Review of Finance (2007) 11: 693–718
doi: 10.1093/rof/rfm025
Advance Access publication: 16 October 2007

Secret Reservation Prices in Bookbuilding*

NEIL BRISLEY and WALID Y. BUSABA
Richard Ivey School of Business, University of Western Ontario

Abstract. Why is the issuer's reservation price not disclosed in bookbuilding? We analyze the differential effect of reservation price disclosure on the underpricing required to elicit truthful indications of interest from investors. We find that a policy of disclosure would increase proceeds for firms with a reservation price sufficiently high relative to possible investor valuations of the shares, but would decrease proceeds for issuers with lower reservation prices. The former group is likely to be absent from the IPO market, explaining why secrecy in reservation prices is the norm.

JEL Classification: D44 (Auctions), G24 (Investment Banking)

1. Introduction

In the United States and increasingly throughout the world, the dominant method by which firms initially offer shares to the public is a two-stage auction-like method, characterized by the bookbuilding process (Sherman, 2005; Ljungqvist et al., 2003). In this process, the investment bank solicits investor indications of interest on which it conditions share allocations and the final offer price. As in many auction settings, the issuing firm reserves the right to withdraw the equity from sale if the resulting offer price does not

* An earlier version of the paper was circulated under the title "Why don't IPO firms disclose a reservation price?" Support is gratefully acknowledged from an "Ivey MBA Class of '89 Faculty Fellowship" (Brisley), a Bank of Montreal Professorship (Busaba), and Social Sciences and Humanities Research Council of Canada grant #410-2004-1035 (both authors). We thank Peter Cramton, Preston McAfee and Daniel Vincent for their insights into the auction literature. We have received useful comments from Moez Bennouri, Jean-Philippe Bonardi, Bernard Dumas, Yrjö Koskinen, Guy Holburn, Dmitry Lukin, Ludovic Phalippou, Jörg Rocholl, Matti Suominen, Josef Zechner (the editor) and an anonymous referee. Also, participants in the 2005 European Finance Association Annual Meeting in Moscow, the 2005 French Finance Association International Meeting in Paris, the 2004 Financial Management Association Annual Conference in New Orleans, the 2004 Multinational Finance Society Conference in Istanbul and seminars at HEC Montreal, Michigan State University, Queen's University, University of Waterloo and York University.

meet its reservation value. Up to 20% of all the IPOs filed with the SEC are later withdrawn (Busaba et al, 2001; Dunbar and Foerster, 2007), and the SEC moved in early 2001 to facilitate the withdrawal of registered offerings and the prompt pursuit of alternative financing sources such as private equity.[1]

It is therefore clear that issuers have a reservation price which binds ex post in a significant proportion of cases. In this paper, we investigate why issuers do not disclose a reservation price at the commencement of bookbuilding, or equivalently, why bookbuilding has evolved with the norm of keeping the reservation price secret.

This question is relevant in light of the following facts. A reservation price is posted in other mechanisms for selling equity, for example in IPO auctions in France, Israel, and Japan.[2] Also, issuers in U.S. corporate bond auctions organized online by W.R. Hambrecht & Co. routinely post a minimum acceptable bid. Outside of financial markets, the literature documents examples of auctions with posted reservation prices, ranging from many internet auctions (Lucking–Reiley, 2000) to "the biggest auction ever" held for the sale of British 3G telecom licenses, where a reservation price was included on the advice of economists consulted on the mechanism design (Binmore and Klemperer, 2002).

For its part, the theoretical auction literature finds in some first and second price auctions of indivisible goods that reservation price disclosure can increase proceeds (e.g., Elyakime et al., 1994). This finding begs the question of a potential role for reservation price disclosure in bookbuilding even though financial securities are common-value divisible goods, and the mechanism we study bases the offer price on information contained in all investor indications. Such a role is particularly relevant in light of the theoretical (Busaba, 2006) and empirical findings (Busaba et al., 2001) that the ability to withdraw in the face of weak investor demand significantly reduces IPO underpricing.[3] Neither paper, however, can address whether the reduction would be larger if issuers

[1] Rule 477 was amended to make the request to withdraw effective immediately when filed, unless the SEC rules otherwise within 15 days. Rule 155 was introduced to allow firms to pursue a private offering as early as 30 days after having withdrawn a public offering. See Busaba (2006) for details.

[2] In France, the *Offre à Prix Minimal* (OPM) process for IPOs includes, as its name suggests, a reservation price which is set before investor bids are sought. In Israel, at least during the period 1993–1996, IPOs were conducted as uniform price auctions and IPO prospectuses specified a minimum price (Kandel et al., 1999). In Japan, at least in the years 1989–1993, there existed a published lower limit to acceptable bids for each IPO auction (Pettway and Kaneko, 1996).

[3] Busaba et al. (2001) explore determinants of IPO withdrawal and find a significant negative correlation between IPO underpricing and an imputed measure of what investors might ex ante perceive to be the issuer's likelihood of withdrawal. For the average firm in their sample, the ability to withdraw is predicted to have cut underpricing by up to one third.

disclosed a reservation price or if they kept it secret. Ours is the first paper to examine the question of reservation price disclosure in an environment that characterizes the primary equity market in the US and increasingly many countries around the world.

We employ a mechanism design approach to the modeling of bookbuilding and compare IPO proceeds if firms' reservation prices are disclosed with the proceeds if the prices are kept secret. Underpricing is required under the optimal mechanism to ensure that it is incentive compatible for investors to be forthright in their indications of interest (e.g., Benveniste and Spindt, 1989, Spatt and Srivastava, 1991). We find that the reservation price disclosure policy does impact proceeds by affecting the cost of satisfying the investors' incentive compatibility constraint.

Disclosure would increase the IPO proceeds of firms with a reservation price sufficiently high relative to possible investor valuations of the shares, but it would decrease the proceeds to firms with a reservation price which is lower relative to possible investor valuations. For firms with a reservation price in an intermediate range, whether proceeds would increase or decrease under the disclosure policy depends on the level of investors' ex ante uncertainty surrounding the reservation price. For these firms, proceeds would be highest at some positive but finite level of investor uncertainty, raising the novel empirical question of whether firms can or do take actions, short of full disclosure, to influence the degree of this uncertainty. To our knowledge, ours is the first paper on any selling mechanism to admit the possibility of—and identify the potential benefits to—"partial disclosure" of a seller's reservation price.

The rationale for our results is as follows. The optimal bookbuilding mechanism gives allocation priority to investors who report strong interest, tapping those who report weak interest only if demand turns out to be weak. This minimizes the allocation, and profit, expected by those who lowball the offering and, therefore, the underpricing necessary to ex ante counter investors' adverse incentive. The knowledge by investors that the issuer will walk away if its reservation price is not met further reduces investors' adverse incentives and the corresponding level of underpricing. If the issuer's reservation price is posted, investors know exactly when the issue will be cancelled and the fewer remaining instances when downplaying interest continues to pay off.

In comparison, if the reservation price is kept secret, investors form probabilistic beliefs about its position. Uncertain beliefs introduce fears for an investor downplaying interest that the issue might be cancelled, and profits eliminated, in some states of demand in which the IPO would actually be completed. On the other hand, they instill hopes that the issue might be completed, and profits created, in some demand states where the IPO would actually be withdrawn. Whether this trade-off increases or decreases the incentive to misrepresent positive information depends on the allocation a cheating investor would expect in each of these states, weighted by the probability he assigns to each state.

Under the optimal mechanism, a cheating investor expects an allocation that is concave and decreasing in the demand state, reaching zero as soon as demand from investors reporting positive interest is enough to buy the whole issue. On the other hand, conditional on possessing positive information, the investor assigns higher probabilities to higher demand states. The product is a state probability-weighted allocation function that is initially increasing and then decreasing in demand. If the reservation price is in a range corresponding to the lowest demand states, reservation price uncertainty causes feared loss of profits which outweigh the profits hoped to be gained, and the incentive to downplay interest is reduced. In a higher range, corresponding to states in which the probability-weighted allocation function is still increasing, the fears of lost profits still dominate, providing that investor uncertainty surrounding the reservation price is not "too high". If the reservation price is in the highest range, corresponding to states in which the function is decreasing, the hopes dominate and there is a greater incentive to downplay interest.

Having shown that a policy of disclosure would benefit issuers with a sufficiently high reservation price (relative to possible investor valuations of shares), we are confronted with the reality that such disclosure is not observed in the US IPO market or, so far as we know, in any other market that employs bookbuilding. Our results can explain this reality. Firms with reservation prices that are high relative to possible investor valuations of the shares are those least likely to even attempt an IPO (i.e., file with the SEC), given the cost of IPO initiation and those firms' low probability of exceeding their reservation prices. Conversely, firms that do find it worthwhile to attempt an IPO are likely to be those with relatively lower reservation prices. These are the very firms we identify as better off under secrecy. Our analysis, therefore, provides a theoretically-founded and rationality-based explanation for the observation that posting a reservation price is not the norm in bookbuilding. The results have policy implications as bookbuilding spreads to more primary equity markets. To the extent that jurisdictions adopting bookbuilding might oblige issuers to post a minimum acceptable offer price, such regulations may be suboptimal for most or all of the firms offering securities to the public.

As we study the IPO results under the policy of disclosure, we find that an issuer would have no incentive to overstate its reservation price, in contrast to results from first and second price auctions of indivisible goods in Riley and Samuelson (1981), Elyakime et al. (1994), and Vincent (1995). Under the optimal bookbuilding mechanism, investors convey truthfully their indications and the offer price is set at full value in demand states where the reservation price might bind. Although overstating the reservation price would reduce the underpricing required to ensure truthtelling, the reduction would be outweighed by the possible loss of efficient transactions.

The remainder of the paper is organized as follows. The model is presented in Section 2, along with the main results and implications. Section 3 summarizes and concludes with a discussion of some salient features of the model.

2. The Model

We draw on an information structure employed in Welch (1992), adapted to the model of the bookbuilding mechanism laid out in Benveniste and Spindt (1989). The issuing firm wishes to sell a fixed fraction of ownership in the form of $\overline{Q}$ shares. There are H risk neutral investors, each willing to buy any number of shares up to a maximum of $\overline{q}$. For notational convenience, we normalize $\overline{q}$ to 1 and the issue size to $Q = \frac{\overline{Q}}{\overline{q}}$. Therefore, each investor is able to buy up to $1/Q^{th}$ of the whole issue and actual allocations can be any fraction of 1. In the model, $H > Q$, so there exist enough investors to take up the issue.

The necessity for the issuer to allocate the shares across a number of investors, potentially in discriminatory quantities, reflects the reality that it is rare for any investor to take more than a few percent of the available shares, potentially due to institutional barriers on investors' dollar exposure to any single stock, or to listing requirements or issuer preference for dispersed ownership. It also highlights the divisible nature of the offered "good".

Prior to bookbuilding, the firm and its banker know only that the per share aftermarket value, V, is uniformly distributed on the normalized interval [0,1]. The H investors know this prior information but each observes a private signal on the value, V, which is independently drawn from a Bernoulli variable, $\{L, U\}$, with L and U being lower and upper signals respectively. The investors' information is naturally correlated with the aftermarket value, V, in that the probability that any investor draws a U is just V. Therefore, measuring the number, $h \in \{0, 1, \ldots H\}$, of U signals held by the H investors provides a more precise estimate of the true V. This updated estimate, by Bayes' rule, is[4]

$$V_h \equiv E(V|h) = \frac{h+1}{H+2}, \tag{1}$$

[4] $\Pr(V|h\ U\text{s from } H \text{ signals}) = \Pr(h|V)\Pr(V)/\Pr(h)$. Multiplying by V and integrating out V generates the posterior expected value, and repeated integration by parts given $V \in [0, 1]$ leads to the result in the text. For a detailed proof, see Welch (1992), Lemma 1, page 699.

the *expected* aftermarket price conditional on h. The marginal value of one investor signal is

$$\alpha \equiv V_h - V_{h-1} = \frac{1}{H+2}\,, \tag{2}$$

naturally a decreasing function of the number of signals aggregated.

Since V is uniformly distributed on [0,1], the ex ante (prior) probability of realizing any particular demand state, h, is just $\pi_h = \frac{1}{H+1}$. However, each informed investor updates his prior on the distribution of h based on the private signal he observes. Conditional on observing one signal that turns out to be U, an investor believes that with probability, π'_h, exactly h of the other $H-1$ investors have received a U signal, where, by Bayes' Rule,[5]

$$\pi'_h = \frac{2\,(h+1)}{H\,(H+1)}\,. \tag{3}$$

In bookbuilding, the investment banker solicits and aggregates investor information, publicizes the realized h and sets a corresponding offer price, P_h. The challenge, however, is to secure *truthful* indications from investors. An investor with a U signal understands how his indication of interest affects the revealed demand state, h, and hence P_h, and has an incentive to misrepresent this signal (falsely claiming L) in the hope of pushing down the offer price. To counter this incentive, the banker, whose objective is to maximize expected proceeds, adopts a price/allocation rule that satisfies the investors' incentive compatibility constraint. We denote by $q_{U,h}$ and $q_{L,h}$ the share allocations given to each investor who reveals U and L, respectively, when h investors in total have revealed a U signal. The "truthtelling" incentive compatibility constraint is

$$\sum_{h=0}^{h=H-1} \pi'_h\,(V_{h+1} - P_{h+1})\,q_{U,h+1} \geq \sum_{h=0}^{h=H-1} \pi'_h\,(V_{h+1} - P_h)\,q_{L,h}\,. \tag{4}$$

The price of the offering is also bound by the investors' participation constraint—since h is publicized at the end of bookbuilding, the offer price cannot exceed the discovered value. That is,

$$P_h \leq V_h \qquad \text{for} \quad h \in \{0, 1, \ldots, H\}\,. \tag{5}$$

[5] $\Pr(h\ U\text{s in } H-1 \text{ signals}|\ 1 \text{ in } 1) = \frac{\binom{H-1}{h}\binom{1}{1}}{\binom{H}{h+1}}\left(\frac{2}{H+1}\right),\ h = 0, \ldots, H-1,$ where $\binom{H}{h}$ denotes the combinations of H outcomes, h by h. For further details, see Benveniste and Busaba (1997), page 388.

Formally, the banker's objective is to

$$\underset{\left(P_h,\, q_{U,h},\, q_{L,h}\right)}{\text{Maximize}} \qquad Q \sum_{h=0}^{h=H} \pi_h P_h, \tag{6}$$

subject to constraints (4) and (5), and[6]

$$\begin{array}{rll} 0 \leq q_{L,h} \leq 1 & \text{for} & h \in \{0, 1, \ldots, H-1\}, \\ 0 \leq q_{U,h} \leq 1 & \text{for} & h \in \{1, \ldots\ldots\ldots, H\}, \\ h q_{U,h} + (H-h)\, q_{L,h} = Q & \text{for} & h \in \{0, 1, \ldots\ldots, H\}. \end{array} \tag{7}$$

Constraints (7) state that individual allocations cannot be negative or exceed one, and that the whole offering must be allocated.

Lemma 1. *(Benveniste and Busaba, 1997, Theorem 2, page 392). The price/allocation schedule that solves the banker's optimization problem is*

$$\left(P_h^*, q_{U,h}^*, q_{L,h}^*\right) = \begin{cases} \left(V_h - u_h, \frac{Q}{h}, 0\right) & \text{for} \quad h \geq Q \\ \left(V_h, 1, \frac{Q-h}{H-h}\right) & \text{for} \quad h < Q \end{cases}, \tag{8}$$

where u_h is an underpricing pattern across strong demand states, $h \geq Q$, which ensures that (4) is satisfied with equality. From the firm's point of view, the total ex ante expected underpricing cost is

$$Q \sum_{h=Q}^{h=H} \pi_h u_h = \alpha \frac{H}{2} \sum_{h=0}^{h=Q-1} \pi'_h \frac{Q-h}{H-h}. \tag{9}$$

Proof. Underpricing is driven by the need to satisfy the incentive compatibility constraint (4). The optimal price/allocation rule (8) minimizes underpricing by minimizing the RHS of (4) and satisfying the constraint with equality (in order not to underprice more than necessary). This is achieved by minimizing $q_{L,h}$, setting it to zero in states $h \geq Q$ and to $\frac{Q-h}{H-h}$ when $h < Q$, and by pricing fully, that is, $P_h = V_h$, in the latter states. The RHS of (4) is then reduced to $\sum_{h=0}^{h=Q-1} \alpha \pi'_h \frac{Q-h}{H-h}$. The LHS of (4), which shows how underpricing is delivered to investors truthfully reporting U, becomes $\sum_{h=Q-1}^{h=H-1} \pi'_h u_{h+1} q_{U,h+1}$. Substituting $\frac{2(h+1)}{H(H+1)}$ for π'_h on the LHS of (4), noting that $(h+1)\, q_{U,h+1} = Q$ for $h \in \{Q-1, \ldots, H-1\}$, and multiplying (4) by $\frac{H}{2}$ gives Equation (9). ■

[6] In principle, the optimal price/allocation rule must also ensure that investors who observe L have no incentive to report U. We show in the Appendix that this incentive compatibility constraint is redundant under the optimal price/allocation rule derived in Lemma 1 below. The same proof can be used for the corresponding rules in Lemmas 2 and 3.

The level of underpricing on the right hand side of (9) reflects the prior expectation that $\frac{H}{2}$ investors will have a U signal, each demanding a truthtelling incentive equal to the benefit they could obtain if they misrepresented the U as L. This benefit is the value, α, of one signal multiplied by the expected allocation the investor could anticipate by reporting L. The posterior probability, π'_h, is increasing in h, and the allocation, $q^*_{L,h} = \frac{Q-h}{H-h}$, is concave and decreasing in h. These combine to make the probability-weighted allocation function, $\pi'_h \frac{Q-h}{H-h}$, increasing then decreasing in h, as shown in Figure 1. From Equation (9), the firm's expected cost of underpricing is simply a multiple, $\alpha\frac{H}{2}$, of the area represented by the bar graph in Figure 1.

2.1 BOOKBUILDING WITH A DISCLOSED RESERVATION PRICE

We now consider the case when the issuing firm has a reservation price for its shares and discloses it at the commencement of bookbuilding. Such a price reflects the value to the issuer of remaining under private ownership and control, perhaps seeking debt financing instead, or even curtailing any investments that were to be funded by IPO proceeds.

The issuer's reservation price is exogenous, containing no information that investors can use to more accurately value the firm as a public concern. Consistent with the other bookbuilding models, we assume that any such

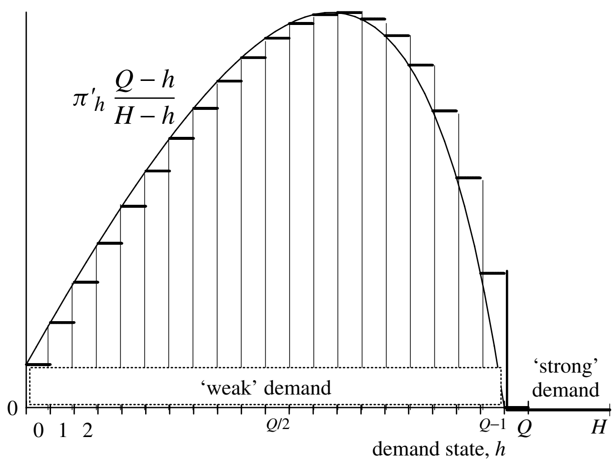

Figure 1. The probability-weighted allocation, $\pi'_h \frac{Q-h}{H-h}$, to an investor misrepresenting good information as bad, as a function of the possible demand states, h. When multiplied by $\alpha\frac{H}{2}$, the area under the humped function yields the expected underpricing under the optimal bookbuilding mechanism when there is no option to withdraw.

information held by the firm and its banker has already been made available to investors during the roadshow and through the prospectus as required by SEC rules. Essentially, how investors value the issuer as a public firm is not affected by what the issuer discloses as a reservation price.

Let V_R denote the issuer's reservation price, where R refers to the particular state, h, for which $V_{h=R} = V_R$.[7] As in the classical auction literature (e.g., Riley and Samuelson, 1981; Vincent, 1995), we assume that the issuer is committed to withdrawing the offering if the offer price does not exceed V_R. Since $P_h \leq V_h$ for every h, the issuer withdraws whenever $h \leq R$. As will become clear below, under the optimal price/allocation rule the issuer completes its offering whenever $h > R$. We henceforth describe R as the "reservation demand".[8,9]

We restrict our attention to the cases when V_R falls in the range $[V_0, V_{H-1}]$. A disclosed reservation price below V_0 is inconsequential, as it will never bind. A price at or above V_H binds with certainty, and the related firm will not even attempt an IPO. We take the liberty at this stage to assume that a firm disclosing a reservation price will disclose V_R, and Proposition 1 subsequently proves that the issuer indeed has no incentive to overstate its reservation price.

The withdrawal of the offering in the "insufficient" demand states $\{0, 1, \ldots, R\}$ reduces the profits that an investor can expect to make by pretending to have an L signal.[10] The new incentive compatibility constraint

[7] A reservation price that happens to fall between two consecutive bookbuilding outcomes, V_j and the higher V_{j+1}, has the same implications for our analysis as a reservation price that corresponds to exactly V_j. The issuer ends up withdrawing in exactly the same states, whether its reservation price corresponds to V_j or to a level between V_j and V_{j+1}. Without loss of generality, therefore, we consider reservation prices that correspond to the discrete outcomes of bookbuilding.

[8] We adopt the convention that the issuer will withdraw the IPO in the event that the realized demand implies a price exactly equal to its reservation price. Committing to this policy is in the interest of the issuer ex ante since it reduces required underpricing, and has no cost ex post since the issuer is indifferent between withdrawing and issuing when the offer price equals V_R.

[9] Our model readily encompasses the case when the issuer's valuation of its next best alternative is affected by the outcome of bookbuilding. In this case, R is the highest demand state, h, at which the issuer's alternative is conditionally at least as valuable as going public. Since the outcomes of bookbuilding can be envisaged ex ante, the rational issuer can calculate V_R at the outset, and this is the reservation price that we consider in the paper.

[10] An argument following that in the Appendix shows that an investor with an L signal does not gain from overplaying his interest and potentially tipping insufficient demand into sufficient demand.

becomes

$$\sum_{h=R}^{h=H-1} \pi'_h (V_{h+1} - P_{h+1}) q_{U,h+1} \geq \sum_{h=R+1}^{h=H-1} \pi'_h (V_{h+1} - P_h) q_{L,h}. \tag{10}$$

The optimal price/allocation schedule that in this setting maximizes expected proceeds, $Q \sum_{h=R+1}^{h=H} \pi_h P_h$, subject to incentive compatibility (10), participation (5), and feasibility and allocation (7) constraints (adjusted for withdrawal in states $h \leq R$), is similar to (8). Required underpricing is less, however, reflecting the diminished benefits of downplaying interest. In fact, in the extreme case $R \geq Q - 1$, underpricing drops to zero as the offering will be completed only in strong demand states, those in which investors who report L receive a zero allocation. The following Lemma focuses on the leading case, $R < Q - 1$.

Lemma 2. *In the presence of a reservation price, $V_R < V_{Q-1}$, that is known to investors, the IPO is withdrawn for $h \leq R$ and the price/allocation schedule for $h \in \{R+1, \ldots, H\}$ that maximizes expected proceeds subject to the incentive compatibility, participation, feasibility and allocation constraints is*

$$\left(P_h^*, q_{U,h}^*, q_{L,h}^*\right) = \begin{cases} \left(V_h - u_h, \frac{Q}{h}, 0\right) & \text{for} \quad h \geq Q \\ \left(V_h, 1, \frac{Q-h}{H-h}\right) & \text{for} \quad R < h < Q \end{cases}, \tag{11}$$

where u_h is such that (10) is satisfied with equality. From the firm's point of view, total ex ante expected underpricing is

$$Q \sum_{h=Q}^{h=H} \pi_h u_h = \alpha \frac{H}{2} \sum_{h=R+1}^{h=Q-1} \pi'_h \frac{Q-h}{H-h}. \tag{12}$$

Proof. The proof parallels that of Lemma 1. ■

Expected underpricing is a multiple, $\alpha \frac{H}{2}$, of the now truncated area represented by the bar graph in Figure 2. The *reduction* in total underpricing relative to the case with no reservation price, (9), has a value of $\alpha \frac{H}{2} \sum_{h=0}^{h=R} \pi'_h \frac{Q-h}{H-h}$.

Would an issuer post an overstated reservation price?

It has been shown in other auction settings that there can exist benefits to posting an overstated reservation price (e.g., Riley and Samuelson, 1981; Vincent, 1995). We now proceed to show that there is no such incentive in

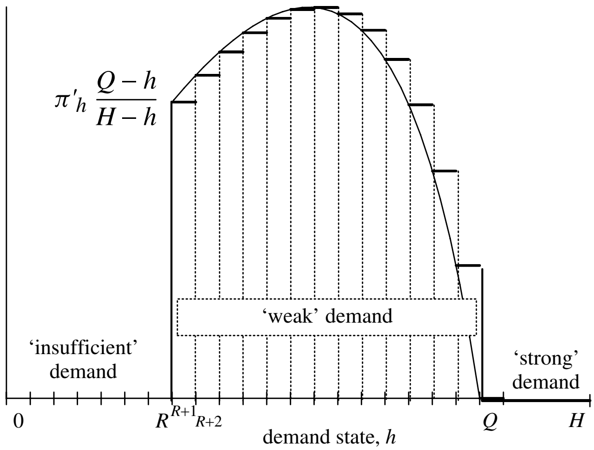

Figure 2. The probability-weighted allocation, $\pi'_h \frac{Q-h}{H-h}$, to an investor misrepresenting good information as bad, as a function of the possible demand states, h, truncated below the issuer's reservation demand, R. When multiplied by $\alpha \frac{H}{2}$, the area under the humped function to the right of the truncation point yields the expected underpricing, expression (12), under the optimal bookbuilding mechanism when the issuer withdraws in states $h \leq R$.

the bookbuilding mechanism. If the issuer were to commit to an overstated reservation price $V_W > V_R$, the profit from downplaying interest investors could have anticipated in states $\{R+1, R+2, \ldots W\}$ would be eliminated, and per-share expected underpricing further reduced by

$$\frac{\alpha}{2} \sum_{h=R+1}^{h=W} \pi'_h \left(\frac{Q-h}{H-h} \Big/ \frac{Q}{H} \right) . \tag{13}$$

On the other hand, the issuer would forgo a surplus of $P_h - V_R = \alpha\,(h - R)$ per share in each of those states, with an expected value of

$$\alpha \sum_{h=R+1}^{h=W} \pi_h\,(h-R) . \tag{14}$$

Proposition 1. *If the issuer overstates its reservation price to $V_W > V_R$, the expected forgone surplus is greater than the expected benefit of reduced underpricing,*

$$\alpha \sum_{h=R+1}^{h=W} \pi_h\,(h-R) > \frac{\alpha}{2} \sum_{h=R+1}^{h=W} \pi'_h \left(\frac{Q-h}{H-h} \Big/ \frac{Q}{H} \right) . \tag{15}$$

Proof. See Appendix. ■

The result is quite intuitive. Due to the rationing of shares to investors revealing L, the benefit of cheating eliminated by overstatement of R is strictly less than α per share in each of the newly eliminated states. Forgone proceeds, $\alpha(h - R)$, on the other hand, are at least α per share in each of these states.[11]

This result means that if a seller using bookbuilding posts a reservation price, it will post its true reservation price. Therefore, we need not concern ourselves with the possibility that an issuer who is better off with secrecy in comparison to truthful disclosure would nevertheless be better off posting an overstated reservation price.

2.2 BOOKBUILDING WITH A SECRET RESERVATION PRICE

In this subsection, we examine the outcome of the IPO in a setting where issuers do not disclose V_R, but investors form unbiased expectations of it. Our research question is motivated by the fact that US issuers do not state their reservation prices explicitly. Yet Busaba et al. (2001) show empirically that some observable characteristics of issuing firms may be used by the market to assess the ex ante probability that the firm ends up withdrawing its IPO. There is no reason to believe that investors should systematically overestimate or underestimate the issuer's reservation price. Hence, we make the natural assumption that investor expectations are unbiased on average and represent them by a symmetric 3-point distribution as follows:

Reservation Price	Equivalent Demand State, h	Probability	
V_{R+r}	$R + r$	p	
V_R	R	$1 - 2p$	(16)
V_{R-r}	$R - r$	p	

where admissible values of r are such that $R + r \leq H - 1$ (since $V_R \leq V_{H-1}$). The uncertainty is characterized by the two exogenous parameters, $p \in [0, 1]$ and $r \in \{1, 2, \ldots\}$, determining respectively the weight on the tails of the distribution and the range of these tails. We focus our attention on r, since only this parameter can affect whether secrecy is better or worse than disclosure. (In interpreting the results of Proposition 2 in Subsection 2.3, we entertain

[11] In an indivisible good auction, with common values but a first-price or second-price mechanism, Levin and Smith (1996) show that competition among bidders causes the optimal reservation price to converge to the true reservation price as the number of bidders increases without bound. They also show [Page 1281] "... that the expected damage from loss of trade eventually outweighs the potential gain from a false reserve for any mechanism under which the high bid converges (with n) to the item's true value".

the possibility of issuers being able to influence r). Changes in p affect only the absolute degree to which one policy is better than the other. Subject to the level of r, investors calculate their truth-telling incentives based on the perceived probability of withdrawal in each demand state, h. We denote by ω_h investors' perceived probability that h would be insufficient for the issue to proceed. Thus

$$\omega_h = \begin{cases} 1 & \text{for} \quad h = 0, 1, \ldots\ldots\ldots\ldots.., (R-r) \\ 1-p & \text{for} \quad h = (R-r+1), \ldots\ldots\ldots...., R \\ p & \text{for} \quad h = (R+1), \ldots\ldots\ldots.., (R+r) \\ 0 & \text{for} \quad h = (R+r+1), \ldots\ldots\ldots...., H \end{cases} . \tag{17}$$

Since investors downplaying interest benefit only if the offering is completed, which they believe happens with probability $1-\omega_h$, $h = 0, 1, \ldots H$, the truthtelling constraint (4) is adjusted accordingly:

$$\sum_{h=0}^{h=H-1} \pi'_h \left(V_{h+1} - P_{h+1}\right)\left(1-\omega_{h+1}\right) q_{U,h+1} \geq \sum_{h=0}^{h=H-1} \pi'_h \left(V_{h+1} - P_h\right)\left(1-\omega_{h+1}\right) q_{L,h} . \tag{18}$$

The participation (5) and feasibility and allocation constraints (7) remain unchanged.

Lemma 3. *Given that the firm will withdraw in states $h \leq R$ and subject to investor beliefs (16) and the corresponding constraint (18), and to constraints (5) and (7), the price/allocation schedule that maximizes expected proceeds is*

$$\left(P_h^*, q_{U,h}^*, q_{L,h}^*\right) = \begin{cases} \left(V_h - u_h, \frac{Q}{h}, 0\right) & \textit{for} \quad h \geq Q \\ \left(V_h, 1, \frac{Q-h}{H-h}\right) & \textit{for} \quad R-r+1 < h < Q \end{cases} , \tag{19}$$

where u_h is such that (18) is satisfied with equality. The firm's expected underpricing cost, $Q\sum_{h=Q}^{h=H} \pi_h u_h$, is

$$\alpha \frac{H}{2}\left[p \sum_{h=\max(R-r+1,0)}^{h=R} \pi'_h \frac{Q-h}{H-h} + (1-p) \sum_{h=R+1}^{h=\min(R+r,Q-1)} \pi'_h \frac{Q-h}{H-h}\right.$$

$$+ \sum_{h=\min(R+r+1,Q)}^{h=Q} \pi'_h \frac{Q-h}{H-h} \Bigg] . \tag{20}$$

Proof. The proof parallels that of Lemma 1. ■

Note that when $R + r + 1 \geq Q$, the final term reduces to zero. If $p = 0$, or if $r = 0$, then there is no uncertainty in the reservation price and expression (20) reduces to expression (12), corresponding to a disclosed reservation price.

2.3 SECRET VERSUS DISCLOSED RESERVATION PRICES

We can now compare the expected underpricing under a policy of reservation price disclosure (expression (12)) to the expected underpricing under a policy of secrecy (expression (20)).

Lemma 4. *For firms with reservation price V_R, let $\Delta(r)$ be the difference between the underpricing associated with the policy of reservation price disclosure and that associated with the policy of non-disclosure, as a function of r. Formally, $\Delta(r) =$ Expression (12) $-$Expression (20), and is given by*

$$\Delta(r) = \alpha \frac{H}{2} p \left[\sum_{h=R+1}^{h=\min(R+r,Q-1)} \pi'_h \frac{Q-h}{H-h} - \sum_{h=\max(R-r+1,0)}^{h=R} \pi'_h \frac{Q-h}{H-h} \right] . \tag{21}$$

For an investor downplaying interest, and compared to certainty on R, uncertainty introduces the fear that with probability p he will not profit in states $h \in [R+1, \min(R+r, Q-1)]$ but introduces the probability, p, that he will enjoy profits in states $h \in [\max(R-r+1, 0), R]$. The expression for $\Delta(r)$ represents the difference between these dashed hopes (left term) and new hopes (right term). It is positive if underpricing is lower under non-disclosure, and negative otherwise. Proposition 2 below characterizes which firms benefit from a policy of secrecy and which firms lose and the tradeoff is illustrated graphically in Figure 3.

Proposition 2. *The difference, Δ, between the underpricing associated with the policy of reservation price disclosure and that associated with the policy of non-disclosure, behaves as follows as a function of R and r:*

(i) For $R \leq \frac{Q}{2} - 1$: $\Delta > 0$ (non-disclosure is associated with lower underpricing) and Δ is monotone increasing in r.

(ii) There exists $\widehat{h} \in \left(\frac{Q}{2} - 1, Q - 1\right)$ *such that for* $R \in \left(\frac{Q}{2} - 1, \widehat{h}\right)$: Δ *is initially increasing and then decreasing in* r, *attaining an internal global maximum at some* $r = r^*$.

(iii) There exists $\overline{h} \in \left(\frac{Q}{2} - 1, \widehat{h}\right)$ *such that*

(a) for $R \in \left(\frac{Q}{2} - 1, \overline{h}\right)$: $\Delta > 0$,

(b) for $R \in \left(\overline{h}, \widehat{h}\right)$: $\exists\, \overline{r}_R$ *such that* $\Delta > 0$ *for* $r < \overline{r}_R$ *and* $\Delta < 0$ *for* $r > \overline{r}_R$.

(iv) For $R \geq \widehat{h}$: $\Delta < 0$ *and* Δ *is monotone decreasing in* r.

Proof. See Appendix. ∎

The interpretation and explanation of the proposition is quite intuitive. Figure 3 shows the "low" and "high" ranges of reservation prices identified in parts (i) and (iv) of the proposition. Figure 4 takes representative reservation prices from each range and shows the advantage of secrecy ($r > 0$) versus full

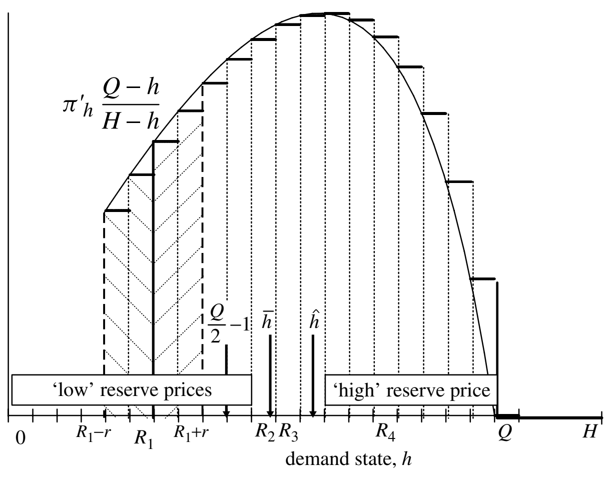

Figure 3. The probability-weighted allocation, $\pi'_h \frac{Q-h}{H-h}$, to an investor misrepresenting good information as bad, as a function of the possible demand states, h. Reservation demands $R_1 \in \left[0, \frac{Q}{2} - 1\right]$, $R_2 \in \left(\frac{Q}{2} - 1, \overline{h}\right)$, $R_3 \in \left(\overline{h}, \widehat{h}\right)$, $R_4 \in \left(\widehat{h}, Q\right)$ illustrate respectively Parts (i)–(iv) of Proposition 2. The solid line at $h = R_1$ shows the truncation in $\pi'_h \frac{Q-h}{H-h}$, when, for example, a reservation demand of R_1 is disclosed. The shaded area between R_1 and $R_1 - r$ shows the additional allocation expected with probability p when R_1 is not disclosed. The shaded area between R_1 and $R_1 + r$ shows the allocation lost with probability p when R_1 is not disclosed.

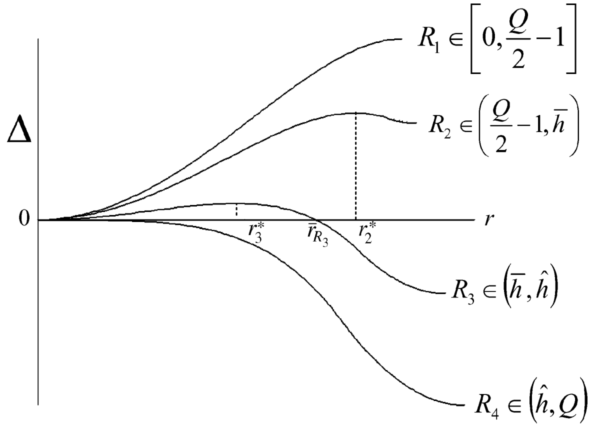

Figure 4. Issuer's advantage (in terms of IPO proceeds) under a policy of reservation price uncertainty versus disclosure of reservation prices. This advantage, $\Delta(r)$, is defined as the underpricing with disclosure (expression (12)) less the underpricing with secrecy (expression (20)), and is shown as a function of the uncertainty, r, at four distinct levels of reservation demand, R_1, R_2, R_3 and R_4, to illustrate respectively Parts (i)–(iv) of Proposition 2. For clarity, the functions are drawn as a continuous function of r, although r actually takes discrete integer values.

disclosure ($r = 0$) as a function of the level of uncertainty, r. For any V_R, IPO proceeds are highest under the policy that makes Δ the highest.

Part (i) indicates that firms with a sufficiently low reservation price (e.g., corresponding to reservation demand R_1 in Figures 3 and 4) are unambiguously better off under a policy of secrecy, and benefit more the higher is r. For these firms, R corresponds to h values over which $\pi'_h \frac{Q-h}{H-h}$ is increasing. Hence, the fears created by a policy of secrecy for investors downplaying interest–that they can profit in states $h \in [R + 1, \min(R + r, Q - 1)]$—outweighs the hope instilled that they can profit in states $h \in [\max(R - r + 1, 0), R]$. Conversely, part (iv) indicates that firms with a sufficiently high reservation price (e.g., corresponding to reservation demand R_4 in Figures 3 and 4) are better off under a policy of reservation price disclosure (i.e., when $r = 0$). For these firms, R corresponds to h values over which $\pi'_h \frac{Q-h}{H-h}$ is decreasing, and the hopes created by reservation price uncertainty outweigh the fears.

Part (ii) indicates that in an intermediate range of reservation prices (e.g., corresponding to reservation demands R_2 and R_3 in Figures 3 and 4), $\Delta(r)$ reaches a maximum at some non-zero but finite level of uncertainty (e.g., r_2^* and r_3^* respectively, in Figure 4). As in part (i), these reservation prices correspond to h values over which $\pi'_h \frac{Q-h}{H-h}$ is increasing. However, because $R > \frac{Q}{2} - 1$ in this range, high levels of r will extend $R + r$ beyond $Q - 1$ before $R - r$ reaches 0. Such levels of r create no investor doubts of profits in states $h > Q - 1$ (as $q_L^* = 0$ anyway, in those states), yet continue to create new hopes of profits in low demand states (until r reaches R, i.e., $R - r = 0$). As such, $\Delta(r)$ is positive and increasing at low levels of r, but is decreasing at higher levels of r.

Part (iii) further subdivides this intermediate range into two regions, highlighting the effects of the disclosure policy for firms in each. In the lower region (e.g., R_2 in Figures 3 and 4), $\Delta(r)$ is positive for every r, and issuers are strictly better off under a policy of secrecy regardless of r. In the upper region (e.g., R_3 in Figures 3 and 4), in comparison, $\Delta(r)$ is negative for r values above a certain level (e.g., those above $\overline{r}_{R_3}$ for an issuer with reservation price R_3 in Figure 4). With such r values, issuers are strictly better off under a policy of reservation price disclosure. The issuers would nevertheless be best off under a policy of reservation price secrecy were they able to influence r by reducing but not eliminating investor uncertainty (e.g., to r_3^* for an issuer with reservation price R_3 in Figure 4).

Our result, for some issuers, that partial disclosure of V_R can be better than total secrecy and can even yield highest proceeds, raises the intriguing possibility that issuers might take actions ex ante to influence how much uncertainty investors have vis-à-vis their reservation price. Informal indications to the investment banker or to investors during the roadshow could be used to offer guidance as to where an issuer's reservation price might lie. Leone, Rock and Willenboorg (2006) find that increased specificity in the preliminary prospectus disclosure "intended use of proceeds" is associated with lower underpricing. This is consistent with a desire, perhaps by a subset of their sample firms, to provide guidance that reduces investor uncertainty concerning the reservation price.

Another avenue for partial disclosure may be available in markets such as Australia or Canada (where bookbuilding is practiced), where issuers have the option to release earnings forecasts as part of the IPO filing. Disclosing earnings forecasts might enable investors to estimate more precisely the position of the issuer's reservation price, for example in cases where this price is tied to the issuer's own opinion about its worth. Alternatively, guidance could be given by the positioning and width of the filing range disclosed in the prospectus.[12] We leave it to future research to formalize and test these predictions.

[12] Since 2001, the SEC generally finds acceptable a filing price range of up to the greater of \$2 or 20% of the lower limit of the price range (Barcaskey, 2005).

2.4 WHY DON'T ISSUERS DISCLOSE A RESERVATION PRICE?

We now illustrate how our results can explain the empirical regularity that issuing firms in the US do not disclose a reservation price. Proposition 2 shows that full disclosure of reservation prices is in the interests only of issuers with reservation prices that are *high* relative to possible investor valuations of the shares (part (iv)). However, such firms are likely to be absent from the IPO market. By definition, these firms have a low likelihood of achieving an offer price in excess of their V_R and, given the significant direct and indirect costs of initiating an IPO, they are the firms least likely to seek an IPO in the first place, preferring to stick with the very alternatives that make their IPO reservation price so high.

Almost by definition, then, the firms which find it worthwhile to file for an IPO are those which ex ante have a sufficiently high probability of completing the IPO, that is, those firms whose reservation price is low compared to the range of possible investor valuations of the shares. This would be consistent with the majority of firms observed filing for an IPO having reservation prices in the range where we show that maintaining reservation price uncertainty is optimal. Although we do not calibrate our model, it is interesting to note that the 20% incidence of withdrawal for firms that file with the SEC (Dunbar and Foerster, 2007) corresponds to the average filing firm having a reservation price of $V_R = 0.2$ in our set-up.

While it is quite reasonable to expect firms with high reservation prices to stay away from the public market, identifying the reservation price threshold below which a firm is willing to file with the SEC remains an empirical question. The threshold is likely to vary across issuers and issue sizes, with variations in the costs of initiating an IPO. Furthermore, the threshold's position relative to the region in our model where issuers are better off with disclosure (Region (iv) in Proposition 2) would depend on the empirical values of our model parameters. Nevertheless, it is straightforward to see how introducing an assumed filing threshold leaves the results of Proposition 2 qualitatively (and literally) unchanged.

With such a threshold, call it T, in place, r cannot assume values that would extend the support of investor beliefs on R beyond T. That is, $r < T - R$. Graphically, for any particular R, this places limits on how far along the x-axis Figure 4 can extend, and those limits are decreasing in R. Except for the limit on the upper bound of r, expression (20) of the underpricing associated with non-disclosure is unchanged, as is the difference, $\Delta(r)$, between this level and that under the policy of disclosure. Part (i) of Proposition 2 still holds.

Of the firms in the intermediate level of R identified in part (ii) of the Proposition, those with R in the sub-range (iii.a) also continue to be better off under non-disclosure, irrespective of the level of r. For those in the sub-range (iii.b), either $\Delta(r) > 0$, and the firms are better off under non-disclosure, for all admissible values of r (if $T - R$ happens to fall below $\overline{r}_R$), or as in the original proposition, $\Delta(r) > 0$ for $r < \overline{r}_R$ and $\Delta(r) < 0$ for admissible r above $\overline{r}_R$. Whatever its threshold T, a firm with an intermediate value of R continues to be better off under non-disclosure (or partial disclosure).

Last, if the reservation price threshold, T, falls to the left of $\hat{h}$, the high-R firms represented by part (iv) of Proposition 2 will not be among those that file to go public. Firms that do attempt a public offering will be ones that are better off under a policy of reservation price non-disclosure. If, on the other hand, $T > \hat{h}$, a restricted subset of the firms that would do better with disclosure will be in the IPO market. However, for these firms, the limited r restricts the disadvantage the firms suffer from a general policy, or practice, of reservation price secrecy. Whether T, in reality, excludes from the IPO market all or part of the firms that would do better under disclosure, our results remain consistent with an equilibrium in which most or all filing firms benefit from reservation price non-disclosure.

3. Summary and Conclusion

Using a mechanism design approach, we compare the differential effect of secret versus disclosed reservation prices on investors' incentive to reveal interest during bookbuilding. Compared to a policy of secret reservation prices, we find that a policy of disclosure would increase the IPO proceeds of firms with a reservation price sufficiently high relative to possible investor valuations of the shares, but would decrease the proceeds to firms with a reservation price that is low relative to possible investor valuations. Interestingly, we find that if issuers were to disclose a reserve price, they would have no incentive to overstate their true reservation price.

Our analysis also reveals that issuers with reservation prices in an intermediate range would enjoy maximum proceeds at some level of partial disclosure—the reduction in, but not elimination of, investor uncertainty surrounding a secret reservation price. The potential for partial disclosure, which to our knowledge has not previously been admitted in the auction literature, raises novel empirical questions regarding actions that an issuer might take ex ante to affect the extent of investors' uncertainty surrounding the issuer's reservation price.

The firms we identify as benefiting under a policy of full disclosure—those with high reservation prices—are precisely those firms least likely to file for an IPO in the first place, given the significant direct and indirect costs of initiating an IPO and the low likelihood for these firms of completing the offer. Our results can therefore explain the observation that firms filing for an IPO in the US do not typically disclose a reserve price and, hence, why institutions have arisen in which maintaining reservation price uncertainty is the norm.

Our results are driven strictly by the effect of reservation price uncertainty on how investors "bid" for the shares, or reveal information during bookbuilding. In line with the common value auction setting in Vincent (1995), the issuer's reservation price in our model does not contain information relevant to the investors' valuation of the shares. As in other bookbuilding models, the issuer has already disclosed all value-relevant information it holds. Another feature of our model is that if an issuer's reservation price is not disclosed, investors nevertheless understand that it exists and form expectations of it which are unbiased on average. Our results are not, therefore, driven by the issuer's desire to influence investors' valuation of the shares through withholding (or signaling) value-relevant information (as is the case in Horstmann and LaCasse, 1997). Neither are they driven by the issuer's desire to correct (or create) biased expectations of its reservation price on the part of investors.

An underlying premise in our paper is that payment for information revelation determines an economically significant part of observed IPO underpricing, consistent with evidence presented by Hanley (1993) and Cornelli and Goldreich (2001, 2003), among others. However, there is a view that underpricing is driven primarily by the need to ensure sufficient information production by investors (Booth and Chua, 1996, and Sherman and Titman, 2002). If the underpricing necessary to ensure information revelation were not in and of itself enough to induce ex ante the required level of information production, issuers in equilibrium would have to offer a deeper discount. Incentive compatibility would then be satisfied with inequality, and any mechanism design enhancements, including that stemming from the reservation price disclosure policy, would become less relevant. This seems inconsistent, however, with the explicit interest in mechanism design within and outside of financial markets, and the strong desire by many investors to participate in IPOs.

Our analysis considers a fixed reservation price for the issuing firm. This is for the convenience of exposition, and the model can easily be refined to allow issuers to post a price that is indexed to (and hence evolves with) certain market benchmarks. This is the approach followed by W.R. Hambrecht & Co. in its OpenBook auctions of corporate bonds—a particular Treasury bond is named as a benchmark and, prior to the auction, a maximum acceptable bid spread over that benchmark's yield is announced.

As in the classical auction literature, we assume that an issuer posting a reservation price can credibly commit to withdrawing the offering at or below this price. Such commitment is essential since, without it, posting a reservation price would be construed by investors as "cheap talk". If required, commitment could presumably be enforced via investment bank reputation, a regulator, or some other contractual mechanism as in the French *Offre à Prix Minimal* or the British 3G telecom license auction, for example.

The economic trade-offs inherent to the reservation price disclosure policy are driven by the shape of the state-contingent allocation function, $\pi'_h q^*_{L,h}$, an investor falsely reporting L would face under the optimal mechanism. As discussed in the model, $q^*_{L,h}$ is concave and decreasing in h, reaching zero at $h = Q$, π'_h is increasing in h, and $\pi'_h q^*_{L,h}$ is "humped" over $h = 0, \ldots, Q$, and zero otherwise. That the posterior of an investor who observes positive information is increasing in h, at least at low levels of h so as to obtain the "hump", can result from any of a large set of plausible priors. It is conceivable, however, that under prior beliefs on V that allocate extremely high probability density on the lowest values, π'_h could be non-increasing in h, at least at low levels of h. If such extreme circumstances were to exist, $\pi'_h q^*_{L,h}$ might become decreasing in h, for all h, in which case all issuers, including those with the lowest reservation prices, would be better off under disclosure. The implication of this scenario is inconsistent with what we observe in practice, however.

Last, the information structure we work under generates a marginal value of information, α, that is dependent on the number of signals aggregated, H. If, under some alternative information setting, α were to depend on the number of U signals, h, as well, the state-contingent profits to a cheating investor would vary also with a state-contingent α, or α_h. Again, as long as the resultant state-contingent probability-weighted profit function, $\alpha_h \pi'_h q^*_{L,h}$, maintains a humped shape as it does in Figure 1, our results are unaffected.

Appendix

Redundancy of incentive compatibility constraint for L-investor

Conditional on observing one signal that turns out to be L, an investor believes that with probability, π''_h, exactly h of the other $H - 1$ investors have received a U signal, where, by Bayes' Rule,

$$\pi''_h = \frac{2\,(H - h)}{H\,(H + 1)} \tag{1}$$

To ensure that there is no incentive for this investor to overplay his interest, the "truthtelling" incentive compatibility constraint is

$$\sum_{h=0}^{h=H-1} \pi''_h (V_h - P_h)\, q_{L,h+1} \geq \sum_{h=0}^{h=H-1} \pi''_h (V_{h+1} - P_{h+1} - \alpha)\, q_{U,h+1}\, . \tag{2}$$

Under the optimal price allocation rule $(V_h - P_h) = 0$ for $h = 0, 1, \ldots Q-1$, and $q_{L,h+1} = 0$ for $h = Q-1, Q, \ldots H$ and the constraint reduces to

$$\alpha \sum_{h=0}^{h=H-1} \pi''_h q_{U,h+1} \geq \sum_{h=Q-1}^{h=H-1} \pi''_h u_{h+1} q_{U,h+1} \tag{3}$$

Decomposing the sum on the LHS, using the definitions (3) and (1) of π'_h and π''_h, and noting that (4) implies that the expected underpricing is $\sum_{h=Q-1}^{h=H-1} \pi'_h u_{h+1} q_{U,h+1} = \alpha \sum_{h=0}^{h=Q-1} \pi'_h q_{L,h}$ we see that

$$\begin{aligned}
\alpha \sum_{h=0}^{h=H-1} \pi''_h q_{U,h+1} &= \alpha \sum_{h=0}^{h=Q-1} \pi''_h + \alpha \sum_{h=Q-1}^{h=H-1} \pi''_h q_{U,h+1} \\
&> \alpha \sum_{h=0}^{h=Q-1} \pi''_h > \alpha \sum_{h=0}^{h=Q-1} \pi'_h \\
&> \alpha \sum_{h=0}^{h=Q-1} \pi'_h q_{L,h} = \sum_{h=Q-1}^{h=H-1} \pi'_h u_{h+1} q_{U,h+1}.
\end{aligned} \tag{4}$$

Now the pricing rule, is not unique, insofar as the underpricing, u_h, may be positive in any or all of the states $h = Q, \ldots .H$, subject to (4). Without loss of generality, consider the case when all the underpricing in concentrated in the state $h = H$. Then

$$\begin{aligned}
\alpha \sum_{h=0}^{h=H-1} \pi''_h q_{U,h+1} &> \sum_{h=Q-1}^{h=H-1} \pi'_h u_{h+1} q_{U,h+1} = \pi'_{H-1} u_H q_{U,H} \\
&> \pi''_{H-1} u_H q_{U,H} = \sum_{h=Q-1}^{h=H-1} \pi''_h u_{h+1} q_{U,h+1}
\end{aligned} \tag{5}$$

and the incentive compatibility constraint (3) is shown to hold.

Proof of Proposition 1. For $h \geq R+1$ we have

$$\alpha\frac{H}{2}\pi'_h q_{L,h} - \alpha(h-R)\,Q\pi_h = \alpha\frac{1}{H+1}\left((h+1)\frac{(Q-h)}{(H-h)} - (h-R)\,Q\right)$$
$$< \alpha\frac{1}{H+1}\left((h+1)\frac{(Q-h)}{(H-h)} - Q\right) < 0 \quad (6)$$

since $(h+1)\frac{Q-h}{H-h} < (h+1)\frac{Q}{H} < Q$ ■

Proof of Proposition 2.

$$\Delta(r) = \alpha\frac{H}{2}p\left[\sum_{h=R+1}^{h=\min(R+r,Q-1)}\pi'_h q_{L,h} - \sum_{h=\max(R-r+1,0)}^{h=R}\pi'_h q_{L,h}\right] \quad (7)$$

can be written

$$\Delta(r) = \frac{\alpha p}{(H+1)}\left[\sum_{h=R+1}^{h=R+r}A(h) - \sum_{h=R-r+1}^{h=R}A(h)\right] \quad (8)$$

where

$$A(h) = \begin{cases} 0 & \text{if} \quad h < 0 \\ \frac{(h+1)(Q-h)}{(H-h)} & \text{if} \quad 0 \leq h < Q \\ 0 & \text{if} \quad h \geq Q \end{cases} \quad (9)$$

In particular we note $A(0) = \frac{Q}{H}$ and $A(Q-1) = \frac{Q}{(H-Q)+1}$ hence $A(Q-1) > A(0)$

The impact of increasing reservation price uncertainty from $r-1$ to r is to introduce positive probability (from the perspective of investors) that withdrawal might occur in state $(R+r)$, whilst introducing positive doubt (removing the 100% certainty) that withdrawal will necessarily occur in state $(R-r+1)$ The increase in Δ (increase in IPO proceeds caused by decrease in required expected underpricing) is therefore a multiple of the expression $A(R+r) - A(R-r+1)$.

When $R-r+1 < 0$, then $A(R-r+1) = 0$ and this expression is non-negative and when $R+r \geq Q$ then $A(R+r) = 0$ and our expression is non-positive. When $R-r+1$ and $R+r$ are both "in range", then

$$
\begin{aligned}
&A(R+r)-A(R-r+1)\\
&\quad=\frac{((R+r)+1)(Q-(R+r))}{(H-(R+r))}-\frac{((R-r+1)+1)(Q-(R-r+1))}{(H-(R-r+1))}\\
&\quad=2\left(r-\frac{1}{2}\right)\frac{\left(R+\frac{1}{2}\right)^2+Q+2H\left(\frac{Q}{2}-(R+1)\right)-\left(r-\frac{1}{2}\right)^2}{\left(H-\left(R+\frac{1}{2}\right)\right)^2-\left(r-\frac{1}{2}\right)^2}
\end{aligned}
\tag{10}
$$

Note that the denominator $\left(H-\left(R+\frac{1}{2}\right)\right)^2-\left(r-\frac{1}{2}\right)^2=(H-(R-r+1))(H-(R+r))$ is positive and $\left(r-\frac{1}{2}\right)$ is positive for $r=1,2,\ldots$

(i) for "low" reservation demands, $R\leq\frac{Q}{2}-1$, we need to show that $A(R+r)-A(R-r+1)>0$.

(ii) for "intermediate" reservation demands, $R\in\left(\frac{Q}{2}-1,\widehat{h}\right)$, we need to show that $A(R+r)-A(R-r+1)>0$ for "small" r and then $A(R+r)-A(R-r+1)<0$ for "large" r.

(iv) for "high" reservation demands, $R\geq\widehat{h}$, we need to show that $A(R+r)-A(R-r+1)<0$

For (i) this is trivial once $r>R+1$ for then $A(R-r+1)=0$.

And when $r\leq R+1$ then the expression is certainly positive because $\left(R+\frac{1}{2}\right)\geq\left(r-\frac{1}{2}\right)$ and $\frac{Q}{2}-(R+1)\geq 0$

For (ii) and (iv) $R>\frac{Q}{2}-1$ and so when $r=Q-R$ our expression reduces to $A(Q)-A(R-Q+R+1)=-A\left(2\left(R-\left(\frac{Q}{2}-\frac{1}{2}\right)\right)\right)<0$ i.e. our expression is certainly negative for the "highest" r.

Furthermore, the term $\left(R+\frac{1}{2}\right)^2+Q+2H\left(\frac{Q}{2}-(R+1)\right)-\left(r-\frac{1}{2}\right)^2$ is monotone decreasing in r, having at most one zero on the interval $r\in[1,Q-R]$

At $r=1$ the term takes the value

$$\left(R+\frac{1}{2}\right)^2+Q+2H\left(\frac{Q}{2}-(R+1)\right)-\left(1-\frac{1}{2}\right)^2 \tag{11}$$

which can be written

$$\left(\widehat{h}-R\right)\left(H-\left(R+\frac{1}{2}\right)+\sqrt{(H+1)(H-Q)+\frac{1}{4}}\right) \tag{12}$$

where $\widehat{h}=H-\frac{1}{2}-\sqrt{(H+1)(H-Q)+\frac{1}{4}}$

Thus, when $R < \widehat{h}$ our expression is positive at $r = 1$, monotone decreasing and becoming negative for high r.

And when $R > \widehat{h}$ our expression is negative at $r = 1$, remaining so for all higher r.

Part (iii) follows from continuity: when $R = \frac{Q}{2} - 1$, $\Delta > 0$ from Part (i) and when $R \geq \widehat{h}$, $\Delta < 0$ from Part (iv). Using Part (ii) we know that when $R > \frac{Q}{2} - 1$, Δ starts to decrease for large r, but we argue it will remain positive when R is at the lower end of the intermediate range. However as R approaches $\widehat{h}$, the upper end of the intermediate range, we argue that Δ must become negative for large r.

We note here for reference the following facts:

1. $\widehat{h} \in \left(\frac{Q}{2} - 1, Q - 1\right)$, $\widehat{h} \to Q - 1$ as $H \to Q$ and $\widehat{h} \to \frac{Q}{2} - 1$ as $H \to \infty$.
2. As a continuous function, $\pi'_h q_{L,h}$ reaches its internal maximum at $h^* = H - \sqrt{(H+1)(H-Q)}$ where $h^* \in \left(\frac{Q}{2} - \frac{1}{2}, Q\right)$, $h^* \to Q$ as $H \to Q$, and $h^* \to \frac{Q}{2} - \frac{1}{2}$ as $H \to \infty$.
3. $\widehat{h} \in (h^* - 1, h^*)$

■

References

Barcaskey, M. (2005) Do SEC regulations constrain offer price revisions of IPOs? Working paper, College of William and Mary.

Benveniste, L. and Spindt, P. (1989) How investment bankers determine the offer price and allocation of new issues, *Journal of Financial Economics* **24**, 343–361.

Benveniste, L. and Busaba, W. (1997) Bookbuilding vs. fixed price: An analysis of competing strategies for marketing IPOs, *Journal of Financial and Quantitative Analysis* **32**, 383–403.

Binmore, K. and Klemperer, P. (2002) The biggest auction ever: The sale of the British 3G telecom licences, *The Economic Journal* **112**, C74–C96.

Booth, J. and Chua, L. (1996) Ownership dispersion, costly information, and IPO underpricing, *Journal of Financial Economics* **41**, 291–310.

Busaba, W. (2006) Bookbuilding, the option to withdraw and the timing of IPOs, *Journal of Corporate Finance* **12**, 159–186.

Busaba, W., Benveniste, L. and Guo, R. J. (2001) The option to withdraw IPOs during the premarket: Empirical analysis, *Journal of Financial Economics* **60**, 73–102.

Cornelli, F. and Goldreich, D. (2001) Bookbuilding and strategic allocation, *Journal of Finance* **56**, 2337–2369.

Cornelli, F. and Goldreich, D. (2003) Bookbuilding: How informative is the order book? *Journal of Finance* **58**, 1415–1443.

Dunbar, C. and Foerster, S. (2007) Second time lucky? Withdrawn IPOs that return to the market, *Journal of Financial Economics, forthcoming*.

Elyakime, B., Laffont, J. J., Loisel, P. and Vuong, Q. (1994) First-price sealed-bid auctions with secret reservation prices, *Annales d'économie et de statistique* **34**, 115–141.
Hanley, K.W. (1993) The underpricing of Initial Public Offerings and the partial adjustment phenomenon, *Journal of Financial Economics* **34**, 231–250.
Horstmann, I. and LaCasse, C. (1997) Secret reserve prices in a bidding model with a resale option, *American Economic Review* **87**, 663–684.
Kandel, S., Sarig, O. and Wohl, A. (1999) The demand for stocks: An analysis of IPO auctions, *Review of Financial Studies* **12**, 227–247.
Leone, A., Rock, S. and Willenborg, M. (2006) Disclosure of intended use of proceeds and underpricing in Initial Public Offerings, *Journal of Accounting Research* **45**, 111–153.
Levin, D. and Smith, J. L. (1996) Optimal reservation prices in auctions, *The Economic Journal* **106**, 1271–1283.
Ljungqvist, A., Jenkinson, T. and Wilhelm, W. (2003) Global integration in primary equity markets: The Role of U.S. Banks and U.S. Investors, *Review of Financial Studies* **16**, 63–99.
Lucking-Reiley, D. (2000) Auctions on the internet: What's being auctioned, and how? *Journal of Industrial Economics* **48**, 227–252.
Pettway, R. and Kaneko, T. (1996) The effects of removing price limits and introducing auctions upon short-term IPO returns: The case of Japanese IPOs, *Pacific-Basin Finance Journal* **4**, 241–258.
Riley, J. and Samuelson, W. (1981) Optimal auctions, *American Economic Review* **71**, 381–392.
Sherman, A. (2005) Global trends in IPO methods: Book building vs. auctions with endogenous entry, *Journal of Financial Economics* **78**, 615–649.
Sherman, A. and Titman, S. (2002) Building the IPO order book: Underpricing and participation limits with costly information, *Journal of Financial Economics* **65**, 3–29.
Spatt, C. and Srivastava, S. (1991) Preplay communication, participation restrictions, and efficiency in Initial Public Offerings, *The Review of Financial Studies* **4**, 709–726.
Vincent, D. (1995) Bidding off the wall: Why reserve prices may be kept secret, *Journal of Economic Theory* **65**, 575–584.
Welch, I. (1992) Sequential sales, learning and cascades, *Journal of Finance* **47**, 695–732.