = 2$ and note that in the fully-revealing equilibrium as well as in the partially-revealing equilibrium the issue is priced along the participation constraint of investor 2, given that investor 2 observes a favorable signal. Investor 2 thus gets a negative payoff if he is allocated shares if his signal is unfavorable. Similarly, investor 1 obtains a strictly negative payoff, regardless of his signal. Finally, investor 3 gets a positive payoff if his signal is favorable, but a strictly negative payoff if his signal is unfavorable. The latter follows since the signal observed by investor 3 is more precise than that of investor 2, and hence the valuation of the firm from the viewpoint of investor 3 must be below that of investor 2.

Consider then cases $N = 1, 3$. (These cases are considered more fully in Appendix B.) For $N = 1$, the issuer may price the issue at $v(g_1, b_2, b_3)$, $v(b_1, g_2, b_3)$, or $v(b_1, b_2, g_3)$, depending on which of these prices maximize expected proceeds. However, the true value of the firm equals $v(b_1, b_2, b_3)$, which is strictly less than $\min[v(g_1, b_2, b_3), v(b_1, g_2, b_3), v(b_1, b_2, g_3)]$. This implies that an investor with unfavorable information will get a negative payoff if allocated shares. For $N = 3$, the issue is priced at $v(g_1, g_2, g_3)$ and hence an investor $1, 2, 3$ with unfavorable information will obtain a negative payoff if he is allocated shares, since the true value of the firm in this case is strictly less than $v(g_1, g_2, g_3)$. □

Appendix B. Fully revealing, partially revealing, or pure fixed price

The IPO method considered in the text gives two version of a bookbuilding process whereby the issuer induces investors to reveal the realizations in their signals. If condition (17) is satisfied the issuer seeking to maximize expected proceeds will also induce investors to reveal the precision in their signal. If condition (17) is not satisfied then the issuer will set a fixed price conditional on the stated demand for the issue and the precision in the signals observed by investors are not revealed. A third method available to the issuer is to price the issue before any demand information becomes known, referred to as the *pure fixed price* method.

B.1. Bookbuilding: truthtelling and conditional fixed price

The demand N for the issue is revealed in stage one, where $N \in \{0, 1, 2, 3\}$. We may consider each realization of N to represent a sub-game in a sequential security issuance game whereby the issuer prices that issue optimally given $N \in \{1, 2, 3\}$. If $N = 0$, then the issue is withdrawn. As discussed in the text, this represents an assumption and is needed to induce investors to reveal the realizations in their signals at zero cost. Consider then cases $N \in \{1, 2, 3\}$.

$N = 1$. The issuer observes the demand for the issue but is unable to observe the quality in this demand. The issuer is facing a choice of three alternative prices, picks the price that maximizes expected proceeds, given $N = 1$. If priced at $v(g_1, b_2, b_3)$, then the issue succeeds with probability one and expected proceeds conditional on $N = 1$ are given by $v(g_1, b_2, b_3)$. Alternatively, if priced at $v(b_1, g_2, b_3)$ the issue succeeds with probability $p(b_1, g_2, b_3) + p(b_1, b_2, g_3)$ and its expected proceeds are

$$\frac{p(b_1, g_2, b_3) + p(b_1, b_2, g_3)}{p(g_1, b_2, b_3) + p(b_1, g_2, b_3) + p(b_1, b_2, g_3)} \times v(b_1, g_2, b_3). \tag{41}$$

Finally, the issue may be priced at $v(b_1, b_2, g_3)$, in which case it succeeds with probability $p(b_1, b_2, g_3)$ and yields expected proceeds of

$$\frac{p(b_1, b_2, g_3)}{p(g_1, b_2, b_3) + p(b_1, g_2, b_3) + p(b_1, b_2, g_3)} \times v(b_1, b_2, g_3). \tag{42}$$

$N = 2$. This is the case analyzed in the text. If condition (17) is satisfied then it will be optimal for the issue to price the issue so as to induce investors to reveal the precision in their signals; otherwise, the issuer sets a fixed price conditional on N.[10]

$N = 3$. The issuer now has complete information about the demand for the issue and prices it at $v(g_1, g_2, g_3)$. There is no underpricing and the issue succeeds with probability one.

B.2. Pure fixed price

In the pure fixed price case the issue is priced before investors indicate their interest in the issue. The issuer therefore has no information about the demand for the issue before pricing it. Pricing the issue along the participation constraint of investor 1 gives a price equal to

$$P_{F1} = \frac{p(g_1, b_2, b_3)v(g_1, b_2, b_3) + \frac{1}{2}p(g_1, g_2, b_3)v(g_1, g_2, b_3)}{p(g_1, b_2, b_3) + \frac{1}{2}p(g_1, g_2, b_3) + \frac{1}{2}p(g_1, b_2, g_3) + \frac{1}{3}p(g_1, g_2, g_3)}$$

[10] There is a third alternative, which is to price the issue at its expected value conditional on $s_3 = g_3$, or

$$\frac{p(g_1, b_2, g_3)v(g_1, b_2, g_3) + p(b_1, g_2, g_3)v(b_1, g_2, g_3)}{p(g_1, b_2, g_3) + p(b_1, g_2, g_3)},$$

in which case the issue succeeds as long as $s_3 = g_3$ and hence expected proceeds of $p(g_1, b_2, g_3)v(g_1, b_2, g_3) + p(b_1, g_2, g_3)v(b_1, g_2, g_3)$. However, for the present argument this case is not interesting and in the numerical examples this is never optimal.

$$+\frac{\frac{1}{2}p(g_1,b_2,g_3)v(g_1,b_2,g_3)+\frac{1}{3}p(g_1,g_2,g_3)v(g_1,g_2,g_3)}{p(g_1,b_2,b_3)+\frac{1}{2}p(g_1,g_2,b_3)+\frac{1}{2}p(g_1,b_2,g_3)+\frac{1}{3}p(g_1,g_2,g_3)}. \tag{43}$$

At this price the issue fails with probability $p(b_1,b_2,b_3)$ and hence expected proceeds are equal to

$$\big(1-p(b_1,b_2,b_3)\big)P_{F1}. \tag{44}$$

Trading off price and the probability that the issue succeeds to maximize expected proceeds, it may be optimal increase the price so that either investor 2 or investor 3 becomes the marginal investor. However, this will never be optimal when comparing the pure fixed price case to either the fully revealing case or the conditional fixed price case. To see this, note that if the issuer under the pure fixed price method prices the issue with investor 2 as the marginal investor, this implies a price equal to P_0 as used under the conditional fixed price method for $N=2$. But under the conditional fixed price method the issue fails with a lower probability and hence the conditional fixed price method will be preferred. A similar argument applies to the case in which the issue is priced with investor 3 as the marginal investor.

B.3. Comparing truthtelling, conditional fixed price, and pure fixed price

The comparison is done numerically, and is done for pure fixed price versus truthtelling ("bookbuilding"). (The comparison between the pure fixed-price and the conditional fixed price follows implicitly by condition (17).) For case $N=1$ the issuer prices the issue at $v(g_1,b_2,b_3)$, $v(b_1,g_2,b_3)$, or $v(b_1,b_2,g_3)$ depending on which of these prices maximize expected proceeds. Figs. 1 through 4 depict expected proceeds as functions of α, γ_1, γ_2, and γ_3.

An increase in α reduces the winner's curse problem in the issue, which makes the (pure) fixed-price method perform relatively better. This is depicted in Fig. 1, where bookbuilding is shown to yield higher (lower) expected proceeds compared to the pure fixed-price method for low (high) values of α. Similarly, an increase in the precision γ_1 of the signal observed by investor 1 reduces the winner's curse problem in the issue. This implies that the fixed price method will be

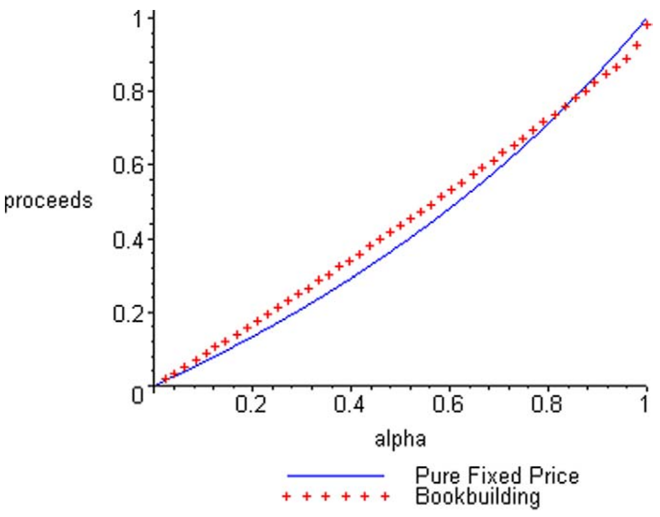

Fig. 1. Expected proceeds versus ex ante probability α of high value firm.

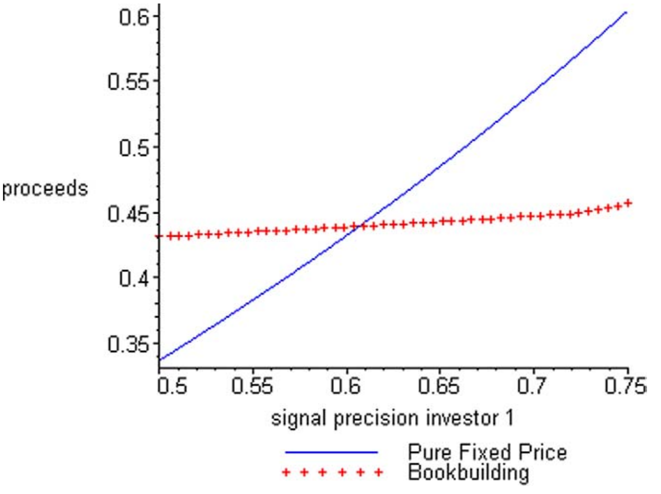

Fig. 2. Expected proceeds versus the precision in the signal observed by investor 1.

preferred for γ_1 sufficiently close to γ_2, and that bookbuilding is preferred for low values of γ_1. This is seen in Fig. 2.

An increase in γ_2 increases the winner's curse problem and thus an increase in γ_2 reduces expected proceeds under the pure fixed-price method, as depicted in Fig. 3. Expected proceeds under bookbuilding is increasing in γ_2 and thus bookbuilding will be preferred for sufficiently large γ_2. The effect of γ_2 on expected proceeds under bookbuilding depends on N. For $N = 2$ an increase in γ_2 increases expected proceeds since in this case the issue is priced with investor 2 as the marginal investor. For $N = 1$, an increase in γ_2 will decreases expected proceeds if the issuer prices the issue at $v(g_1, b_2, b_3)$; otherwise, an increase in γ_2 will increase expected proceeds. This effect appears as the discontinuity in expected proceeds under bookbuilding as a function of γ_2. For $N = 3$, an increase in γ_2 will strictly increase proceeds. This is because the price in this case is given by $v(g_1, g_2, g_3)$ which is strictly increasing in γ_2.

Consider finally the effect of γ_3. Expected proceeds under the pure fixed-price method are strictly decreasing in γ_3. This is because the winner's curse problem unambiguously becomes more severe as the precision in the signal observed by the better-informed investor is increased. The effect of γ_3 under bookbuilding is more complex and depends on N. For $N = 1$, if the issue is priced at $v(b_1, b_2, g_2)$, then an increase in γ_3 increases expected proceeds since $v(b_1, b_2, g_2)$ is increasing in γ_3; otherwise (i.e. if issue is priced at $v(g_1, b_2, b_3)$ or $v(b_1, g_2, b_3)$), then expected proceeds are decreasing in γ_3. As γ_3 is increased the issue is more likely to be priced at $v(b_1, b_2, g_3)$, giving rise to the observed discontinuity in expected proceeds as γ_3 is increased. For $N = 2$, the issue is priced at $v(g_1, g_2, b_3)$ with probability $p(g_1, b_2, g_3) + p(g_1, g_2, b_3)$ and at $v(b_1, g_2, g_3)$ with probability $p(b_1, g_2, g_3)$. Simulations show that expected proceeds conditional on $N = 2$ are most likely to be decreasing in γ_3, but may be decreasing in γ_3 for sufficiently large α and for values of γ_3 sufficiently close to γ_2. Finally, if $N = 2$, then the issue is priced at $v(g_1, g_2, g_3)$ which is increasing in γ_3. Note that although expected proceeds under bookbuilding are depicted as decreasing in γ_3 for values of γ_3 close to γ_2, patterns under which expected proceeds are increasing in γ_3 for this range are available as well. All simulations though show that bookbuilding is more likely to be preferred for high values of γ_3 and the (pure) fixed-price method for values of γ_3 close to γ_2.

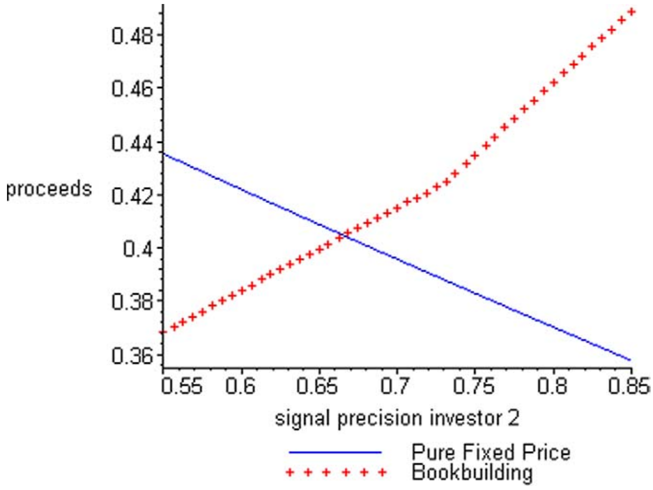

Fig. 3. Expected proceeds versus the precision in the signal observed by investor 2.

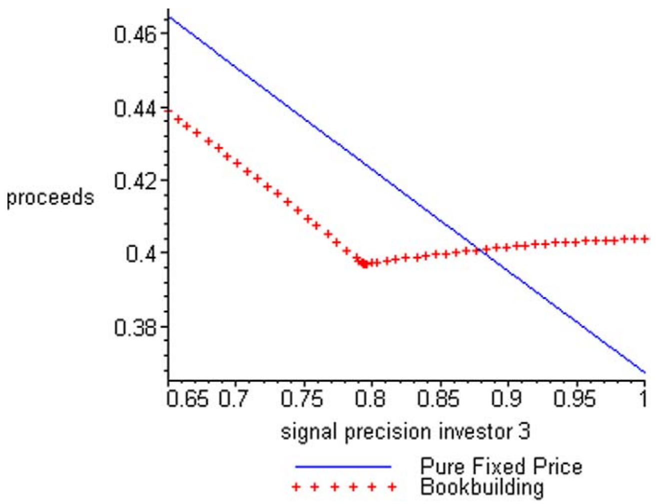

Fig. 4. Expected proceeds versus the precision in the signal observed by investor 3.

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