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What Determines the Level of IPO Gross Spreads?

Underwriter Profits and the Cost of Going Public*

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Abstract

This paper addresses three empirical findings of the literature on initial public offerings. (i) Why do investment banks earn positive profits in a competitive market? (ii) Why do banks receive lower gross spreads in venture capitalist (VC) backed than in non-VC backed IPOs? (iii) Why is underpricing more pronounced in VC than in non-VC backed IPOs? While each phenomenon can be explained by itself, there is no explanation yet why all three occur simultaneously. We propose an integrated theoretical framework to address this issue. The IPO procedure is modeled as a two-stage signaling game: In the second stage banks set offer prices given their private information and the level of the spread. Issuing firms anticipate their bank’s pricing decision and, in the first stage, set spreads to maximize expected revenue. Investors are aware of this process and subscribe only if their expected profits are non-negative. Firms’ equilibrium spreads are large so as to induce banks to set high prices, allowing banks to make profits. Superiorly informed VC backed firms impose smaller spreads but face larger underpricing than non-VC backed firms.

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1 Introduction

A large number of reputable institutions can administer initial public offerings. The underwriting industry should thus be highly competitive and profit margins should be low. Yet out of all investment banking fields, the IPO business is generally recognized to be among the most profitable. For an issuing firm (henceforth ‘firm’), on the other hand, its first listing is usually a costly endeavor. While underpricing has been the focus of the literature, it is not the only cost of going public.¹ The ‘explicit’ price tag is the discount – the gross spread – at which firms sell the shares to their underwriter (henceforth ‘bank’), who then passes them on to investors at the public offer price.

The IPO market is plagued with various conflicts of interest and informational asymmetries between the parties involved, as is well-documented – both empirically and theoretically – in the literature on IPO underpricing.² Yet there is only little theoretical work³ that assesses how these conflicts and informational asymmetries affect the gross spread level, and how the gross spread level and IPO pricing are interrelated. With this paper, we attempt to fill this gap.

What is known empirically about gross spread levels? Chen & Ritter (2000) find that spreads amount to 7 percent on average for a sample of 3,203 IPOs between 1985 and 1998. They report that “investment bankers readily admit that the IPO business is very profitable.” Furthermore, spreads are not only on average but exactly 7 percent in most of the offerings. Hansen (2001) documents that this finding triggered 27 lawsuits and a U.S. Department of Justice investigation of “alleged conspiracy among securities underwriters to fix underwriting fees.” Thus in practice, the spread level plays an important role, and it allows banks to generate substantial profits.

Notwithstanding the legal debate and empirical indications on investment bank collusion, our theoretical formulation allows a very different, subtle explanation for high spreads.

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¹Ritter & Welch (2002), for example, report an average first-day return of 18.8 percent for 6,249 IPOs in the U.S. between 1980 and 2001.
²Ljungqvist (2005) provides a comprehensive overview of the literature.
³Exceptions are Baron (1982) and Yeoman (2001), which we discuss below.
We find that it can be in the best interest of the firm to pay ‘high’ spreads — even if a competing bank offered its service at a lower spread. Firms, therefore, do not bargain for lower spreads and banks do not compete in them.

Apart from the generally high level of spreads, there are also structural differences. Many IPOs are backed by a venture capitalist (VC). In their pioneering contribution on the role of VCs in IPOs, Megginson & Weiss (1991) compare VC backed and non-VC backed IPOs matched by industry and offer size between 1983 and 1987. They find that, on average, VC backed IPOs have lower spreads than non-VC backed IPOs. In a more recent study, Francis & Hasan (2001) confirm that VC backed IPOs are associated with less underwriter compensation than non-VC backed IPOs. However, they, and also Lee & Wahal (2004) and Loughran & Ritter (2004), find that VC backed IPOs exhibit larger average underpricing than non-VC backed IPOs.4

One obvious explanation for the first finding, i.e. that a VC-backed firms face a lower spreads, is that they are experienced, repeat players with a lot of bargaining power. But this does not explain the second empirical finding: why would an experienced player leave more money on the table and allow more underpricing than an inexperienced, non-VC firm? Appealing to ‘experience’ or ‘repeated interaction’ simply cannot explain why lower spreads and higher underpricing occur jointly. In our model, however, this arises as a natural result of the information revelation procedure in the offering process.

In the IPO process, there are three major players: the issuing firm, the bank, and investors. Each will react rationally to preceding actions by other players and/or in anticipation of a rational response. The only meaningful way to model this situation is as an extensive form game. Furthermore, in IPOs there is substantial uncertainty and thus it is reasonable to model asymmetric, noisy information that is correlated among agents. Finally, the aftermarket price should aggregate information that the offer price could not – why else would we often observe substantial price-jumps? The nature of the problem

4These papers contrast earlier studies, e.g. Barry, Muscarella, Peavy & Vetsuypons (1990) and Megginson & Weiss (1991) who found that VC backed IPOs are associated with less underpricing.
therefore requires a model that incorporates three-player strategic considerations coupled with informational asymmetries. We thus set up our model as a three-stage signaling game, in which market prices aggregate more information than do offer prices.

There are drawbacks to this approach: The analysis of any three player game is intrinsically complex. However, complexity is a price worth paying: The model accomplishes to exactly integrate the above described stylized facts. In addition, we derive a novel, testable implication in that relationship-bank\(^5\) backed IPOs should have the highest spreads.

In our model, we assume that banks, investors, and issuing firms (may) have private but noisy information about the intrinsic value of the offered security, which is either ‘good news’ or ‘bad news’. In a wider sense, this signal can also be understood as information about how the market perceives the firm’s fundamentals. Initially, the firm offers the bank a contract that specifies the gross spread level. If the firm is privately informed, the spread level can be either separating or pooling. The level of the spread critically affects the bank’s pricing decision: Banks choose the offer price strategically to maximize their expected profits from the gross spread of the offer revenue. A higher price does not necessarily increase revenue: at high prices the IPO can fail as there may not be enough investors to buy up the entire offering. Given the spread, the bank sets a price that, first, either reveals (separation) or camouflages (pooling) its private information and, second, is either low so that all investors order (risk-free) or high so that only investors with ‘good news’ order (risky). Banks account for the spread’s information content when deciding on the offer price. Anticipating the bank’s pricing decision, the firm sets the level of the gross spread strategically so that the bank sets the offer price that gives the firm the highest expected profit. Investors are aware of this process and subscribe only if their expected profits are non-negative.

Our first main result is to show that at the equilibrium spread the bank earns positive profits on average. The intuition for the result is straightforward. Loosely speaking, firms want banks to set high, risky prices. And since banks have the power to set the prices,

\(^5\)A commercial bank with strong, long-lasting ties with the firm, for instance through credit-financing.
spreads must be incentive compatible so that banks do not deviate to a low price at which they would receive a safe, positive payoff. Therefore, a bank’s expected profit is at least what it would gain by deviating to a low risk-free price.

Our second main result is a comparative static on the effect of a change in the informational assumptions on the spread. We distinguish two cases: in the first, the firm receives no information (later interpreted as non-VC backed IPOs), and in the second, the firm receives a private signal that is conditionally independent from the bank’s signal (later interpreted as VC backed IPOs). We first show that privately informed firms set pooling spreads that hide their signal, but that at these spreads banks set separating prices. In contrast, uninformed firms cannot convey information through the spread, and in equilibrium they choose spreads that induce banks to set high, risky pooling prices. We then show that the pooling spreads with privately informed firms are lower than the spread set by an uninformed firm.

The intuition for these results consists of three parts: First, the spread provides incentives for the bank to choose risky prices. If the spread is too low, then banks avoid the risk of a failing IPO completely and set very low, risk-free prices; at these prices there would be a lot of underpricing. Suppose firms want to induce banks to set the risky pooling price: then the spread has to be large enough so that both a low- and a high-signal bank set risky prices. Intuitively this spread must thus be larger than spreads that induce price-separation, and this yields the order of spread-sizes.

Second, while the high-signal firm would like to set a spread that separates it from its low-signal counterpart, the low-signal firm can always gain so much from mimicking the high-signal firm that there cannot be spread separation. This leads to two candidate outcomes: one where firms set spreads that induce price-pooling, the other where firms set spreads that induce price-separation. The high-signal firm prefers price separation because, first, it believes that the bank also has a high signal and will thus set a high price and, second, these spreads are also lower than the pooling-inducing spreads. In equilibrium the high-signal, privately informed firm can then ensure the spread-pooling, price-separating
equilibrium.

Third, uninformed firms think that with price-separation the high and the low price would be equally likely. While spreads that induce price-separation are lower than spreads that induce price-pooling, underpricing is larger with price-pooling. It turns out that uninformed firms prefer the price-pooling equilibrium. Intuitively, informed firms have an informational advantage, and, therefore, it should be cheaper for them to provide the banks with the right incentives. Since spreads with informed and uninformed firms have the same informational content, the informational advantage should cause spreads to induce different equilibrium prices; hence uninformed firms’ preference for price-pooling. Spreads that privately informed firms offer are then lower than the spreads that uninformed firms offer.

Our third main result shows that the model is consistent with the empirical findings on first-day returns. In equilibrium there is, on average, underpricing, and it is more pronounced in VC than in non-VC backed offerings.

Our final result analyzes the spread level when banks and firms receive a common signal (later interpreted as ‘relationship-banking’). We show that a firm with favorable information sets a spread that prevents its low-signal counterpart from mimicking. However, even the low signal firm finds it optimal to choose a spread that is large enough so that the bank sets a high, risky price. We then find that IPOs under this informational assumption have the highest spreads on average.

In a related theoretical paper that addresses investment bank compensation in IPOs, Baron (1982) develops the optimal bank-compensation contract assuming that the bank is better informed about the capital market’s demand than the issuer. The contract is geared to resolve this information asymmetry and to induce the bank to exert a distribution effort. Baron then allows a contract that conditions the bank’s compensation on the offer price, the overall proceeds, and the bank’s report of market conditions. In contrast, the compensation scheme considered in our paper is restricted to setting the level of the spread, because we focus primarily on understanding how this key variable is determined and how it influences
other aspects of the offer procedure. This leads to different observations: in Baron’s work, if
the issuer and the bank have the same information, then the compensation is smallest; in our
paper, the spread is largest if they have the same information. In our paper, underpricing
is largest when the issuer is independently informed (and larger than when the issuer is
uninformed); in Baron underpricing is largest if the issuer is uninformed. These differences
stems from the chosen frameworks: In our signalling model, both the spread and the
price may reveal information about the security on offer. Investors use this information in
their decisions, so that the spread and the offer price influence market demand and thus
payoffs and underpricing. In Baron, on the other hand, the market reaction is essentially
stochastically independent of the offering process. In another theoretical contribution,
Yeoman (2001) models a competitive environment in which information asymmetries play
no role and there are no strategic considerations. The size of the spread and the magnitude
of underpricing in his model are thus determined as the solution of a maximization problem
over exogenous variables.

The remainder of the paper is organized as follows. Section 2 presents the model.
Section 3 summarizes the equilibrium outcomes and discusses the underlying assumptions.
Section 4 derives the equilibrium prices set by the bank, given the spread level. Section 5
analyzes the strategic choice of the spread level by issuing firms. Section 6 presents the
main results on levels and differences of gross spreads. Section 7 concludes.

2 A Stylized Model of the IPO Procedure

The Security. The security on offer can take one of two equally likely values \( V \); for
simplicity \( V \in \mathbb{V} = \{0, 1\} \). The realization is not known to any player in the game.

The Investors. There are \( N \) identical, risk neutral investors who can place unit orders
of the security. Each investor receives a costless, private, conditionally i.i.d. signal \( s_i \in \mathbb{V} \)
about the value of the security. This information is noisy, i.e. \( \Pr(s_i = v|V = v) = q \) with
\( q \in (\frac{1}{2}, 1) \). If an investor receives a share, his payoff is the market price minus the offer
price, otherwise it is zero. An investor’s type is his signal, thus a ‘high-signal investor’ has $s_i = 1$, a ‘low-signal investor’ has $s_i = 0$. Each investor maximizes his expected payoff.

**The Issuing Firm.** In general the issuing firm (henceforth ‘the firm’) can be either uninformed or informed. For the latter we consider two subcases: in the first, the issuing firm receives a private signal $s_f \in \{0, 1\}$, in the second, the firm and the bank receive the identical signal. Any signal is costless and conditionally independent from the investors’ signals but, for simplicity, of the same quality, i.e. $\Pr(s_f = v | V = v) = q$. The uninformed firm receives no signal. We will refer to these types of firms as ‘privately informed’, ‘identically informed’, and ‘uninformed’. In Section 6 we interpret the meaning of informative signals and relate informed and uninformed firms to real-world types such as VC backed and non-VC backed firms. The firm is risk neutral and signs a contract with a bank that delegates the pricing decision and constitutes the number of shares, $S$, to be sold. It also specifies the publicly observed gross spread level $\beta \in (0, 1)$, which is chosen by the firm. If the offer is floated, its revenue is fraction $(1 - \beta)$ of the offer revenue, otherwise it is zero. The objective of the firm is to maximize its expected revenue.

**The Investment Bank.** The risk neutral bank receives a private signal $s_b \in V$ about the value of the security. This signal is costless, conditionally independent from investors’ signals, and, for simplicity, of the same quality, i.e. $\Pr(s_b = v | V = v) = q$. If $s_b = 1$ we refer to the bank as a ‘high-signal bank’, for $s_b = 0$, it is a ‘low-signal bank’. After the bank receives the contract it announces the offer price $p$. If the offer fails, the bank incurs cost $C$. These costs are external to our formulation and can be thought of as a loss in reputation or as an opportunity costs from lost market share subsequent to a failed IPO.\(^6\)\(^7\)\(^8\)

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\(^6\)Another candidate choice variable is the number of shares $S$, or even the number of potential investors $N$ that are addressed, e.g. during the road-show. However, including these as choice variables would require a different, more elaborate modeling approach.

\(^7\)Alternatively, one can think that the bank adjusts the offer price down in case there is insufficient demand; again one can argue that the bank then incurs a reputation loss. The model could be extended to allow the bank to buy up unsold securities. Costs then result from expensively bought inventory positions and not from failure. $C$ would thus be ‘smoothed’. This would not alter our qualitative results but complicate the analysis considerably.

\(^8\)Dunbar (2000) provides evidence that banks lose market share after withdrawn offerings. For the issuing firm, on the other hand, we do not include costs of a failure. Clearly, if the IPO fails, then the firm must choose a different, possibly less preferred financing or exit channel. However, since these costs...
Without loss of generality, we do not specify any costs the offering procedure itself may cause for the investment bank. Thus, if the offer is successful, the bank’s payoff is $\beta p S$; if it fails, its payoff is $-C$. The bank’s objective is to maximize its payoff. The timing of the game is summarized in Figure 1.

**The Offer.** A fixed number of $S < N$ shares is offered at a fixed price $p$. If the demand $d$ is insufficient, $d < S$, then the offer fails and the security does not get listed. If $d \geq S$, then the offer is successful. If it is oversubscribed, the share-allocation is pro-rated. After the distribution, demand $d$ is revealed, and the security is traded on the market at market price $p^m$.

**Signaling Value of Gross Spread and Offer Price.** The gross spread level and the offer price are announced first. Then investors decide whether to order, based on their private information and on the information that firm and bank reveal about their signals through the gross spread level and the offer price. We denote information contained in prices by $\mu(p)$, information in spreads by $\nu(\beta)$. In the case of the uninformed firm, the spread is uninformative and only prices can carry information. In the case of an identically informed firm, the information contained in $\beta$ is hierarchical to the information in $p$. Firms with different signals may set different levels of the gross spread which then reveals the signal of the firm. Since the firm’s signal is the same as the bank’s, prices cannot carry further information. We write $\mu(p) = 1$ if the price reflects that the bank’s signal is $s_b = 1$, $\mu(p) = 0$ if reveals that $s_b = 0$, and $\mu(p) = \frac{1}{2}$ to indicate that the price is uninformative; likewise for $\nu(\beta)$. In equilibrium these will turn out to be the only relevant cases.

**The Aftermarket Price.** The equilibrium market price is determined by the aggregate number of investors’ favorable signals. In our model this number is always revealed, either should be small, explicitly modeling any costs that this might cost would only add another parameter to the model without altering our findings.
directly through investor demand or immediately after the float through trading activities. Thus write \( p^m(d) \) for the market price as a function of the number of high-signal investors \( d \in \{0, \ldots, N\} \). Appendix A fleshes out this argument.

**Investors’ Decisions and Expected Payoffs.** We admit only symmetric pure strategies; thus all investors with the same signal take identical decisions. These can then be aggregated so that only three cases need to be considered: First, all investors subscribe, second, only high-signal investors subscribe, and third, no investor subscribes. The extensive form of the game is illustrated in Figure 2.

To compute his expected payoff, an investor has to account for the probability of receiving the security. There are two cases to consider. First, all investors buy: Market demand is \( N \) and all investors receive the security with equal probability \( S/N \). Second, only high-signal investors buy: If \( d \) investors buy, each receives the security with probability \( S/d \). If the overall demand \( d \) is smaller than the number of shares on offer, \( d < S \), the IPO fails and investors who ordered the security obtain it with probability 0. These three types of aggregate order decisions are denoted as follows: If all investors subscribe, then we use \( B_{0,1} \), if only high-signal investors subscribe, then we use \( B_1 \), and if no investor subscribes, then we use \( B_0 \). Thus, the set of potential collective best replies is \( \mathcal{B} := \{B_{0,1}, B_1, B_0\} \).

If it turns out that the number of favorable signals is small then the aftermarket price may drop below the offer price; the reverse may happen if the number of favorable signals is large. Investors require to be compensated for the risk of low aftermarket prices; since they are risk neutral, the benefit of an underpriced issue must be balanced with the loss of an overpriced issue so that investors at least break even on average. Suppose only high-signal investors buy. After observing the gross spread and the offer price, an investor’s information set contains both his signal \( s_i \) and the information inferred from the offer price and the spread, \( \mu(p) \) and \( \nu(\beta) \). Since signals are conditionally i.i.d., for each \( V \in \mathcal{V} \) there is a different distribution over the number \( d \) of others’ favorable signals \( (s_i = 1) \). Investors combine these densities with their own signal to determine the distribution over the number of others’ favorable signals. An investor orders if at price \( p \) his rational-expectation payoff
from buying is non-negative (details are in Appendix A),

\[
E[\text{market price (demand } d) - \text{ offer price } | \text{ signal, spread-price info, IPO successful}] \geq 0. \quad (1)
\]

**Threshold Prices.** Denote by \( p_{s_i, \mu, \nu} \) the highest price that an investor with signal \( s_i \), price information \( \mu(p) \) and spread-information \( \nu(\beta) \) is willing to pay in equilibrium if all investors with signals weakly larger than \( s_i \) order. If the firm is uninformed, \( \nu \) is replaced with a diamond, \( \diamond \). If firm and bank get the same signal and if the firm signals its private information, \( \mu(p) \) is replaced with a diamond to indicate that the price cannot reveal further information. Suppose the firm reveals information \( \nu \). For example, \( p_{1,1,\nu} \) is the price at which the bank signals that it has received information \( s = 1 \) (thus the price is separating) and it is the largest such price at which only the high-signal investors are willing to buy; \( p_{1,\frac{1}{2},\nu} \) is the highest price at which banks reveal no information (they pool) and only the high-signal investors buy. Note that at all these prices investors are aware that the security price may drop (or rise) in the aftermarket and that they may not get the security. The threshold prices are formally derived in Appendix A.

**The Bank’s Expected Payoff.** With binary signals, the probability that \( d \) investors have the favorable signal and \( N - d \) have not, conditional on true value \( V \), is binomial. The unconditional distribution, which convolutes the high and low value case, is bimodal. The bank is interested in the cumulative probability that there are at least \( S \) investors with the favorable signal (recall that \( S \) denotes the number of shares on offer), given its own information and the information it derived from the spread. We use notation \( \alpha_{sb,\nu}(S) \) for this cumulative probability; details of its functional form are in Appendix A.

If the bank sets a price \( p \) at which only high-signal investors buy, then the bank’s expected profit is

\[
\Pi(p|s_{b, \nu}, B_1) = \alpha_{sb,\nu}(S) \cdot \beta pS - (1 - \alpha_{sb,\nu}(S)) \cdot C. \quad (2)
\]

If the offer price is low enough so that all investors are willing to buy, irrespective of their
signals (case $B_{0,1}$), then the offer never fails and payoffs are given by $\Pi(p|B_{0,1}) = \beta p S$. If the price is set so high that no investor buys (case $B_0$) then a loss of $C$ results with certainty. Consequently, a necessary condition for the bank to be willing to set a high, risky price at which only high-signal investors buy, is that the expected share of the proceeds $\alpha_{s_b,\nu}(S) \cdot \beta p S$ at least compensates the bank for the risk of a failed IPO, measured by expected costs $(1 - \alpha_{s_b,\nu}(S)) \cdot C$.

3 Equilibrium Outcomes

The derivation of the equilibrium in any signaling game, albeit indispensable and insightful, can be cumbersome at times. We thus list the equilibrium outcomes before we derive them in detail. Some readers may want (in a first read) to skip Sections 4 and 5 and proceed directly to Section 6, where we discuss the implications of the equilibrium behavior.

The Equilibrium Concept and Selection Criteria. The equilibrium concept for this signaling game is the Perfect Bayesian Equilibrium (PBE). A common problem with signaling PBEs is the multiplicity of equilibria, some being supported by “unreasonable” out-of-equilibrium beliefs. The most intuitive equilibrium, is the one in which the least surplus is lost through costly signalling (sometimes called the ‘Riley-outcome’). To single out this outcome, we only consider equilibria that satisfy Cho & Kreps (1987)’s Intuitive Criterion. If this does not yield a unique outcome, then we select the equilibrium that is payoff dominant for the agent who takes the signaling action.

The Equilibrium. The timing of the game is as described in Figure 1. First, all parties receive their private signals (if informed). Second, the firm offers a contract to the bank that specifies the gross spread. Third, the bank sets the offer price given the spread, the information contained therein, and its own signal. Fourth, investors decide whether or not to order (using all the information available to them). Finally, in case the IPO takes place, the number of favorable signals is revealed in the aftermarket and the price adjusts accordingly. The following outcomes arise as equilibria.
Summary (Equilibrium Predictions)

(1) *If the firm is uninformed, then it will set a spread that induces the bank to set a pooling price.* At the pooling price, only investors with the high signal buy.

(2) *If the firm receives a private, conditionally independent signal, then it sets a spread that does not reflect its information.* This spread induces the bank to set a separating price (which reveals the bank’s information). At the high separating price, only high-signal investors order, at the low separating price all investors order.

(3) *If the firm has the same signal as the bank, then the firm will set a separating spread that reveals the firm’s (and thus the bank’s) information.* Both separating spreads induce prices at which only high-signal investors order.

The equilibrium is derived by backward induction. In Section 4 we analyze the price setting of the bank given the level of the gross spread. Anticipating the bank’s price setting, the firm chooses the spread, and we derive the details of this choice process in Section 5. Section 6 interprets the findings of Sections 4 and 5 and presents our main results on banking profits and differences in spread levels for different classes of issuing firms.

**Simplifying Assumptions.** There are four restrictive assumptions. We make these assumptions for two reasons. First, we want to keep the analysis tractable and strive to obtain approximate closed form solutions for success-probabilities and prices. The first three assumptions allow this (see Appendix A). Second, to keep our statements concise, we make the fourth assumption where we restrict the spread level not to exceed 10 percent, which is consistent with empirically observed levels.

The unconditional distribution over favorable signals is a composite of the two conditional distributions and thus bimodal. The two modes of the distribution over favorable signals are centered around $N(1 - q)$ and $Nq$. We now require

**Assumption 1** $S = (1 - q)N$.

Nothing speaks against an analysis with a different number of shares (as long as the number
is below $N/2$), but then the model can only be solved numerically. The assumption is conceptually innocuous, yet helps to keep the analysis tractable.\footnote{Allowing $S$ to be the firm’s or bank’s choice variable is a different matter. In that case, there would be a two-dimensional signal and, conceptually, this changes the model and the analysis substantially.}

For every signal quality $q$, there exists an $\bar{N}(q)$ so that for all $N > \bar{N}(q)$ the two conditional distributions over favorable signals generated by $V = 0$ and $V = 1$ do not ‘overlap’. By standard results from statistics, a sufficient condition for $\bar{N}(q)$ is given by $\bar{N}(q) > 64q(1 - q)/(2q - 1)^2$.

**Assumption 2** The number of investors $N$ is larger than $\bar{N}(q)$.

As a consequence of the second assumption we can apply the Law of Large Numbers (LLN) and DeMoivre-Laplace’s Theorem. Since we assume that the IPO fails whenever $d < S$, Assumption 1 implies, for instance, that if the spread is uninformative, i.e. $\nu = 1/2$, then $\alpha_{0.4}(S) = (2 - q)/2$ and $\alpha_{1.4} = (1 + q)/2$.\footnote{The probability of a successful IPO is determined by computing how likely it is that demand $d$ is larger than $S = N(1 - q)$. The underlying distribution is a (bimodal) binomial distribution and as such the two modes are generally not exactly symmetric around the centers of their modes (which are $N(1 - q)$ and $Nq$). However, if $N$ is large enough so that $0 < q < 2\sqrt{q(1 - q)/N} < 1$ then by DeMoivre-LaPlace the binomial distribution can be approximated by the normal distribution. The latter is symmetric and thus we can treat each mode to be symmetric. This then allows simple closed-form expressions for the success probabilities as derived in Appendix A.} In what follows we omit $S$ from $\alpha$. Another consequence of $N$ being large is that $p^m(d) \in \{0, 1\}$ for almost all values of $d$.\footnote{To be more precise, for $d \gg N/2$, $p^m(d) = 1$, and for $d \ll N/2$, $p^m(d) = 0$.} That is, market prices will be fully informative and reflect the true value.

**Assumption 3** Signals are sufficiently precise, $q \in (0.6, 1)$.

Another simplifying and useful feature in our analysis is that we can describe closed form approximations for the threshold offering prices. When signals are very imprecise ($q$ is close to $0.5$), however, then our closed form approximation for prices can no longer be applied\footnote{The reason is the following: The threshold price approximations are formed by computing the conditional expectation in equation (1). The market price is a function of the number of positive signals and it is S-shaped (around $N/2$); further, it is 0 for a small number of positive signals and 1 for a large number of positive signals. The probability density used to compute this expectation is bimodal with modes at $N(1 - q)$ and $Nq$, and for large $N$ the probability mass is tightly concentrated around the centers of these modes. The crucial idea behind the approximations is to observe that for $q$ sufficiently large, positive probability mass occurs only when the price is either 0 or 1. When $q$ is close to 1/2, however, then this is no longer true and thus closed forms are not feasible.}
and consequently the equilibrium analysis would become cumbersome. In principle, all that we require is that the signal quality is distinctively better than random; this seems a small burden given that the closed form approximations are very useful for the analysis (and potentially even beyond this paper). For a concise analysis, we make a fourth assumption.

**Assumption 4** *Spread levels $\beta$ do not exceed 10 percent.*

Empirically observed spreads typically range from 2 and 9 percent, and so we merely restrict attention to the real-world observed range of values. To assess the implications of this assumption consider the following. In our model, the threshold spreads (which we will derive in the next two sections) depend on two variables: The costs per potential investor, $C/N$, and the signal precision $q$. The first variable, $C/N$, is an exogenous factor in our model; there is no equilibrium condition that specifies or restricts its size. Imposing an upper bound on $\beta$ is implicitly the same as requiring $C/N$ to be sufficiently small for any $q$. (Details are in Appendices A and B.)

While an analysis with larger spreads is possible, the derivation of the equilibria and the exposition of the results would involve an unwarrantably large number of case distinctions. Thus, instead of fully solving the model for all possible parameter constellations and then characterizing the parameter set for which our results apply, we restrict the allowed parameter set ex ante, provide an empirically backed interpretation of that condition (namely that empirically $\beta < 0.1$), and then derive the unique equilibrium within this set. Assumption 4 is thus merely a sufficient condition for which our results hold.

## 4 The Investment Bank’s Equilibrium Price Choice

There are two cases to consider: First, spreads are uninformative or reflect the firm’s independent information. In that case, the bank plays a signaling game and needs to decide whether or not to reveal its private information. Second, in case of the identically informed firm, spreads can reveal the bank’s signal. Then the bank has no strategic decision problem but merely chooses the price that is optimal given all public information.
4.1 Equilibrium Price Setting when Spreads are Uninformative or Reveal Independent Information

In the following we identify the conditions under which a profit maximizing bank reveals its information through the offer price. A separating equilibrium is defined as *informationally efficient* since investors can derive the bank’s signal from the offer price. Hence a pooling equilibrium is *informationally inefficient*. In this case, investors decide only on the basis of their private signals. In what follows we take the information that may be contained in spreads, \( \nu(\beta) \), as given. Separation and pooling thus always refers to prices.

A *pooling equilibrium* in prices is specified through (i) an equilibrium offer price \( p^* \) from which investors infer (ii) price-information \( \mu = \frac{1}{2} \), and (iii) investors’ best replies given their private signals, \( \mu \), and \( p^* \). A *separating equilibrium* in prices is (i) a system of prices \( \{p^*, \bar{p}^*\} \) and price-information such that (ii) at \( p^* = \bar{p}^* \), the high separation price, the price-information is that the bank has the favorable signal, \( \mu = 1 \), at \( p^* = p^* \), the low separation price, the price-information is that the bank has the low signal, \( \mu = 0 \), and (iii) investors’ best replies given their private signals, \( \mu \), and \( \bar{p}^* \) or \( p^* \). In both separating and pooling equilibrium, for \( p \not\in \{\bar{p}^*, p^*\} \) or \( p \neq p^* \), respectively, out-of-equilibrium public beliefs are chosen ‘appropriately’. The following result is a straightforward consequence of signaling, the proof of which is in Appendix B.

**Lemma 1 (The Highest Possible Low Separating Price)**

There exists no PBE (price-)separating offer price \( p^* > p_{0,0,\nu} \).

In any separating equilibrium, therefore, the low price must be such that all investors buy, and the highest such separating price, given price-information \( \mu = 0 \), is \( \bar{p}^* = p_{0,0,\nu} \). In what follows we refer to \( p_{0,0,\nu} \) as *the* low separation price.

In our setting there are three types of price-signaling equilibria: The already mentioned separating equilibrium, a pooling equilibrium in which only high-signal investors buy, and a pooling equilibrium in which all investors buy. In the following, we characterize the conditions guaranteeing that only separating equilibria survive our selection criterion.
Fix a candidate safe price \( p \in [p_{0,0,\nu}, p_{0,1,\nu}] \), the interval of potential pooling prices at which all investors would buy. Define \( \phi_{1,\nu}(p) \) as the price at which the high-signal bank would be indifferent between charging a risky price \( \phi_{1,\nu}(p) \) at which only high-signal investors buy, and a safe pooling price \( p \) with all investors buying. Formally,

\[
\alpha_{1,\nu}\beta\phi_{1,\nu}(p)S - (1 - \alpha_{1,\nu}) C = \beta p S \iff \phi_{1,\nu}(p) = \frac{p}{\alpha_{1,\nu}} + \frac{1 - \alpha_{1,\nu}}{\alpha_{1,\nu}}\frac{C}{\beta S}. \tag{3}
\]

Price \( \phi_{0,\nu}(p) \) is defined analogously for the low-signal bank. Thus price \( \phi_{s_b,\nu}(p) \) is the lowest risky price that a bank with signal \( s_b \) is willing to deviate to from safe price \( p \). In what follows we refer to \( \phi_{1,\nu}(p) \) as the high-signal bank’s deviation price, and to \( \phi_{0,\nu}(p) \) as the low-signal bank’s deviation price. It is straightforward to see that the low-signal bank requires a higher price as compensation for risk taking, and that, the higher the pooling price, the higher the lowest profitable deviation price. In what follows we analyze equilibria depending on two conditions on primitives.

**Condition 1** The high-signal bank’s deviation price from the highest safe pooling price is not higher than the highest separating price, \( \phi_{1,\nu}(p_{0,1,\nu}) \leq p_{1,1,\nu} \).

**Condition 2** The low-signal bank’s deviation price from the low separating price is not smaller than the highest risky pooling price, \( \phi_{0,\nu}(p_{0,0,\nu}) \geq p_{1,1,\nu} \).

These two conditions will determine what kind of equilibrium (separating or pooling) arises. While this section focusses on prices, Section 5 focusses on spreads. In Section 5.1 we provide an intuitive interpretation of the two conditions in terms of the gross spread level. Effectively, the higher the gross spread, the lower the deviation price (this transpires straightforwardly from (3)): thus since the conditions ensure whether there is pooling or separation, there will be threshold spreads that ensure pooling or separation.

**Proposition 1 (Equilibrium Price Setting)**

(a) *If both Condition 1 and 2 are fulfilled then the unique PBE that satisfies the IC is*
the separating equilibrium \( \{(\bar{p}^* = p_{0,0,\nu}, \mu = 0, B_{0,1}); (p^* = \min\{p_{1,1,\nu}, \phi_{0,\nu}(p_{0,0,\nu})\}, \mu = 1, B_1); (p \neq \{\bar{p}^*, \bar{p}^*\}, \mu = 0, B_{0,1} \text{ if } p \leq p_{0,0,\nu}, B_1 \text{ if } p_{0,0,\nu} < p \leq p_{1,0,\nu}, B_0 \text{ else})\}. \)

(b) If Condition 1 is not fulfilled then the only PBE that satisfies the IC and payoff dominance is the pooling equilibrium \( \{(p^* = p_{0,\frac{1}{2},\nu}, \mu = \frac{1}{2}, B_{0,1}); (p \neq p_{0,\frac{1}{2},\nu}, \mu = 0, B_1 \text{ if } p \leq p_{1,0,\nu}, B_0 \text{ else})\} \) in which all investors buy.

(c) If Condition 2 is not fulfilled then the only PBE that satisfies the IC and payoff dominance is the pooling equilibrium \( \{(p^* = p_{1,\frac{1}{2},\nu}, \mu = \frac{1}{2}, B_1); (p \neq p_{1,\frac{1}{2},\nu}, \mu = 0, B_1 \text{ if } p \leq p_{1,0,\nu}, B_0 \text{ else})\} \) in which only high-signal investors buy.

Condition 1 together with the intuitive criterion (IC) is necessary and sufficient to rule out pooling equilibria in which all investors buy, irrespective of their signals. Condition 2 ensures that there is no pooling where only investors with ‘good news’ buy.

The IC itself ensures that the high-signal bank always charges the highest sustainable separating price. The high separation price \( \bar{p}^* \) is the minimum of \( p_{1,1,\nu} \) and \( \phi_{0,\nu}(p_{0,0,\nu}) \). The bank cannot charge more than \( p_{1,1,\nu} \), and it cannot credibly charge more than \( \phi_{0,\nu}(p_{0,0,\nu}) \) as otherwise the low-signal bank would deviate. Finally, since \( \phi_{1,\nu}(p_{0,0,\nu}) < \phi_{1,\nu}(p_{0,\frac{1}{2},\nu}) \leq p_{1,1,\nu} \), the high-signal bank is willing to separate.

If Condition 1 is violated not even the high-signal bank wants to take the risk of setting a price where only high-signal investors buy. A separating price pair with all investors buying at both prices cannot be an equilibrium. The bank charging the lower price always had an incentive to deviate to the higher price since the success probability remains unchanged. Payoff dominance for banks together with the IC then ensures that the highest pooling price at which all investors buy results as the unique equilibrium outcome.

If Condition 2 is violated also the low-signal bank wants to set a high price at which only high-signal investors buy. A separating price pair with only high-signal investors buying at both prices cannot be an equilibrium. Again, the bank charging the lower price always had an incentive to deviate. Under payoff dominance only the highest such pooling price survives as the unique equilibrium.
4.2 Equilibrium Price Setting when Spreads Reveal the Firm’s and the Bank’s Identical Information

If an identically informed firm reveals its information, the bank has no more control over the price’s signaling value – the information is already out. We signify this by including a diamond, $\diamond$, instead of $\mu(p)$ in threshold prices $p_{s_i,\diamond,\nu}$. The bank continues to choose the price that, given its private information, maximizes expected profit. Now, however, a low-signal bank can no longer mimic a high-signal bank because investors have inferred the bank’s signal form the spread.

Suppose the firm (and thus also the bank) has signal $s_f = 0$ and spread-information is ‘bad news’, $\nu(\beta) = 0$. Then high-signal investors are not willing to pay more than $p_{1,\diamond,0}$ as risky price at which only high-signal investors buy. Price $p_{0,\diamond,0}$ is the highest safe price at which all investors buy. However, if the spread is high enough, the risk of a failing IPO may still be outweighed by expected potential gains. If $\beta$ is large enough such that

$$\text{risky profits at } p_{1,\diamond,0} \geq \text{riskless profits at } p_{0,\diamond,0} \iff \alpha_{0,0} \beta S p_{1,\diamond,0} - (1 - \alpha_{0,0}) C \geq \beta S p_{0,\diamond,0} \quad (4)$$

then the low-signal bank will choose risky price $p_{1,\diamond,0}$. Denote the minimal spread such that (4) holds by $\beta_0$, where the subscript indicates the bank’s/firm’s signal. The high-signal bank faces a similar choice if spread-information is $\nu(\beta) = 1$. If the spread is too low, it would rather choose a safe price. Here, the highest riskless price is $p_{0,\diamond,1}$, as at this price low-signal investors will buy, given they believe that the bank’s/firm’s signal is ‘good news’. The high-signal bank only chooses risky price $p_{1,\diamond,1}$ if $\beta$ is so large that

$$\text{risky profits at } p_{1,\diamond,1} \geq \text{riskless profits at } p_{0,\diamond,1} \iff \alpha_{1,1} \beta S p_{1,\diamond,1} - (1 - \alpha_{1,1}) C \geq \beta S p_{0,\diamond,1} \quad (5)$$

Using the same notation, the minimal spread such that (5) holds is denoted by $\beta_1$. The
respective threshold spreads are given by

\[ \beta_0 = \frac{1 - \alpha_{\diamond,0}}{\alpha_{\diamond,0}p_{1,0,0} - p_{0,0,0}} \frac{C}{S} \quad \text{and} \quad \beta_1 = \frac{1 - \alpha_{\diamond,1}}{\alpha_{\diamond,1}p_{1,1,1} - p_{0,1,1}} \frac{C}{S}. \]  

(6)

It is straightforward to check that the low signal-spread must be larger than the high-signal spread, \( \beta_0 - \beta_1 = (2(1 - q))^{-1}C/S > 0 \). Consequently, if spreads are separating and sufficiently large, the bank will set risky prices.

5 The Firm’s Strategic Choice of the Gross Spread

As with the bank, the analysis is split into two parts. In the first, the firm is uninformed and thus not involved in strategic signaling. It will set the spread such that the bank sets revenue-maximizing equilibrium prices. In the second part, the firm does have private information, so it is involved in a signaling game. It anticipates the behavior of the bank and the investors, and sets spreads strategically to maximize its expected revenue.

5.1 Equilibrium Spreads if the Firm is Uninformed

For the bank, the choice of equilibrium prices critically depends on Conditions 1 and 2 from Proposition 1. In the following we give an intuitive interpretation of the equilibrium outcome in terms of the gross spread, demonstrating how the spread affects these conditions. We then derive the uninformed firm’s decision about the spread level. As before we indicate that the firm is uninformed by replacing \( \nu \) with a diamond.

**An Intuitive Characterization of the Equilibrium.** The concept of deviation prices \( \phi_{a,0} \) is a convenient tool to describe restrictions. We now reformulate Conditions 1 and 2 from Proposition 1 in terms of the gross spread \( \beta \). This allows us to derive a simple linear descriptive characterization of the equilibrium. Consider first Condition 1,
\( \phi_{1,\diamond}(p_{0,1,\diamond}) \leq p_{1,1,\diamond} \). If \( \beta \) is so low that the condition does not hold,

\[
\phi_{1,\diamond}(p_{0,1,\diamond}) = \frac{p_{0,1,\diamond}}{\alpha_{1,\diamond}} + \frac{1 - \alpha_{1,\diamond}}{\alpha_{1,\diamond}} C \beta S > p_{1,1,\diamond} \tag{7}
\]

then the separating equilibrium cannot be sustained and the pooling equilibrium in \( p_{0,1,\diamond} \) prevails. In other words, if the gross spread is low then the incentive to set a high and thus risky price is reduced whereas the cost of failure remains unchanged. The threshold value for \( \beta \) such that for spreads below this threshold not even the high-signal bank sets a risky price is given by

\[
\beta_s = \frac{1 - \alpha_{1,\diamond}}{\alpha_{1,\diamond} p_{1,1,\diamond} - p_{0,1,\diamond}} C \beta S \tag{8}
\]

Variable \( \beta_s \) thus denotes the lowest uninformative spread such that the two types of bank separate in prices, indicated by subscript \( \diamond \) and superscript \( s \). More generally, from now on the superscript on \( \beta \) indicates what the spread induces the bank to do, the subscript indicates the information conveyed through the spread. Consider now Condition 2, \( \phi_{0,\diamond}(p_{0,0,\diamond}) \geq p_{1,1,\diamond} \). If \( \beta \) is so high that price separation is payoff-dominated

\[
\phi_{0,\diamond}(p_{0,0,\diamond}) = \frac{p_{0,0,\diamond}}{\alpha_{0,\diamond}} + \frac{1 - \alpha_{0,\diamond}}{\alpha_{0,\diamond}} C \beta S < p_{1,1,\diamond} \tag{9}
\]

then a price-separating equilibrium, again, cannot be sustained and the price-pooling equilibrium in \( p_{1,1,\diamond} \) prevails. In this case the gross spread is so high that even the low-signal bank is willing to take the risk of failure and set a high price at which only high-signal investors buy. For the high-signal bank it becomes too costly to uphold separation, i.e. it would have to lower the high separation price so much that it prefers pooling. The lowest uninformative spread such that pooling in a high, risky price results is given by\(^{13}\)

\[
\beta_p = \frac{1 - \alpha_{0,\diamond}}{\alpha_{0,\diamond} p_{1,1,\diamond} - p_{0,0,\diamond}} C \beta S \tag{10}
\]

\(^{13}\)Notice that the lowest spread that induces the bank to pool in a low, riskless price is always zero.
Finally, there exists a $\hat{\beta}_s \in [\beta_s^l, \beta_p^l]$ such that the deviation price of the low-signal bank is just $p_{1,1,o}$, i.e. for values of $\beta$ above $\hat{\beta}_s$ the high-signal bank must lower its high separation price in order to uphold separation. The following Corollary to Proposition 1 summarizes the above characterization. Figure 3 offers an illustration of the corollary.

**Corollary 1 (Proposition 1 in Terms of the Gross Spread)**

If spreads are uninformative and $\beta \in [\beta_s^l, \beta_p^l]$ then the unique equilibrium is the separating equilibrium in Proposition 1. If $\beta \in [\hat{\beta}_s, \beta_s^l]$ then $\bar{p}^* = p_{1,1,o}$, and if $\beta \in (\hat{\beta}_s, \beta_p^l)$ then $\bar{p}^* = \phi_{0,o}(p_{0,0,o})$. If $\beta < \beta_s^l$ pooling in $p_{0,\frac{1}{2},o}$ prevails. If $\beta \geq \beta_p^l$ there is pooling in $p_{1,\frac{1}{2},o}$.

**Strategic Choice of the Gross Spread.** If the firm is uninformed, its strategic choice of spreads conveys no information. For every spread, however, the firm knows the best response of both types of banks. Consequently, the firm has to choose the spread level that maximizes its overall expected payoff. If it sets the spread too low, even a bank with favorable information chooses a low, risk-free price. If spreads are high, the firms get a smaller share of the revenue. Furthermore, for large spreads the high-signal bank may be unable to set a separating price. Payoff dominance for the first mover (the firm) ensures that out of all $\beta$s triggering separation or pooling, the firm will always choose the smallest one. In particular, to get pooling in the risk-free price $p_{0,\frac{1}{2},o}$, the firm can set the spread equal to zero. The firm then has the choice between the following expected profits

$$
(1 - \beta_s^l)\frac{\alpha_{1,o} p_{1,1,o} + p_{0,0,o}}{2} S, \quad p_{0,\frac{1}{2},o} S, \quad \text{and} \quad (1 - \beta_p^l)\frac{\alpha_{0,o} + \alpha_{1,o}}{2} \ p_{1,\frac{1}{2},o} S
$$

in price-separation, low risk-free price-pooling, and high risky price-pooling, respectively. To find the equilibrium spreads, one has to compare the firm’s payoffs for given equilibrium spreads. This leads to the following proposition.
Proposition 2 (Gross Spreads with Uninformed Firms)

There is a unique equilibrium that satisfies the IC and payoff dominance: The uninformed firm offers a contract with $\beta = \beta^p$ and both types of bank set pooling offer price $p_{1,\frac{1}{2},\circ}$.

The choice of $\beta$ follows from the comparison of the respective expected profits. The resulting price-setting by banks follows from Proposition 1. For the result to hold, we thus must have that (i) pooling in $p_{1,\frac{1}{2},\circ}$ is more profitable than separation, i.e.

$$
(1 - \beta^p) \frac{\alpha_{0,\circ} + \alpha_{1,\circ}}{2} p_{1,\frac{1}{2},\circ} S \geq (1 - \beta^s) \frac{\alpha_{1,\circ} p_{1,1,\circ} + p_{0,0,\circ}}{2} S
$$

and (ii) pooling in $p_{1,\frac{1}{2},\circ}$ is more profitable for the firm than pooling in $p_{0,\frac{1}{2},\circ}$, i.e.

$$
(1 - \beta^p) \frac{\alpha_{0,\circ} + \alpha_{1,\circ}}{2} p_{1,\frac{1}{2},\circ} S \geq p_{0,\frac{1}{2},\circ} S.
$$

Making use of the closed form expressions for prices and success probabilities that are derived in Appendix A, there are essentially three free variables: $q$, $N$ and $C$. We treat $C/N$, the costs per potential investors as one variable, since in all payoff conditions they always enter as a ratio. To check our results, both conditions can be described as functions of $C/N$ and $q$. Restricting $\beta$ to be smaller than 10 percent allows to cap the functions that form the restrictions, and it ensures that high, risky pooling is in expectation more profitable than separation. Furthermore, numerically it can easily be checked that if high risky pooling is better than separation, it is also better than low, risk-free pooling. The details are in Appendix B.

5.2 Equilibrium Spreads if the Firm is Independently Informed

Suppose now that the firm gets its own, private signal, $s_f$, conditionally independent from all signals $s_i$ and $s_b$. Then the signaling game has two stages. In the first, the firm may or may not signal its information. Bank and investors incorporate this information. In the second stage, the bank chooses its equilibrium price, which may or may not reveal the
bank’s private signal. The following cases may arise as equilibrium:

1. The firm pools in spreads and the bank separates in prices, pools in a riskless price \( p_{0,0,1} \), or pools in a risky price \( p_{1,1,1} \).

2. The firm separates in spreads, and

   (a) given a low-signal firm \( \nu = 0 \), the bank separates in \( p_{1,1,0} \) or \( p_{0,0,0} \), pools in \( p_{1,0,0} \), or pools in \( p_{0,1,0} \);

   (b) given a high-signal firm, \( \nu = 1 \), the bank separates in \( p_{1,1,1} \) or \( p_{0,0,1} \), pools in \( p_{1,1,1} \), or pools in \( p_{0,1,1} \).

The bank’s equilibrium price setting given the spread-information is covered in Proposition 1, the firm’s optimal spread-choice, anticipating this reaction, is analyzed now.

Analogously to Corollary 1 we can determine threshold levels for the gross spread such that banks just set the low pooling price, separating prices, or the high pooling price. The lowest spread that induces banks to set the low pooling price is \( \beta = 0 \). The two other threshold levels are denoted by \( \beta^s \) for separation and \( \beta^p \) for risky pooling.

The firm’s strategic choice of the spread follows from the comparison of the respective profits. As it turns out, there are no spread-separating equilibria, i.e. firms always pool in the spread. Furthermore, the equilibrium pooling spread induces the bank to play a separating equilibrium in prices.

**Proposition 3 (Gross Spreads with Independently Informed Firms)**

The unique equilibrium is a spread-pooling equilibrium: Both types of firm offer a contract with \( \beta = \beta^s \) and banks separate by setting prices \( p_{1,1,1} \) and \( p_{0,0,1} \). At \( p_{1,1,1} \), investors hold price-spread-information \( \mu = 1 \) and \( \nu = \frac{1}{2} \) and only investors with \( s_i = 1 \) buy. At \( p_{0,0,1} \), investors hold price-spread-information \( \mu = 0 \) and \( \nu = \frac{1}{2} \) and all investors buy.

To prove the claim we proceed counterfactual: We first describe spreads and price-choices in a spread-separating equilibrium and show that such an equilibrium cannot satisfy incentive
compatibility for the low-signal firm — it would always deviate and mimic the high-signal firm. The underlying reason is, that the high firm would set its separating spread so that it induces risky pooling prices; the low signal firm would also set spreads in this manner. But since the risk is the same, a low-signal firm would prefer the higher price that is set with the high-signal firm, a contradiction. Furthermore, the high-signal firm cannot defend its position by setting a spread that induces price-separation (which is less preferred than the price-pooling inducing spread). We then show that only spread-pooling can result. There will be two candidates for spread-pooling: The first spread induces price-pooling, the second price-separation. However, only price-separation satisfies incentive compatibility. Details of the proof are in Appendix B.

5.3 Equilibrium Spreads if the Firm is Identically Informed

If the firm pools in spreads, price setting by the bank is as in Subsection 4.1. If the spread, however, is informative the bank has no strategic considerations in its optimal price choice: Its signal is the same as the firm’s that has just revealed its information. The high-signal bank does not have to defend itself against the low-signal bank. In Subsection 4.2 we have already described the bank’s price setting in this case.

Proposition 4 (Gross Spreads with Identically Informed Firms)

There exists a unique equilibrium which is a spread-separating equilibrium:

(a) The identically informed low-signal firm sets spread $\beta_0$ and the bank sets price $p_{1,o,0}$. 
Investors derive information $\nu(\beta) = 0$, and only those with signal $s_i = 1$ buy.

(b) The identically informed high-signal firm sets spread $\beta_1$ and the bank sets price $p_{1,o,1}$.  
Investors derive information $\nu(\beta) = 1$ and only those with signal $s_i = 1$ buy.

The respective threshold spreads were derived in Subsection 4.2. The proof of the proposition now follows in three steps. First, we derive the conditions under which each type of firm is satisfied with the bank choosing the risky price at the proposed spreads. The conditions ensure that expected payoffs are higher than those from setting zero spreads.
Second, we show that the spreads are proof to deviations, so that no type of firm wants to mimic the other, and no type favors playing out of equilibrium spreads. Third, we show that there cannot be a pooling equilibrium. Details are in Appendix B.

To summarize, if the firm has the identical signal as the bank, it plays a separating equilibrium in which both low- and high-signal firm set spreads at which the bank sets a risky price. Notice that this is the only informationally efficient case where prices contain all existing information. In the case with uninformed firms, banks pool in prices; in the case with independently informed firms, spreads are pooling.

6 Results and Interpretation

In this paper, we address three issues: First, why do banks make positive profits in a competitive market? Second, why do VC backed IPOs have lower spreads? Third, why, as recent evidence shows, are VC backed IPOs more underpriced than non-VC backed IPOs? In the following we argue that our model integrates all there phenomena. Furthermore, we address implications of the model on the level of spreads when a commercial bank conducts the IPO of a former client (‘relationship’ banking).

In Sections 4 and 5 we derived the equilibrium prices and spreads for three different informational scenarios: firms are either uninformed, or independently informed, or identically informed. We will now argue that these three informational scenarios can be reinterpreted as situations with non-VC backed, VC backed, and relationship-banking IPOs, respectively.

6.1 Investment Banking Profits

It is difficult to obtain direct data on banking profits; Chen & Ritter (2000) argue that there are economies of scale in underwriting IPOs, so spreads should be declining in the size of the offer. Yet they don’t — spreads do not differ in offerings with revenue between $20 million and $80 million. Since banks at least break even in small offerings large offerings must be profitable.
In our model, equilibrium spreads allow banks positive profits in all three informational scenarios. The intuition for this result can be seen as follows. Firms have a keen interest that banks set high prices, as they receive almost always more than 90 percent of the revenue. At high prices, however, only high-signal investors buy, rendering such prices risky. Spreads, therefore, have to be sufficiently high so that banks are compensated for the risk of failure. This effect by itself should leave banks only with zero expected profits. However, spreads must be incentive compatible so that banks set high prices and do not deviate to a risk-free low price: Once firms have set the level of the spread, banks can always set a low, riskless price at which all investors buy, so that they receive their revenue share with certainty. A bank’s expected profit, therefore, is always at least what it would gain by deviating to a low risk-free price. It follows that banks earn positive profits.

**Proposition 5 (Positive Profits for Investment Banks)**

*Investment banks enjoy positive profits that will not disappear in the face of competition.*

The second part of the proposition claims that the positive profits would not disappear if there was competition among banks. To see this, suppose that a competing bank offers to conduct the IPO at a lower spread than specified in the initial contract. The firm would not accept: even though it would receive a higher fraction of the revenue, a lower spread would trigger a different equilibrium price, leading to lower payoffs.

In our model, banks have full discretion over the offer price. Firms must, therefore, set incentive compatible spreads. In reality banks do not have full discretion over prices and many offerings fail because firm and bank cannot agree on the offer price.\(^{14}\) However, our qualitative result does not hinge upon the assumption that banks have *full* discretion. Banks have a good deal of power and influence when it comes to price setting, and this is all that is needed for the qualitative result to hold.

Our model provides one explanation why equilibrium spreads may be high and thus why there may be substantial profits for investment banks — but there are also other explanations for this phenomenon. Collusion among banks could be one explanation: Hansen

\(^{14}\)See Busaba, Benveniste & Guo (2001).
(2001), for example, reports that Chen and Ritter’s results triggered a large number of lawsuits over alleged collusion. What our analysis suggests, is that even if banks compete in the spread level, spreads may still be ‘high’.

Furthermore, there is recent evidence on IPO allocation practices\footnote{See Loughran & Ritter (2002), Loughran & Ritter (2004), Goldstein, Irvine, Kandel & Wiener (2006), Nimalendran, Ritter & Zhang (2007), and Reuter (2006).} suggesting that several parties share IPO profits across several offerings.\footnote{For instance, founding shareholders of one issuing firm may receive allocations in another ‘hot’ IPO in return for agreeing to underprice their own IPO.} Consequently, investment banks may have other sources of profits besides the gross spread that we do not model in this paper. Instead, our model argues that even if there were no such other profit opportunities, investment banks would still enjoy positive profits in an competitive equilibrium where all parties involved behave rationally.

### 6.2 Spread Levels

Megginson & Weiss (1991) were the first to report that spreads are significantly lower in VC backed IPOs than in non-VC backed IPOs. They show for their sample of 640 IPOs between 1983 and 1987 that gross spreads for VC backed firms amount to 7.4 percent whereas they are 8.2 percent for non-VC backed firms. Francis & Hasan (2001) also find significant differences (though of smaller magnitude).

Signals provide information about the asset’s true fundamental value. The true liquidation value affects the aftermarket price $p^m$ through the distribution of signals, i.e. if the true value is high, by the law of large numbers, there will be substantially more high than low signals (the reverse if the true value is low). Signals are conditionally i.i.d., unconditionally, however, signals are correlated. That is, if the bank receives, say, a high signal, it updates its belief about the fundamental value and regards it as likely that there will be more investors with the high than with the low signal. In this sense, signals can also be interpreted as information about how the market is going to perceive the fundamental value of the security on offer.
Therefore, it also seems reasonable to assert that a firm, being managed by a technically skilled, yet financially inexperienced founder-owner, is uninformed. Venture capitalists, on the other hand, are financial institutions and so they should be able to assess the market’s valuation. As the venture capitalist usually holds relevant control rights, we interpret the independently informed firm to be a VC backed issuer, whereas we interpret the uninformed firm to be the non-VC backed issuer. Banks hold private information because they closely interact with investors, for example during the road show, and thus are informed about the market’s valuation of the firm on offer.

**Proposition 6 (VC Backed Firms set Lower Gross Spreads)**

*VC backed firms set lower levels of the gross spread than non-VC backed firms.*

To prove this result we have to compare the equilibrium spreads derived in Proposition 3 (independently informed firms = VC backed) with the spreads from Proposition 2 (uninformed firms = non-VC backed). Proposition 3 identifies that in equilibrium, independently informed firms pool in spreads but these spreads induce banks to separate in prices; Proposition 2 shows that uninformed firms offer spreads so that the bank sets a high, risky pooling price. Table 1 summarizes the results from Sections 4 (price-setting) and 5 (spread-choice). Generally speaking, to induce risky price-pooling, firms have to give up a larger share of their revenue than for price-separation, because in risky price-pooling the low-signal bank needs a sufficient incentive to set a risky price.

Table 1 here.

So why do VC backed firms pool in spreads? Intuitively, a VC backed firm with ‘good news’ finds it likely that the bank will also receive ‘good news’, and it wants the bank to confer this information to investors via separating prices. The high-signal VC backed firm also considers it likely that there are enough high-signal investors such that the IPO will not fail at the risky separation price. So it favors price separation. At the same time, however, spread-separation is not an equilibrium: the high-signal VC backed firm’s spread
would be lower than the low-signal firm’s spread and a firm with ‘bad news’ can cheaply mimic the ‘good news’ firm’s behavior. Non-VC backed firms, however, prefer risky price pooling; Proposition 7 below offers one rationale for non-VC backed firms’ behavior because with risky price-pooling, there is on average no underpricing whereas with price-separation, there is.

6.3 Underpricing

Even though underpricing is not the main focus of this paper, the analysis allows predictions about the relative size of first-day returns in different classes of IPOs (VC vs. non-VC backed). In this model underpricing is the difference between the market price $p^m$ and the offer price $p$. In the following we show that our model is consistent with empirically observed patterns of first-day returns, in particular with respect to VC backed issues being more underpriced than non-VC backed issues.\textsuperscript{17}

**Proposition 7 (Underpricing)**

*VC backed issues are on average more underpriced than non-VC backed issues.*

The market price is, by the LLN, almost always either 0 or 1. With offer prices $p \in (0, 1)$ the offer is thus either overpriced and first-day returns are given by $-p$, or it is underpriced and returns are $1 - p$. To prove Proposition 7, we compute the ex-ante combination of these two cases, i.e. the average before signals are being distributed. The threshold offer prices are set so that the lowest investor type who orders breaks even in expectation.

The intuition behind underpricing is as follows: Both types of investors only buy if their expected payoffs are non-negative. Take the case where spreads are uninformative and prices separating (as occurs with VC backed issuers). At $p_{0,0}$ the low-signal investor breaks even in expectation whereas the high-signal investor expects a strictly positive payoff. At $p_{1,1}$ the high-signal investor merely breaks even and the low-signal investor abstains. Ex-ante, that is before receiving a signal, an investor expects to be receiving either a low or

\textsuperscript{17}For instance, Lee & Wahal (2004) show that the differential in underpricing as a proportion of total underpricing is 28 percent.
a high signal. In case of a high signal, he makes an expected profit, with a low signal he breaks even. Thus ex ante, he makes a profit. If the investor makes a profit, the other side must lose money, and thus there is underpricing on average.

Consider now the case where spreads are uninformative and prices risky (as is the case with non-VC backed issues). Then only investors with the favorable signal buy. Prices in this case are defined so that the high-signal types earn zero expected profit (low signal types abstain). Thus there is no underpricing on average.

### 6.4 Strong Commercial Banking Ties

Before going public many companies have strong, long-lasting ties with commercial banks (relationship-banking), for instance through credit-financing. Thus if a commercial bank organizes a long-term client’s IPO, it is reasonable to believe that through these tight bonds the firm and the bank have exactly the same information. Only recently U.S. regulators allowed commercial banks to offer investment banking services, including IPO underwriting. Our model predicts that gross spreads in such IPOs will be, on average, higher than in non-VC backed (uninformed) or VC backed (independently informed) IPOs.

**Proposition 8 (Relationship Banking Spreads are Highest)**

*On average, spread-levels with relationship banking (identically informed firms) are higher than with non-VC backed (uninformed) or VC backed (independently informed) firms.*

Given Proposition 6, we only need to argue why spreads with uninformed firms are smaller than those with firms that receive the same signal as the bank. When the bank and the firm receive the same signal, the firm chooses separating spreads at which banks set high, risky, and separating prices; see also Table 1. A high-signal firm wants to provide a sufficient incentive for the high-signal bank to set a price at which only high-signal investors buy (rather than a low price at which all investors buy). Moreover, the spread must be high enough so that the low-signal firm would not mimic it. A low-signal firm also wants to provide incentives for the low-signal bank to set a risky price. This price, despite being
risky, is low because the spread reveals bad information. As a consequence, in both cases spreads must be large, and this is why spreads with identically informed firms (relationship banking) exceed those with uninformed (non-VC backed) and thus those with privately informed (VC backed) firms.

In the relationship banking case, one may now conjecture that the low-signal firm contemplates abandoning its commercial bank to look for an independent third-party bank, because its equilibrium spread is the highest of all cases. However, in equilibrium this deviation cannot be profitable. The reason is that the replacement of the relationship-bank is publicly observable and the resulting beliefs would render this deviation unprofitable: It is straightforward to see that the high-signal firm would not be interested in this move, because the best that can happen is that it is perceived as a high-signal firm. But then even the highest expected payoff it will get from working with an independent bank is, in expectation, lower than what it gets from its commercial bank: there is the risk that the new bank gets an unfavorable signal and charges the low price. Thus, since the high-signal firm would not replace its relationship-bank, any change of banking-partner would be perceived as coming from a low-signal firm which then would not want to deviate either.

7 Conclusion

In this paper, we proposed a framework to integrate three empirical findings of the literature on IPOs, namely that investment banks earn positive profits in a competitive market, that banks receive lower gross spreads in VC backed than in non-VC backed IPOs, and that there is more underpricing in VC-backed IPOs. We modeled the IPO procedure as a two-stage signaling game. In the second stage banks set offer prices given their private information and the level of the spread. Firms anticipate the bank’s pricing decision and, in the first game stage, set spreads to maximize expected revenue. As a result, firms offer high spreads to induce banks to set high prices, allowing them profits.

The intuition for investment banking profits and spread-setting behavior of firms is
straightforward: Firms tentatively prefer higher prices, even if these are risky. Banks, on the other hand, need an incentive to set high prices, and this incentive is provided by obtaining a sufficiently high fraction of the IPO proceeds. Firms will thus not set low spreads because otherwise the banks would set low, riskless prices. Investors know this process and derive information from it. In the paper we showed how different informational scenarios influence this process and lead to different spread-levels. In particular, we showed that in equilibrium VC-backed issuing firms, which are assumed to be better informed, impose smaller spreads but face larger underpricing than less well informed, non-VC backed firms.

There are without doubt several other forces at work that influence the setting of IPO prices and spreads. For instance, there are repeated interactions between banks and firms (but also investors); also, there may be (implicit) collusion between banks, reputation building of banks (“we don’t do it for less”), or side payments (quid-pro-quo between the issuer and the bank). We abstract from many of these interesting questions to keep the analysis manageable. Instead we focus merely on how (asymmetric) information influences the interaction of the setting of the offer price, the determination of the offer spread, and the order decisions of investors.

References


A Tools Used in the Analysis

Aftermarket Price Formation

An efficient market price aggregates the number of positive and negative signals about the value of the security. The offer demand is published after securities have been issued. If only high-signal investors buy, demand reveals the total number of good (and bad) signals. If all investors order, stated demand is $N$, securities are allocated at random, but demand is uninformative. Still, high-signal investors expect the security to be worth more than low-signal investors and thus high-signal investors without a share-allocation are willing to buy it from low signal investors with an allotment. Without modeling the price-finding procedure explicitly we assume an intermediate market process takes place that reveals the number of high signals $d$. For instance, high-signal investors without a share-allocation submit unit market-buy-orders, low-signal investors with a share-allocation submit unit market-sell-orders. All other investors abstain. Let $\tilde{d}$ be the number buyers and $\tilde{S}$ the number of sellers. Then the number of high-signal investors is $\tilde{d} + S - \tilde{S}$ and the market price $p^m$ will again depend on the number of favorable signals $d$. The updated expectation of $V$ thus becomes the aftermarket price, $p^m(d) = \mathbb{E}[V|d, \mu, \nu] = \Pr(V = 1|d, \mu, \nu)$. The conditional prior distribution over signals has binomial structure, $\Pr(d|V = 1) = \binom{N}{d}q^d(1-q)^{N-d}$. Price-information $\mu$ about $s_b$ and $\nu$ about $s_f$ is unambiguous in a separating equilibrium. We can therefore replace it with the conditional probability of the bank’s and the firm’s
signal being correct, \( q \) or \( 1 - q \). Then, for instance,

\[
p^m(d|\mu = 1, \nu = 0) = \frac{q(1-q)q^{2d-N}}{q(1-q)q^{2d-N} + (1-q)q(1-q)^{2d-N}}. \tag{14}
\]

### Functional Form of Success Probabilities

Variable \( d \) denotes the number of orders, i.e. the number of high-signal investors. Then, conditional on \( V = 1 \), the probability that there are at least \( S \) investors is

\[
\Pr(d \geq S|B_1) = \sum_{d=S}^{N} \binom{N}{d} q^d (1-q)^{N-d}, \tag{15}
\]

analogously for \( V = 0 \). A bank with signal \( s_b \) assigns probability \( \alpha_{s_b,\nu}(S) \) to the event that at least \( S \) investors have the favorable signal. If the bank has signal \( s_b \) and spread information \( \nu \), then

\[
\alpha_{s_b,\nu}(S) = \sum_{d=S}^{N} \binom{N}{d} \left( \Pr(V = 1|s_b, \nu) \cdot q^d (1-q)^{N-d} + \Pr(V = 0|s_b, \nu) \cdot (1-q)^d q^{N-d} \right). \tag{16}
\]

Assumptions 1 and 2 then imply the success probabilities at high, risky prices as summarized in Table 2.

---

### Table 2 here.

---

### Threshold Prices

Denote by \( p_{s_i,\mu,\nu} \) the maximum price at which an investor with signal \( s_i \) and price information \( \mu \) and spread information \( \nu \) buys, given all investors with \( \tilde{s}_i \geq s_i \) buy. At this price the investor’s expected return from buying the security is zero, normalizing outside investment opportunities accordingly.

Define \( \psi(1|1,1,\nu) := \Pr(V = 1|s_i = 1, \mu = 1, \nu) \) and \( \psi(0|1,1,\nu) := \Pr(V = 0|s_i = 1, \mu = 1, \nu) \). Consider now the structure of the conditional distribution \( f(d-1|V) \). For \( V = 1 \), this is a binomial distribution over \( \{0, \ldots, N-1\} \) with center \((N-1)q\), and likewise
for \( V = 0 \) with center \((N - 1)(1 - q)\). Since by Assumption 2, \( N \) is ‘large enough’ for every \( q \), \( f(d - 1|1) = 0 \) for \( d < N/2 \) and \( f(d|0) = 0 \) for \( d > N/2 \). When combining both \( f(d - 1|1) \) and \( f(d - 1|0) \), we obtain a bi-modal function. Knowing \( f(d - 1|V) \), we can find the probability that \( d - 1 \) other have a favorable signal to be

\[
g(d|s_i, \mu(p), \nu(\beta)) := \sum_{V \in \mathcal{V}} \Pr(V|s_i, \mu(p), \nu(\beta)) \cdot f(d|V).
\]  

(17)

Thus in \( g(\cdot|s_i, \mu, \nu) \), investors’ posterior distribution over demands, \( f(d - 1|1) \) and \( f(d - 1|0) \) are weighted with \( \psi(1|s_i, \mu, \nu) \) and \( \psi(0|s_i, \mu, \nu) \). Assumption 2 now satisfies two purposes. The first is to ensure that we pick \( N \) large enough, so that the two modes do not overlap. The second can be seen as follows.

**Lemma 2** For any \( q > \frac{1}{2} \), there exists a number of investors \( N(q) \), such that \( p^m(d) \cdot g(d|s_i, \mu, \nu) \in \{0, g(d|s_i, \mu, \nu)\} \) almost everywhere.

The lemma states that market prices are mostly 0 or 1, if they are not, then the weight of this demand is negligible. To see this consider the following heuristic argument.

**Proof:** \( p^m(d) \) is a s-shaped function in \( d \), given by equation (14). For large \( N \), \( p^m(d) \in \{0, 1\} \) almost everywhere. Define \( \mathbb{I}^* \) as the interval of \( d \) around \( N/2 \) s.t. for \( d \in \mathbb{I}^* \) we have \( p^m(d) \notin \{0, 1\} \). \( p^m(d) \) is multiplied with density \( g(d|s_i, \mu, \nu) \), which peaks at \((N - 1)(1 - q)\) and \((N - 1)q\). For \( N \) increasing \( \mathbb{I}^*/N \to 0 \) and the bi-modal distribution becomes more centered around \((N - 1)(1 - q)\) and \((N - 1)q\). Hence, for every \( q \) there is an \((N - 1)(q)\) such that for \( d \in \mathbb{I}^* \), \( g(d|s_i, \mu, \nu) \cdot p^m(d) = 0 \), i.e. the weight on \( p^m(d) \notin \{0, 1\} \) can be made arbitrarily small. □

If only investors with favorable signals order, then for a high-signal investor, at price \( p \) his rational-expectation payoff from buying has to be non-negative,

\[
\sum_{d=S}^{N-1} \frac{S}{d} \cdot (p^m(d) - p) \cdot g(d - 1|s_i = 1, \mu(p), \nu(\beta)) \geq 0.
\]  

(18)

Likewise for the respective low-signal investors when all investors order in which case the
summation runs from 1 to \( N \), and \( s_i = 1 \) is replaced by \( s_i = 0 \).

Using Lemma 2 we can determine the threshold prices as follows. Consider first \( p_{1,1,\nu} \).

\[
0 = (1 - p_{1,1,\nu}) \sum_{d=N/2}^{N-1} \frac{S}{d+1} g(d-1|1,1,\nu) - p_{1,1,\nu} \sum_{d=s-1}^{N/2} \frac{S}{d+1} g(d-1|1,1,\nu)
\]

\[
\Leftrightarrow p_{1,1,\nu} = \sum_{d=N/2}^{N-1} \frac{S}{d+1} g(d-1|1,1,\nu) / \sum_{d=s-1}^{N/2} \frac{S}{d+1} g(d-1|1,1,\nu). \tag{19}
\]

For \( d > N/2 \), \( g(d-1|\cdot) = \psi(1|\cdot) f(d-1|1) \) and for \( d < N/2 \), \( g(d-1|\cdot) = \psi(0|\cdot) f(d-1|0) \).

Also define

\[
\Sigma_0 := \sum_{d=s-1}^{N/2} \frac{f(d-1|0)}{d+1} \quad \text{and likewise} \quad \Sigma_1 := \sum_{d=N/2}^{N-1} \frac{f(d-1|1)}{d+1}, \quad \text{and} \quad \sigma := \Sigma_0 / \Sigma_1. \tag{20}
\]

Write \( \ell(\mu, \nu) := \psi(0|1,\mu,\nu) / \psi(1|1,\mu,\nu) \). Thus for the combination of signal \( s_i \), price-information \( \mu \) and spread-information \( \nu \) with \( B_1 \) we have

\[
p_{1,1,\nu} = (1 + \sigma \ell(1,\nu))^{-1} \quad \text{and likewise} \quad p_{1,1,\nu} = (1 + \sigma \ell(1,\nu))^{-1}. \tag{21}
\]

Consider now the case for \( p_{0,0,\nu} \). At this price all agents receive the security with equal probability and we sum from 0 to \( N-1 \). Thus

\[
0 = (1 - p_{0,0,\nu}) \sum_{d=N/2}^{N-1} \frac{S}{N} g(d-1|0,0,\nu) - p_{0,0,\nu} \sum_{d=0}^{N/2} \frac{S}{N} g(d-1|0,0,\nu)
\]

\[
\Leftrightarrow p_{0,0,\nu} = \psi(1|0,0,\nu). \tag{22}
\]

Likewise we have

\[
p_{0,1,\nu} = \psi(1|0,\frac{1}{2},\nu). \tag{23}
\]
Approximate Closed Form Solutions

We will now derive approximate closed form solutions so that we can solve our model analytically. In this appendix we let \( d \) denotes the number of other investors with favorable information — this contrasts the exposition of the main text, but it simplifies the notation here. First consider the strategy of agent number \( N \). There are \( N - 1 \) other investors. Given that he invests and the true value is, say, \( V = 1 \), then by the law of large numbers, demand/the number of favorable signals will always be larger than \( N/2 \). Furthermore, the market price is almost surely \( p_m(d) = 1 \). If \( d \) others order, then when buying he gets the asset with probability \( 1/(d+1) \). Thus his payoff for price \( p \)

\[
(1 - p) \sum_{d=(1-q)N-1}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^d (1-q)^{N-1-d} = (1 - p) \sum_{d=N/2}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^d (1-q)^{N-1-d}. \tag{24}
\]

To compute the sum we proceed in a similar manner as one would to compute the expected value of a binomial distribution: First observe that because \( N \) is large,

\[
\sum_{d=N/2}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^d (1-q)^{N-1-d} = \sum_{d=0}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^d (1-q)^{N-1-d} \tag{25}
\]

Then we can compute

\[
\sum_{d=0}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^d (1-q)^{N-1-d} = \frac{1}{qN} \sum_{d=0}^{N-1} \frac{N!}{(N-(d+1))!(d+1)!} q^{d+1} (1-q)^{N-1-d}
\]

\[
= \frac{1}{qN} \left( \sum_{l=0}^{N} \binom{N}{l} q^l (1-q)^{N-l} - \binom{N}{0} q^0 (1-q)^{N-0} \right) = \frac{1}{qN} (1 - (1-q)^N). \tag{26}
\]

In the second step we made a change of variable, \( l = d + 1 \), but through this change, we had to subtract the element of the sum for \( l = 0 \). Consequently, for large \( N \), we have

\[
\sum_{d=N/2}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^d (1-q)^{N-1-d} \approx \frac{1}{qN}. \tag{27}
\]
Using the same arguments, we could also show that

\[
\sum_{d=0}^{N-1} \frac{1}{d+1} \binom{N-1}{d} q^{N-1-d} (1-q)^d \approx \frac{1}{(1-q)N}. \tag{28}
\]

Use now familiar notation to denote the combination of private and public beliefs \(\phi_{s,\mu}\).

For the time being, assume the firm is uninformed so that \(\nu\) is replaced with a diamond. Recall that we can write \(p_{1,1,\diamond}\) as

\[
p_{1,1,\diamond} = \left(1 + \ell(1, \diamond) \frac{\Sigma_0}{\Sigma_1}\right)^{-1}. \tag{29}
\]

What we now need to find is a closed form for

\[
\Sigma_0 = \sum_{d=N(1-q)-1}^{N/2} \frac{1}{d+1} \binom{N-1}{d} q^{N-1-d} (1-q)^d. \tag{30}
\]

For increasing \(N\) one can see that \((1/(d+1)) \binom{N-1}{d} q^{N-1-d} (1-q)^d\) gets numerically symmetric around \((1-q)N - 1\). Thus we can express

\[
\Sigma_0 = \frac{1}{2} \sum_{d=0}^{N/2} \frac{1}{d+1} \binom{N-1}{d} q^{N-1-d} (1-q)^d
\]

\[
= \frac{1}{2} \sum_{d=0}^{N} \frac{1}{d+1} \binom{N-1}{d} q^{N-1-d} (1-q)^d \approx \frac{1}{2} \frac{1}{(1-q)N}. \tag{31}
\]

We obtain

\[
p_{1,1,\diamond} = \left(1 + \ell(1, \diamond) \frac{\Sigma_0}{\Sigma_1}\right)^{-1} \approx \left(1 + \frac{(1-q)^2}{q^2} \frac{qN}{2(1-q)N}\right)^{-1} = \frac{2q}{1+q} = \frac{q}{\alpha_{1,\diamond}}. \tag{32}
\]

Equivalently, we get

\[
p_{1,\frac{1}{2},\diamond} \approx \left(1 + \frac{1-q}{q} \frac{qN}{2(1-q)N}\right)^{-1} = \frac{2}{3}, \quad \text{and} \quad p_{1,0,\diamond} \approx \frac{1-q}{\alpha_{0,\diamond}}. \tag{33}
\]

The information content of a high pooling price is 1/2, and knowing this information,
the probability of the offering being successful is 3/4. Thus the interpretation of risky prices is thus the ratio of the expected liquidation value given price- and spread-information to the share of successful offerings given this information

$$p_{1,\mu,\nu} = \frac{\Pr(V = 1 \mid \mu, \nu)}{\Pr(\text{IPO successful} \mid \mu, \nu)}.$$  (34)

Table 3 summarizes the approximate closed form solutions of the different prices that can occur.

**Table 3 here.**

**B  Omitted Proofs**

**Proof of Lemma 1**

Suppose $p^* > p_{0,0,\nu}$. At this price only investors with signal $s_i = 1$ buy. A high-signal bank will always set a price where at least investors with signal $s_i = 1$ buy. Hence, investors with signal $s_i = 1$ buy at both prices $p^*$ and $\bar{p}^*$. A low-signal bank can now increase its payoff by setting a higher price because $\alpha_{0,\nu}$ is not affected by this, a contradiction. □

**Proof of Proposition 1**

(a) First we show that given Conditions 1 and 2 the only separating equilibrium surviving the intuitive criterion (IC) is the one outlined in Proposition 1(a). We then argue that pooling cannot occur.

**Step 1 (Separating):** First observe that there cannot be a separating price $\bar{p}^*$ with $B_{0,1}$ as otherwise the low-signal bank would deviate to this price. Note that no separating price with $\bar{p}^* < \phi_{0,\nu}(p_{0,0,\nu})$ can exist because at this price, the low-signal bank would prefer to deviate. No price $\bar{p}^* > p_{1,1,\nu}$ can exist since not even investors with $s_i = 1$ would buy. Furthermore, $\bar{p}^* \geq \phi_{1,\nu}(p_{0,0,\nu})$ must be satisfied since otherwise the high-signal bank would deviate to $p_{0,0,\nu}$. Finally no price $\bar{p}^*$ below $p_{1,0,\nu}$ is possible as the high-signal bank would
deviate to this price. Take \( \tilde{p} \), with \( \max\{\phi_{1,\nu}(p_{0,0,\nu}), p_{1,0,\nu}\} \leq \tilde{p} \leq \min\{p_{1,1,\nu}, \phi_{0,\nu}(p_{0,0,\nu})\} \).

Note that such a \( \tilde{p} \) always exists as long as \( \phi_{1,\nu}(p_{0,0,\nu}) \leq p_{1,1,\nu} \) and \( p_{1,0,\nu} \leq \phi_{0,\nu}(p_{0,0,\nu}) \).

Conditions 1 and 2 ensure this is the case because \( \phi_{1,\nu}(p_{0,0,\nu}) > \phi_{1,\nu}(p_{0,0,\nu}) \) and \( p_{1,0,\nu} > p_{1,0,\nu} \).

We analyze the candidate separating equilibrium

\[
\{(p^* = p_{0,0,\nu}, \mu = 0, B_0, 1); (\bar{p}^* = \tilde{p}, \mu = 1, B_1); \\
(p^* \not\in \{(p^*, \bar{p}^*), \mu = 0, B_0, 1 \text{ if } p \leq p_{0,0,\nu}, B_1 \text{ if } p_{0,0,\nu} < p \leq p_{1,0,\nu}, B_0 \text{ else})\}\}
\]

By definition of \( \phi_{0,\nu}(p_{0,0,\nu}) \) it holds that

\[
\beta_{p_{0,0,\nu}} = \alpha_{0,\nu} \beta_{\phi_{0,\nu}(p_{0,0,\nu})} - (1 - \alpha_{0,\nu})C > \alpha_{0,\nu} \beta \tilde{p} S - (1 - \alpha_{0,\nu})C
\]

so that the low-signal bank would not deviate to \( \tilde{p} \). Since \( \max\{\phi_{1,\nu}(p_{0,0,\nu}), p_{1,0,\nu}\} \leq \tilde{p} \), also the high-signal bank would not deviate. Hence this is a PBE.

Now consider the application of the IC. Suppose a high separation price \( \tilde{p} = \tilde{p} \) is observed, where we have \( \tilde{p} < \tilde{p} \leq \min\{p_{1,1,\nu}, \phi_{0,\nu}(p_{0,0,\nu})\} \). This price is equilibrium dominated for a low-signal bank by definition of \( \phi_{0,\nu}(p_{0,0,\nu}) \). This bank can thus be excluded from the set of potential deviators. The only remaining agent is the high-signal bank. The best response of high-signal investors is then to buy at \( \tilde{p} \). Hence the PBE with \( p^* = \tilde{p} \) does not survive the IC. Applying this reasoning repeatedly, all separating prices with \( \tilde{p} < \min\{p_{1,1,\nu}, \phi_{0,\nu}(p_{0,0,\nu})\} \) can be eliminated.

**Step 2 (Pooling with \( B_{0,1} \)):** For all investors to buy we must have \( p \leq p_{0,0,\nu} \). Suppose there was deviation to \( p = \phi_{1,\nu}(p_{0,0,\nu}) \). For the low-signal bank this would not be profitable by definition of \( \phi_{0,\nu}(p_{0,0,\nu}) \). But for some beliefs about the bank’s signal and corresponding best responses, investors with \( s_b = 1 \) could be better off. The best response for investors with beliefs on the remaining set of types, i.e. \( \mu = 1 \), however, is \( B_1 \) as we have \( \phi_{1,\nu}(p_{0,0,\nu}) < p_{1,1,\nu} \). Hence, applying the IC, there cannot be a pooling equilibrium with \( B_{0,1} \).
Step 3 (Pooling with $B_1$): We must have $p \leq p_{1, 1, \nu}$. Since $\phi_{0, \nu}(p_{0, 0, \nu}) \geq p_{1, 1, \nu}$, the low-signal bank would prefer to deviate to $p_{0, 0, \nu}$, hence this cannot be an equilibrium.

(b) We first argue that if Condition 1 is not fulfilled each separating equilibrium is payoff dominated by pooling in the riskless price. Then we show that also a pooling price with $B_1$ is payoff dominated. We finally argue that among all PBE pooling equilibrium prices with $B_{0,1}$, only the one outlined in Proposition 1 is payoff dominant.

Step 1 (Separating): If Condition 1 is not fulfilled we have

$$\beta p_{0, \frac{1}{2}, \nu}S = \alpha_{1, \nu} \beta \phi_{1, \nu}(p_{0, \frac{1}{2}, \nu})S - (1 - \alpha_{1, \nu})C > \alpha_{1, \nu} \beta p_{1, 1, \nu}S - (1 - \alpha_{1, \nu})C$$

so the high-signal bank prefers pooling in $p_{0, \frac{1}{2}, \nu}$ to the highest possible separation price $p_{1, 1, \nu}$. Likewise, since $p_{0, \frac{1}{2}, \nu} > p_{0, 0, \nu}$ the riskfree pooling price generates higher payoffs for the low-signal bank. Separation is thus always payoff dominated.

Step 2 (Pooling with $B_1$): Since the high-signal bank can profitably deviate from $p_{1, 1, \nu}$ it can do so from $p_{1, \frac{1}{2}, \nu} < p_{1, 1, \nu}$. Pooling with $B_1$ can thus be no equilibrium.

Step 3 (Pooling with $B_{0,1}$): Not even the high-signal bank wants to set a price where only high-signal investors buy. Candidate prices for an equilibrium are thus only prices with $B_{0,1}$. Consider $p = \tilde{p} < p_{0, \frac{1}{2}, \nu}$. Since both types of banks would prefer $p = \tilde{p}$ with $\tilde{p} < \tilde{p} < p_{0, \frac{1}{2}, \nu}$ Pareto-efficiency prescribes that investors must hold $\mu = \frac{1}{2}$ and thus all investors will buy at $p = \tilde{p}$. Applying this reasoning repeatedly, all prices with $p < p_{0, \frac{1}{2}, \nu}$ can be eliminated.

(c) We first argue that if Condition 2 is not fulfilled every separating equilibrium is payoff dominated. We then argue that the only pooling equilibrium with $B_1$ is the one outlined in Proposition 1. We finally show that pooling with $B_{0,1}$ cannot be an equilibrium.

Step 1 (Separating): Since Condition 2 does not hold we have

$$\beta p_{0, 0, \nu}S = \alpha_{0, \nu} \beta \phi_{0, \nu}(p_{0, 0, \nu})S - (1 - \alpha_{0, \nu})C < \alpha_{0, \nu} \beta p_{1, 1, \nu}S - (1 - \alpha_{0, \nu})C$$

\[37\]
so the low-signal bank will mimic the high-signal bank at any price $\tilde{p} \geq \phi_{0,\nu}(p_{0,0,\nu})$. To uphold separation the high-signal bank must lower its price below $\phi_{0,\nu}(p_{0,0,\nu}) < p_{1,\frac{1}{2},\nu}$. However, a high separation price below $p_{1,\frac{1}{2},\nu}$ cannot be a payoff dominant equilibrium since both types of banks would prefer pooling price $p_{1,\frac{1}{2},\nu}$. There can thus be no separating equilibrium.

**Step 2 (Pooling with $B_1$):** From Step 1 we know that both types of bank prefer pooling in $\tilde{p} \in [\phi_{0,\nu}(p_{0,0,\nu}), p_{1,\frac{1}{2},\nu}]$ even to the separating equilibrium with the highest possible $\bar{p}$. Consider the candidate pooling price $\tilde{p}$ with $\tilde{p} < \tilde{p} < p_{1,\frac{1}{2},\nu}$. Since both types prefer $\tilde{p}$ to $\bar{p}$ payoff dominance prescribes $\mu = 0.5$ and thus $\tilde{p}$ cannot be an equilibrium. Applying this reasoning repeatedly, all prices with $p < p_{1,\frac{1}{2},\nu}$ can be eliminated. Therefore, the only pooling equilibrium surviving is the one depicted in Proposition 1.

**Step 3 (Pooling with $B_{0,1}$):** Suppose, for the moment being, that $p_{0,\frac{1}{2},\nu}$ is an equilibrium, supported by out-of-equilibriums belief that any deviation is by a low-signal bank. Then consider a deviation to $\phi_{1,\nu}(p_{0,\frac{1}{2},\nu})$. Naturally, $\phi_{1,\nu}(p_{0,\frac{1}{2},\nu}) < \phi_{0,\nu}(p_{0,\frac{1}{2},\nu})$, and thus, applying the IC, this deviation can only be triggered by a high-signal bank. It is straightforward to check that, numerically, a violation of Condition 2 implies that Condition 1 holds, i.e. $\phi_{1,\nu}(p_{0,\frac{1}{2},\nu}) < p_{1,1,\nu}$. Furthermore,

$$\phi_{1,\nu}(p_{0,\frac{1}{2},\nu}) = \frac{p_{0,\frac{1}{2},\nu}}{\alpha_{1,\nu}} + \frac{1 - \alpha_{1,\nu}}{\alpha_{1,\nu}} \frac{C}{\beta S},$$

which is increasing in costs $C$. $\underline{C} = \beta S(\alpha_{0,\nu} p_{0,\frac{1}{2},\nu} - p_{0,0,\nu})/(1 - \alpha_{0,\nu})$ is the largest $C$ so that Condition 2 just holds. Any $C$ violating Condition 2 is smaller than $\underline{C}$. Numerically then $\phi_{1,\nu}(p_{0,\frac{1}{2},\nu}) < p_{1,\frac{1}{2},\nu}$, thus payoff dominance holds. □
Proof of Proposition 2

To prove the result we first show that pooling in \( p_{1,\frac{1}{2},0} \) is more profitable than separation, i.e.

\[
(1 - \beta_s^p) (\alpha_{0,0} + \alpha_{1,0}) p_{1,\frac{1}{2},0} > (1 - \beta_s^s) (\alpha_{1,0} p_{1,1,0} + p_{0,0,0})
\]

\[
\Leftrightarrow C/N < 2q(2q - 1)^2(1 - q)^2(1 + q - q^2)/(-1 + 4q - 9q^2 + 19q^3 - 25q^4 + 17q^5 - 2q^6). (39)
\]

Second, we show that pooling in \( p_{1,\frac{1}{2},0} \) is more profitable than pooling in \( p_{0,\frac{1}{2},0} \), i.e.

\[
(1 - \beta_s^p) (\alpha_{0,0} + \alpha_{1,0}) p_{1,\frac{1}{2},0}/2 > p_{0,\frac{1}{2},0}
\]

\[
\Leftrightarrow C/N < 2(2q - 1)(1 - q)(-1 + q + 3q^2 - 2q^3)/3q(1 - 2q + 2q^2). \quad (40)
\]

The above transformations make use of the closed form expressions for prices and success probabilities that are derived in Appendix A. Requiring \( \beta < 0.1 \) allows to cap the functions that form the restrictions. The highest spread that arises in equilibrium is \( \beta_0 \) as derived in Section 4.2. It induces the identically informed low-signal bank to set the risky price. Requiring \( \beta_0 < 0.1 \) translates into requiring

\[
C/N < (4q - 1 - 5q^2 + 2q^3)/5(1 - 2q + 2q^2) =: R_0(q). \quad (41)
\]

Numerically it is easy to check that for \( q \in (.6, 1) \), \( C/N < R_0(q) \) is sufficient for (39) and (40) to hold.

Proof of Proposition 3

To prove the result, we proceed in five steps: First, we derive the firm’s payoff maximizing spread, given spreads are separating. This step serves as benchmark for comparing deviation payoffs. Second, we show that the low-signal firm would always mimic the high-signal firm’s spread choice. Third, we show that the high-signal firm cannot defend separation in
spreads: neither price-separation nor price-pooling inducing spreads can be upheld. Forth, we show that there are two candidate spread-pooling equilibria. Fifth, we finally argue that only the price-separation inducing spread satisfies the Intuitive Criterion (IC).

Table 4 shows how a firm computes expected payoffs. The results can only be obtained numerically as payoffs are complicated polynomials that cannot be expressed in a simple, intuitive form. Throughout the proof we require, for \( q \in (0.6, 1) \), that \( C/N < R_0(q) \) as derived in the proof of Proposition 2.

Table 4 here.

Let \( \beta^s_1 (\beta^p_1) \) denote the lowest spread that yields separation (high pooling) given spread-information \( \nu \). Spreads are computed in the same way as demonstrated in Subsection 5.1 and are given as follows.

\[
\begin{align*}
\beta^s_1 &= \frac{1 - \alpha_{1,1}}{\alpha_{1,1}p_{1,1,1} - p_{0,0,1}} \frac{C}{S}, \\
\beta^s_0 &= \frac{1 - \alpha_{0,1}}{\alpha_{0,1}p_{1,1,0} - p_{0,0,0}} \frac{C}{S}, \\
\beta^p_1 &= \frac{1 - \alpha_{1,0}}{\alpha_{1,0}p_{1,0,1} - p_{0,0,1}} \frac{C}{S}, \\
\beta^p_0 &= \frac{1 - \alpha_{0,0}}{\alpha_{0,0}p_{1,0,0} - p_{0,0,0}} \frac{C}{S}
\end{align*}
\]

Step 1 (Separating Spreads): Suppose first that the spread is separating and indicates \( s_f = 1 \), i.e. \( \nu = 1 \). The firm has the choice between expected profits in separation, low riskless pooling, and high risky pooling. For given parameters \( q, C, N \), the firm will always choose the spread with maximal expected payoffs. Pooling in \( p_{1,1,1} \) is better than separation in \( p_{1,1,1} \) and \( p_{0,0,1} \) if

\[
(1 - \beta^p_1) \alpha_1 p_{1,1,1} > (1 - \beta^s_1) \left((q^2 + (1 - q)^2/2)p_{1,1,1} + 2q(1 - q)p_{0,0,1}\right)
\]

(42)

and pooling in \( p_{1,1,1} \) is better than pooling in \( p_{0,0,1} \) if

\[
(1 - \beta^p_1) \alpha_1 p_{1,1,1} > p_{0,0,1}.
\]

(43)

As explicitly shown in the proof of Proposition 2, the two inequalities translate into re-
restrictions of the form \( C/N < R(q) \). Numerically, it is straightforward to check that both inequalities hold if \( C/N < R_0(q) \).

Suppose now that the spread triggers \( \nu = 0 \). Again, we have to compare expected profits. Pooling in \( p_{1,\frac{1}{2},0} \) is better than separation in \( p_{1,1,0} \) and \( p_{0,0,0} \) if

\[
(1 - \beta_0^p) \alpha_0 p_{1,\frac{1}{2},0} > (1 - \beta_0^s) \left( (3/2) q(1 - q)p_{1,1,0} + (q^2 + (1 - q)^2)p_{0,0,0} \right)
\]  

(44)

and pooling in \( p_{1,\frac{1}{2},0} \) is better than pooling in \( p_{0,\frac{1}{2},0} \) if

\[
(1 - \beta_0^p) \alpha_0 p_{1,\frac{1}{2},0} > p_{0,\frac{1}{2},0}.
\]

(45)

Again, (44) and (45) hold if \( C/N < R_0(q) \). Thus if spreads are separating, inducing high price-pooling is better than both price-separation and low price-pooling — irrespective of the spread-information.

**Step 2 (Spread Mimicking):** We now show that the low-signal firm will always mimic the high-signal firm, and that defending separation is too costly. It is profitable to mimic the high-signal firm in \( \beta_1^p \) if

\[
(1 - \beta_1^p) \alpha_0 p_{1,\frac{1}{2},1} > (1 - \beta_0^p) \alpha_0 p_{1,\frac{1}{2},0}.
\]

(46)

Numerically the deviation profit is always higher, i.e. spread-separating in \( \beta_1^p, \beta_0^p \) cannot be an equilibrium.

**Step 3 (Defending Separating Spreads):** The high-signal firm’s defenses against mimicking have to be analyzed for any of the three candidate equilibria: high price-pooling inducing \( \beta_1^p \), price-separating inducing \( \beta_1^s \), and low price-pooling inducing \( \beta = 0 \) would be defended by setting higher \( \beta \)s. However, none of these turn out to be feasible.

(i) Defending Price-Separation: The lowest spread \( \tilde{\beta} \) for which the low-signal firm will
not mimic the price-separation inducing spread any longer, is given by

\[(1 - \tilde{\beta}) \left( (3/2) q(1 - q)p_{1,1,1} + (q^2 + (1 - q)^2)p_{0,0,1} \right) = (1 - \beta_0^p) \alpha_0 p_{1, \frac{1}{2}, 0}. \] (47)

(ii) Defending Risky Price-Pooling: If the high-signal firm sets \( \tilde{\beta} > \beta_1^p \) the low-signal firm will no longer mimic if

\[(1 - \tilde{\beta}) \alpha_0 p_{1, \frac{1}{2}, 1} = (1 - \beta_0^p) \alpha_0 p_{1, \frac{1}{2}, 0}. \] (48)

(iii) Defending Riskless Price-Pooling: If the high-signal firm sets \( \tilde{\beta} \in (0, \beta_1^s) \) the low-signal firm will no longer mimic if

\[(1 - \tilde{\beta}) p_{0, \frac{1}{2}, 1} = (1 - \beta_0^p) \alpha_0 p_{1, \frac{1}{2}, 0}. \] (49)

Solving for \( \tilde{\beta} \), numerically, in all three cases it exceeds by far 10 percent. Thus, there is no spread-separating equilibrium.

**Step 4 (Pooling Spreads):** As usual, there are three candidate pooling spreads: \( \beta = 0, \beta_1^s \) and \( \beta_1^p \). It turns out that expected profits at \( \beta = 0 \) are dominated by those at the other two spreads. Consider first the high-signal firm. Price-separation is preferred to riskless price-pooling if

\[(1 - \beta_1^s) \left( (q^2 + (1 - q)^2/2)p_{1,1, \frac{1}{2}} + 2q(1 - q)p_{0,0, \frac{1}{2}} \right) > p_{0, \frac{1}{2}, \frac{1}{2}}. \] (50)

and risky price-pooling is preferred to risk-free price-pooling if

\[(1 - \beta_1^p) \alpha_1 p_{1, \frac{1}{2}, \frac{1}{2}} > p_{0, \frac{1}{2}, \frac{1}{2}}. \] (51)

Both inequalities hold numerically, given \( C/N < R_0(q) \). However, price-separation is preferred to risky price-pooling if

\[(1 - \beta_1^s) \left( (q^2 + (1 - q)^2/2)p_{1,1, \frac{1}{2}} + 2q(1 - q)p_{0,0, \frac{1}{2}} \right) > (1 - \beta_1^p) \alpha_1 p_{1, \frac{1}{2}, \frac{1}{2}}. \] (52)
which, given $C/N < R_0(q)$, holds only for, roughly, $q > .78$. For smaller $q$, risky price-pooling is preferred.

Consider now the low-signal firm. Risky price-pooling is preferred to riskless price-pooling if

$$\left(1 - \beta^p \frac{q}{2}\right) \alpha_0 p_{1,1,1,1} > p_{0,0,0,0,1} \quad (53)$$

and risky price-pooling is preferred to price-separation if

$$\left(1 - \beta^p \frac{q}{2}\right) \alpha_0 p_{1,1,1,1} > \left(1 - \beta^s \frac{q}{2}\right) \left((3/2) q(1 - q)p_{1,1,1,1} + ((1 - q)^2 + q^2)p_{0,0,0,0,1}\right). \quad (54)$$

Both inequalities hold numerically, given $C/N < R_0(q)$.

**Step 5 (Equilibrium Selection):** Thus there are two candidates for spread-pooling equilibria. Conveniently, however, spread $\beta^p \frac{q}{2}$ fails the IC. To see this, define $\hat{\beta}(q)$ to be the spread for given $q$ such that the low-signal firm does not want to deviate from $\beta^p \frac{q}{2}$, even if it was perceived to be the high-signal firm. Suppose a deviation to a price-separation inducing spread. Then $\hat{\beta}(q)$ must be such that

$$\left(1 - \hat{\beta}(q)\right) \left((3/2) q(1 - q)p_{1,1,1,1} + ((1 - q)^2 + q^2)p_{0,0,0,0,1}\right) < \left(1 - \beta^p \frac{q}{2}\right) \alpha_0 p_{1,1,1,1} \quad (55)$$

Numerically, for $q > 0.72$, $\hat{\beta}(q)$ can be set to $\beta^s \frac{q}{2}$; for smaller $q$, it has to be larger. However, for all $q$ it holds that $\hat{\beta} < \beta^s \frac{q}{2} = (1 - \alpha_{0,1})C/(\alpha_{0,1}p_{1,1,1,1} - p_{0,0,1})S$, where $\beta^s \frac{q}{2}$ is the spread so that the low-signal bank is indifferent between choosing $p_{1,1,1,1}$ and $p_{0,0,1}$. (Recall that for higher spreads the high-signal bank lowers the high separation price to $\phi_{0,1}(p_{0,0,1})$; see Figure 3.) Consequently, every such $\hat{\beta}(q)$ induces price-separation with $p_{1,1,1,1}$ and $p_{0,0,1}$. Furthermore, numerically for all $q$, the high-signal firm prefers to deviate to $\hat{\beta}(q)$ if it is perceived to be the high type. Hence there is a deviation that, in the best of all worlds for beliefs, is only profitable for the high-signal firm, thus $\beta^p \frac{q}{2}$ fails the IC.

Consider now the price-separation inducing pooling spread and construct the same
deviation $\tilde{\beta}(q)$ as above. It turns out, however that for every $q$ and every $\tilde{\beta} < 10\%$,

\[(1 - \tilde{\beta}) \left( (3/2)q(1 - q) p_{1,1,1} + (q^2 + (1 - q)^2) p_{0,0,1} \right) >
\]
\[(1 - \beta_{I}^s) \left( (3/2)q(1 - q) p_{1,1,1/2} + ((1 - q)^2 + q^2) p_{0,0,1/2} \right). \tag{56}
\]

Any $\tilde{\beta}$ satisfying this equation with equality could be taken as a benchmark for deviation-
considerations. However, since there's no feasible $\tilde{\beta}$ that satisfies our restrictions and
equation (56) with equality, the out-of-equilibrium belief that the deviation comes from
the low-signal firm does not fail the IC. Finally, numerically it is straightforward to check
that this out-of-equilibrium belief renders deviation unprofitable.

Consequently, the only equilibrium that satisfies the IC and payoff dominance is pooling
in spreads $\beta_{I}^s$ which induce price-separation.

\section*{Proof of Proposition 4}

If the firm separates in spreads, the bank’s price choice carries no extra information. Thus
in prices, $\mu$ is substituted with a diamond. For the bank’s probability assessment of a
successful IPO, spreads do not carry information, thus in $\alpha_{j,\nu}$, $j = 0, 1$, spread-information
$\nu$ is substituted with a diamond. In Subsection 4.2, equation (6) we have derived the spreads
$\beta_0$ and $\beta_1$ that induce the bank to choose risky prices: The high-signal bank chooses risky
$p_{1,0,1}$ with $B_1$ if it is offered at least $\beta_1$. The low-signal bank chooses risky $p_{1,0,0}$ with $B_1$ if
it is offered at least $\beta_0$.

**Step 1 (Risky Pricing):** We have to show that both types of firm prefer the respective
bank to set those risky prices. The high-signal firm prefers the bank to set $p_{1,0,1}$ and not
$p_{0,0,1}$ if its expected revenue is higher at the risky price, $\alpha_{1,0}(1 - \beta)p_{1,0,1} > p_{0,0,1}$. Recall
that $\beta = 0$ is sufficient for the bank to set the riskfree price. Solving for $\beta$ yields that the
spread must satisfy

\[\beta_1 < 1 - p_{0,0,1}/\alpha_{1,0} p_{1,0,1} \iff C/N < (2q - 1)^2/2q. \tag{57}\]
Applying the same reasoning to the low-signal firm, it prefers the low-signal bank to set the risky price if \( p_{1,0,0} > p_{0,0,0} \). Thus the separating threshold \( \beta_0 \) must satisfy

\[
\beta_0 < 1 - p_{0,0,0}/\alpha_{0,0} p_{1,0,0} \iff C/N < 2q(2q - 1)^2(1 - q)^2/(1 - 2q + 2q^2)^2. \tag{58}
\]

Since \( \beta_0 > \beta_1 \) and since the analysis is restricted to the parameter space where spreads do not exceed 10 percent, we impose \( \beta_0 < 0.1 \). This translates into \( C/N < R_0(q) \) as derived in the proof of Proposition 2. Numerically it is easy to check that for \( q \in (0.6, 1) \), \( C/N < R_0(q) \) is sufficient for (57) and (58) to hold.

**Step 2** (*Deviations*): We have to show that there is no profitable deviation for either firm. Consider first the low-signal firm. Since \( \beta_0^s > \beta_1^s \) and \( p_{1,0,0} < p_{1,0,1} \), it would deviate if the low-signal bank set \( p_{1,0,1} \) given \( \beta_1^s \). However, at \( \beta_1^s \) the high-signal bank is indifferent between risky \( p_{1,0,1} \) and risk-free \( p_{0,0,1} \). Since the low-signal bank holds less favorable prospects it would not set \( p_{1,0,1} \) and thus the firm’s/bank’s signal \( s = 0 \) is revealed. But in this case \( \beta_0^s \) is the best choice for the low-signal firm. Consider now the high-signal firm. Since \( \beta_0^s > \beta_1^s \) and \( p_{1,0,0} < p_{1,0,1} \), it will never mimic the low-signal firm.

**Step 3** (*Pooling Spreads*): We have to check if pooling in spreads can be an equilibrium. With Proposition 2 we know that \( \beta_{p_1}^p \) induces price-pooling in \( p_{1,0,1} \). Since \( \beta_{p_1}^p > \beta_1^s \) and \( p_{1,0,1} < p_{1,0,1} \) the high-signal firm will deviate, and it is the only one who can do so profitably under the IC. Hence, this cannot be an equilibrium.

**Proof of Proposition 5**

We show that the bank earns positive profits at all equilibrium spread levels.

**Step 1** (*Uninformed Firms*): In this case, the spread is \( \beta_p^p \) and both types of bank set high pooling price \( p_{1,0,0} \) and incur the risk of losing \( C \). Incentive compatibility requires that equilibrium profits must be at least as high as worst case deviation payoffs. Both types of bank could always set riskfree price \( p_{0,0,0} > 0 \) and receive \( \beta_p^p \mathbf{S} p_{0,0,0} > 0 \), thus equilibrium profits must be positive.
**Step 2 (Independently Informed Firms):** In this case, both types of firm set spread level $\beta_{\frac{s}{2}}$. The low-signal bank sets $p_{0,0,\frac{1}{2}}$ and thus receives $\beta_{\frac{s}{2}} p_{0,0,\frac{1}{2}} > 0$. The high-signal bank sets $p_{1,1,\frac{1}{2}}$ and the same argument as in Step 1 applies. Thus equilibrium profits must be positive.

**Step 3 (Identically Informed Firms):** If $s_b = 0$, the spread is $\beta_0$ and the bank sets $p_{1,0,0}$ and incurs the risk of losing $C$. Likewise, if $s_b = 1$, the firm sets $\beta_1$ and the bank sets $p_{1,0,1}$ and incurs the risk of losing $C$. In both cases, the argument in Step 1 applies. Thus equilibrium profits must be positive.

□

**Proof of Proposition 6**

Proposition 2 states that uninformed firms set spread level $\beta^u$. From Proposition 3, the only spread-equilibrium that satisfies the IC and payoff dominance with independently informed firms is pooling spread $\beta_{\frac{s}{2}}$. Numerically it is straightforward to show that $\beta_{\frac{s}{2}} < \beta_{\frac{p}{2}} = \beta^p$. □

**Proof of Proposition 7**

We will only show that if spreads are uninformative but prices are separating, then on average securities are underpriced. It follows analogously that if spreads are uninformative and the equilibrium (pooling) price risky, then on average ordering the security yields zero profits (as outlined in the text).

When spreads are uninformative, four scenarios can occur with respect to value $V \in \{0,1\}$ and signal $s_b \in \{0,1\}$. Scenario $(V = 0, s_b = 0)$ occurs with probability $q/2$, $(V = 0, s_b = 1)$ with $(1 - q)/2$, $(V = 1, s_b = 0)$ with $(1 - q)/2$ and $(V = 1, s_b = 1)$ with $q/2$. When $s_b = 0$, the bank sets price $p_{0,0,\frac{1}{2}}$, with $s_b = 1$ it sets $p_{1,1,\frac{1}{2}}$. At $p_{0,0,\frac{1}{2}}$, the IPO is always successful, at $p_{1,1,\frac{1}{2}}$ it is always successful if $V = 1$, and it fails half the time when $V = 0$ (because the true distribution of signals is distributed around $N(1 - q)$ and thus half the time, demand is too small). By the LLN if $V = 0$ then the market price is $p^m = 0$, if $V = 1$ it is $p^m = 1$. The pricing error (underpricing or overpricing) is $p^m - p$. Thus with $(V = 0, s_b = 0)$ it is $0 - p_{0,0,\frac{1}{2}}$, with $(V = 0, s_b = 1)$ it is $0 - p_{1,1,\frac{1}{2}}$, with $(V = 1, s_b = 0)$ it
is $1 - p_{0,0,\frac{1}{2}}$, and with $(V = 1, s_b = 1)$ it is $1 - p_{1,1,\frac{1}{2}}$. Combining this with the probabilities of each scenario and with the probability of a successful offering, we obtain

$$\frac{1}{2} \left( q(-p_{0,0,\frac{1}{2}}) + \frac{1}{2} q(-p_{1,1,\frac{1}{2}}) + (1 - q)(1 - p_{0,0,\frac{1}{2}}) + q(1 - p_{1,1,\frac{1}{2}}) \right)$$

$$= \frac{1}{2} \left( 1 - \frac{1+q}{2} p_{1,1,\frac{1}{2}} - p_{0,0,\frac{1}{2}} \right) = \frac{1}{2} \left( 1 - q - p_{0,0,\frac{1}{2}} \right) > \frac{1}{2} (1 - q - (1 - q)) = 0 \quad \Box$$

**Proof of Proposition 8**

From Propositions 2 and 4 we know that an uninformed firm always sets $\beta^c_p$; an identically informed firm with signal $s_b = 0$ sets $\beta^s_0$, if it has signal $s_b = 1$ it sets $\beta^s_1$. Ex ante, the identically informed firm gets either signal with equal probability. Thus for the claim to be true it must hold that

$$\frac{1}{2} \beta^s_1 + \frac{1}{2} \beta^s_0 > \beta^p_0 \iff \frac{1}{2} \frac{1 - \alpha_1}{\alpha_1 p_{1,1} - p_{0,1}} + \frac{1}{2} \frac{1 - \alpha_0}{\alpha_0 p_{1,0} - p_{0,0}} > \frac{1 - \alpha_0}{\alpha_0 p_{1,\frac{1}{2}} - p_{0,0}}. \quad (60)$$

Checking this numerically, the inequality holds for all $q > 0.5$. By Proposition 6, the VC-backed firm sets even lower spreads. \Box
Signals are received. The firm offers a contract specifying the spread level. The bank sets the offer price. Investors decide whether to order or to abstain. Shares are floated or offering fails.

Figure 1: The Timing of the Game.
Figure 2: The Signaling IPO-Game.
Figure 3: Equilibrium Offer Prices at Different Levels of Uninformative Spreads.

For levels of the spread below $\beta^s$, both types of banks pool in $p^* = p_{0,1.0}$. For $\beta \in [\beta^s, \hat{\beta}^s]$ there is separation: The low-signal bank always sets $p^* = p_{0,0.0}$, and the high-signal bank sets $p^* = p_{1,1.0}$ for $\beta \in [\beta^s, \hat{\beta}^s]$ and $p^* = \phi_{0,0}(p_{0,0.0})$ for $\beta \in (\hat{\beta}^s, \beta^p)$. If $\beta \geq \beta^p$ there is pooling in $p_{1,1.0}$.
<table>
<thead>
<tr>
<th></th>
<th>spreads</th>
<th>offer prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC backed (independently informed)</td>
<td>pooling</td>
<td>separating</td>
</tr>
<tr>
<td>non-VC backed (uninformed)</td>
<td>uninformative</td>
<td>high, risky pooling</td>
</tr>
<tr>
<td>‘relationship banking’ (identically informed)</td>
<td>separating</td>
<td>high, risky (uninformative)</td>
</tr>
</tbody>
</table>

Table 1: **Spread and Price Setting for Different Classes of IPOs.** Prices, at which only high-signal investors buy, are risky (because there may not be sufficiently many investors with high signals). Independently informed firms pool in spreads but this pooling spread induces banks to set separating prices; the high separating price is risky, the low separating price is safe (all investors order). If the firm is uniformed then spreads are, naturally, also uninformative; at the equilibrium spread, banks set a risky pooling price. Finally, identically informed firms choose separating spreads; both these spreads induce banks to set risky prices.
\[ \alpha_{s_b, \nu} \quad s_b = 1 \quad s_b = 1/2 \text{ or } \bullet \quad s_b = 0 \]

<table>
<thead>
<tr>
<th>$\nu$</th>
<th>$s_b = 1$</th>
<th>$s_b = 1/2 \text{ or } \bullet$</th>
<th>$s_b = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu = 1$</td>
<td>( \frac{q^2 + (1-q)^2/2}{q^2+(1-q)^2} )</td>
<td>( \frac{1+q}{2} )</td>
<td>( \frac{3}{4} )</td>
</tr>
<tr>
<td>$\nu = 1/2 \text{ or } \bullet$</td>
<td>( \frac{1+q}{2} )</td>
<td>( \frac{3}{4} )</td>
<td>( \frac{2-q}{2} )</td>
</tr>
<tr>
<td>$\nu = 0$</td>
<td>( \frac{3}{4} )</td>
<td>( \frac{2-q}{2} )</td>
<td>( \frac{q^2/2+(1-q)^2}{q^2+(1-q)^2} )</td>
</tr>
</tbody>
</table>

Table 2: The success probability $\alpha_{s_b, \nu}$ for prices at which only high-signal investors buy.
Table 3: **Approximate closed form solutions of threshold prices** $p_{s_i, \mu, \nu}$. Each entry in the table corresponds to a price $p_{s_i, \mu, \nu}$, i.e. to the threshold price for each combination of the investor’s signal $s_i$, price information $\mu$ and spread information $\nu$. Thus the left half of the table (under $s_i = 1$) lists the maximal price that an investor with signal $s_i = 1$ is willing to pay, given information $\mu$ and $\nu$ and given that all others with signal $s_i = 1$ buy, and those with $s_i = 0$ do not. The right half of the table (under $s_i = 0$) indicate the maximal price that an investor with signal $s_i = 0$ is willing to pay, given that all others investors buy too. For instance, if the investor receives signal $s_i = 1$ and derives spread and price information $\nu = 0$ and $\mu = 1/2$, then the maximum he is willing to pay is threshold price $p_{1,1/2,0} = 2(1-q)/(2-q)$.

<table>
<thead>
<tr>
<th>$p_{s_i, \mu, \nu}$</th>
<th>$s_i = 1$</th>
<th>$s_i = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu = 1$</td>
<td>$\mu = 1$</td>
<td>$\mu = 1/2$ or $\diamond$</td>
</tr>
<tr>
<td>$\nu = 1/2$ or $\diamond$</td>
<td>$\frac{2q^2}{(1-q)^2(1+2q^2/(1-q)^2)}$</td>
<td>$\frac{2q}{1+q}$</td>
</tr>
<tr>
<td>$\nu = 0$</td>
<td>$\frac{2q}{1+q}$</td>
<td>$\frac{2}{3}$</td>
</tr>
</tbody>
</table>

Thus, for $s_i = 1$, the approximate closed form solutions are:

- If $\mu = 1$ and $\nu = 1$, the price is $\frac{2q^2}{(1-q)^2(1+2q^2/(1-q)^2)}$.
- If $\mu = 1$ and $\nu = 1/2$ or $\diamond$, the price is $\frac{2q}{1+q}$.
- If $\mu = 0$ and $\nu = 0$, the price is $\frac{2q}{1+q}$.

For $s_i = 0$, the approximate closed form solutions are:

- If $\mu = 1$ and $\nu = 1$, the price is $\frac{2(1-q)}{2-q}$.
- If $\mu = 1$ and $\nu = 1/2$ or $\diamond$, the price is $\frac{2(1-q)}{2-q}$.
- If $\mu = 0$ and $\nu = 0$, the price is $\frac{1-q}{q^2+1/(1-q)^2}$.
Table 4: Prices, signal probabilities, and success probabilities in price-separating equilibria.

| $Pr(V|s_f = 1)$ | $q$ | $1 - q$ |
|-----------------|-----|---------|
| $V = 1$ | $Pr(s_b|V)$ | $Pr(IPO\ successful|V)$ | $Pr(s_b|V)$ | $Pr(IPO\ successful|V)$ |
| $s_b = 1$ | $p_{1,1,1}$ | $1$ | $p_{1,1,1}$ | $\frac{1}{2}$ |
| $s_b = 0$ | $p_{0,0,1}$ | $1$ | $p_{0,0,1}$ | $1$ |
List of Symbols

\( V \) 
set of liquidation values, \( V = \{0, 1\} \).

\( V, v \) 
element of \( V \), realization of random variable \( V \).

\( N \) 
number of potential investors.

\( S \) 
number of securities to be issued.

\( s_b \) 
private signal of the investment bank, \( s_b \in V \).

\( s_f \) 
private signal of the issuing firm, \( s_f \in V \).

\( s_i \) 
private signal of an investor, \( s_i \in V \).

\( q \) 
signal quality.

\( \mu(p) \) 
price information.

\( \nu(\beta) \) 
spread-information.

\( d \) 
demand and also the number of favorable investor signals.

\( B \) 
set of aggregated best replies, \( B = \{B_1, B_{0,1}, B_0\} \).

\( B_1 \) 
all high-signal investors order.

\( B_{0,1} \) 
all investors order.

\( B_0 \) 
no investor orders.

\( \alpha_{s_b, \nu} \) 
belief of an IPO being successful in case \( B_1 \), given signal \( s_b \) and spread-information \( \nu \).

\( C \) 
exogenous costs involved if IPO fails.

\( \beta \) 
gross spread; share of IPO revenue going to the investment bank.

\( \beta'_p \) 
lowest spread that induces the bank to pool in the high price, given spread-information \( \nu \).

\( \beta'_s \) 
lowest spread that induces the bank to separate in prices, given spread-information \( \nu \).

\( \beta_\nu \) 
lowest spread that induces the identically informed bank to set a risky price, given \( \nu \).

\( \Pi(\cdot) \) 
expected profit for the investment bank.

\( p_{s_i, \mu, \nu} \) 
highest price an investor is willing to pay given his signal \( s_i \), price-information \( \mu \), and spread-information \( \nu \).

\( p \) 
any offer price.

\( \bar{p}^*, \underline{p}^* \) 
high and low offer price in a separating equilibrium.

\( p^* \) 
pooling equilibrium offer price.

\( p^{\text{m}}(d) \) 
aftermarket price given demand realization \( d \).

\( \phi_{s_b, \nu}(p) \) 
price s.t. bank with \( s_b \) and spread-information \( \nu \) is indifferent between charging a risky \( \phi_{s_b, \nu}(p) \) (with \( B_1 \)) or safe price \( p \) (with \( B_{0,1} \)).

\( f(d|V) \) 
conditional distribution over demand, given the true value is \( V \).

\( g(d|s_i, \mu, \nu) \) 
conditional distribution over demand, given \( s_i \), \( \mu \), and \( \nu \).

\( \psi(V|s_i, \mu, \nu) \) 
conditional probability of \( V \), given \( s_i \), \( \mu \), and \( \nu \).