

# A Theory of the Going-Public Decision

**Thomas J. Chemmanur**  
Boston College

**Paolo Fulghieri**  
INSEAD and CEPR

We address the question: At what stage in its life should a firm go public rather than undertake its projects using private equity financing? In our model a firm may raise external financing either by placing shares privately with a risk-averse venture capitalist or by selling shares in an IPO to numerous small investors. The entrepreneur has private information about his firm's value, but outsiders can reduce this informational disadvantage by evaluating the firm at a cost. The equilibrium timing of the going-public decision is determined by the firm's trade-off between minimizing the duplication in information production by outsiders (unavoidable in the IPO market, but mitigated by a publicly observable share price) and avoiding the risk-premium demanded by venture capitalists. Testable implications are developed for the cross-sectional variations in the age of going-public across industries and countries.

This article develops a model of the going-public decision of a firm and addresses the question, At what stage in its life should a firm go public rather than financing its projects through a private placement of equity (e.g., with a venture capitalist)? Beyond the fact that most firms start out as small private companies and at some point in their growth go public, we know relatively little about the trade-offs underlying a firm's choice between remaining private or going public. Indeed, beyond a general idea that going public allows the firm's shares to become more liquid, discussions of the going-public decision usually do not include a precise notion of the economic advantages or disadvantages of financing a firm's projects by going public

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rather than through private sales of equity to venture capitalists or other large investors.

A thorough understanding of the economic factors underlying the going-public decision is important not only from the firm's viewpoint (when should our firm go public?), but also from the viewpoint of exchanges, which can affect the going-public decisions of firms through their listing requirements (what kind of firms should be allowed to go public at this exchange?). Some of the interesting questions that arise in this regard are the following: What explains the cross-sectional variations across industries in the age at which firms go public? In particular, is there a systematic relationship between the capital intensity or the technological uncertainty in an industry and the average age at which firms in that industry go public? What explains the phenomenon of "hot-issue" markets [see, e.g., Ritter (1984)], in which a disproportionately large number of firms from a particular industry go public within a short interval of time? What explains the tremendous variation across countries in the average age at which firms go public? How stringent should the requirements be on firms wanting to go public by listing its equity in a given exchange?<sup>1</sup>

In order to answer these and other questions related to the going-public decision, it is important to develop a rigorous theoretical analysis of the going-public decision, which is the objective of this article. We consider the situation of an entrepreneur who needs to obtain external financing to undertake a positive net present value project. We focus on three essential differences between private and public firms:

1. *More dispersed share ownership.* In the case of public firms, the required capital is generated (in general) by selling shares to a large number of investors, whereas with private firms, much of the external financing is provided by one large investor (often a venture capitalist) or a small group of large investors ("angels"). The fact that private firms obtain their capital from a much smaller group of investors than public firms has two important consequences. First, the presence of numerous equity holders in public firms, each with a smaller equity stake, implies that these equity holders are much better diversified than those in private firms. Second, a more concentrated shareholding in private firms implies that a large investor (or small group of large investors) will have considerably more bargaining power (against the entrepreneur) in such a firm than the numerous small investors in a public firm.

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<sup>1</sup> For example, several biotech companies recently requested the London Stock Exchange to waive its usual rule that any firm must have a 3-year profit record before it can be listed (see, e.g., *Economist*, July 1993) based on the argument that it was prohibitively expensive for them to raise the large amount of capital they needed for their R&D activities from venture capitalists. Their request was granted, swelling the total market capitalization of biotech firms listed on the exchange from approximately £500 million in June 1992 to around £1 billion in mid-1994. Such situations highlight the need for a rigorous analysis of the going-public decision by raising questions about the appropriateness of having such restrictions in the first place and about the wisdom of waiving them in some cases.

2. *The need to convince a much larger group of investors that its projects are worth investing in.* A direct consequence of the fact that a public firm raises its capital from a much larger number of investors than a private firm is that a much larger group of investors must be convinced about the quality of the firm's projects. In equilibrium, any such costs expended by outsiders in evaluating the firm's projects will be borne by the firm in the form of a lower share price.

3. *Publicly observable share price.* When a firm goes public, the common price at which equity is sold is publicly observable by all outside investors. This implies that the magnitude of the total costs involved in the outsiders' evaluation of the firm's projects will be reduced somewhat by many unsophisticated investors being able to free ride on the information they can infer from this publicly observable share price.<sup>2</sup>

Thus we view the public equity market as a place where the firm sells equity to numerous investors, each of whom contributes only a relatively small share of the capital required (and each of whom is therefore fully diversified, having only a small fraction of his wealth tied up in the firm), at a common share price observable by all. On the other hand, we view a private placement of equity as a transaction in which a small number of large investors deal privately with the firm, each contributing a significant fraction of the firm's capital requirements (and each having a significant fraction of his wealth invested in the firm). The final ingredient of our model is the assumption that the transaction between the entrepreneur and all outside investors (be they private equity investors or those in the public equity market) is characterized by asymmetric information, although outsiders, by incurring a certain cost, can produce additional information about the firm (and thereby reduce their informational disadvantage with respect to the entrepreneur).

In the above setting, selling the required number of shares to a single large investor (the "venture capitalist") has the advantage that it minimizes the information production cost (since such an investor contributes the entire capital required after evaluating the firm only once). However, the disadvantage is that the venture capitalist, who remains less than fully diversified and wields considerably more bargaining power against the entrepreneur than public shareholders, will demand in equilibrium a significantly greater rate of return (for a given level of uncertainty about future cash flows). Conversely, financing the firm's project by selling shares to a large number of investors in the equity market has the advantage that each investor, with only a small stake in the firm, is fully diversified and has almost no bargaining power relative to the entrepreneur (since the equity is priced

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<sup>2</sup> Given that public firms have a more dispersed ownership structure, public firms' insiders (managers) may also be subject to considerably less monitoring of their actions from outside shareholders compared to managers of private firms. We will not focus on this aspect of the problem in our formal model, but will discuss potential implications of incorporating this feature as well in Section 4.

in a competitive market). However, this has the disadvantage of some duplication in information production, and consequently a larger aggregate information production cost is borne by the firm. The resolution of this trade-off depends on the magnitude of outsiders' information production costs: firms with longer track records will clearly have lower costs of information acquisition for outsiders. We show that, in equilibrium, firms go public only when a sufficient amount of information about them has accumulated in the public domain (so that the costs to outsiders of assessing true firm value becomes sufficiently small); younger firms, which entail a greater information acquisition cost, choose the venture capitalist in equilibrium. We also demonstrate that while some amount of duplication in information acquisition is unavoidable in the equity market, the price in the equity market conveys information across investors so that only a fraction of these investors will incur the information production cost, thus lowering the extent of such duplication. Further, the equilibrium price is noisy, with the degree of noise becoming smaller as the cost of information production becomes smaller. Finally, we show that, other things remaining the same, firms which have larger capital requirements and firms in industries characterized by greater technological uncertainty choose the public equity market over private equity financing at an earlier stage in their lives.

An interesting aspect of the equilibrium in our model is that, here, the fixed offering price set by the firm when it goes public conveys information across investors in equilibrium.<sup>3</sup> This is a direct consequence of the fact that, in our setting, the entrepreneur has information superior to outsiders about the type of his own firm, and consequently, aware of how the IPO offering price he sets affects the demand for equity from information producers. The fact that, in setting the offer price, the entrepreneur strategically takes into account the behavior of informed investors, in turn, makes this price informative to all outsiders. Thus, even uninformed investors are able to infer some of the information available to information producers through observing the offering price.<sup>4</sup>

There has been very little research so far which addresses the going-public decision. Focusing solely on the corporate control aspects of the

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<sup>3</sup> It is useful to contrast our modeling approach with the rational expectations equilibrium (REE) setting assumed in a number of articles [see, e.g., Grossman and Stiglitz (1976) or Grossman (1981)]. In such a setting, the price is always assumed to be set at the intersection of demand and supply. Thus, in a rational expectations equilibrium, uninformed investors can back out the information produced by other investors, since, assuming a linear equilibrium, the price is one to one with the information produced by outsiders. The REE modeling approach is clearly not the appropriate one to capture the fixed offer price setting of the IPO market, where the price cannot be altered in response to excess demand.

<sup>4</sup> Clearly it is the fact that the entrepreneur has private information about firm type that makes the price set by him informative to uninformed outsiders. If, in contrast, the entrepreneur himself were uninformed about the type of his own firm, he would not be able to strategically account for the differential demand for the equity in different types (type G and type B in our model) of firms from informed outsiders; this, in turn, would make the IPO price set by him uninformative to outsiders.

going-public decision, Zingales (1995) argues that, when management obtains private benefits from control, going public helps to raise the bargaining power of the incumbent relative to potential buyers, thus allowing the incumbent to extract value from the buyer.<sup>5</sup> In research subsequent to ours, Maximovic and Pichler (1999) study a setting in which the firm's IPO conveys valuable information to competitors in the product market. Here the timing of the going-public decision trades off this disincentive to going public with the potential advantages of expanding early in the product market using the capital raised in the IPO. Titman and Subrahmanyam (1999) study a setting in which outside investors may obtain information, unavailable to firm insiders, which is useful in making investment decisions. They show that, if such information is freely available to outsiders, the firm chooses to go public; it remains private if outsiders have to incur significant costs to acquire this information. Finally, Benveniste, Busaba and Wilhelm (1997) study a setting where insiders can engage in costly learning about firm's value from outsiders. Here, firms which go public later are able to free ride on the costly information generated by those in the industry which have gone public ahead of them. They demonstrate that, by acting as "gatekeepers" in the new issues market, investment banks can minimize such free riding by forcing firms going public over a period of time to share these learning costs.<sup>6</sup>

The rest of our article is organized as follows. Section 1 presents the model. Section 2 characterizes the equilibrium and develops results. Section 3 discusses the empirical and policy implications of our results. Section 4 concludes. All proofs are in Appendix A.

## **1. The Model**

The model consists of two dates. At time 0, a risk-neutral entrepreneur has monopoly access to a single project. The project requires a certain investment at time 0, which the entrepreneur wishes to raise from outside investors, since he has zero wealth at this time. He can obtain this capital through one of two alternative financing strategies: he can either raise the amount required through a private placement of equity with a venture capitalist, or he can obtain the required external financing by taking his firm public and selling shares to numerous investors in the new issues market. To begin with, the equity in the firm is assumed to be divided into a large

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<sup>5</sup> See also Pagano (1993), who points out the possibility that a small stock market may get trapped in a "bad equilibrium" in which no entrepreneur goes public, due to the failure of entrepreneurs in such an economy to internalize the positive externality arising from the increase in the diversification opportunities available to investors due to their decision to go public.

<sup>6</sup> The large literature on IPO underpricing [see, e.g., Rock (1986), Allen and Faulhaber (1989), Benveniste and Spindt (1989), and Chemmanur (1993)] does not study the going-public decision, focusing instead on the firm's equity pricing decision after it has decided to go public.

number of shares  $m$ , all owned by the entrepreneur. The entrepreneur now sells a certain number of additional shares to outsiders, either to a single venture capitalist if he chooses private equity financing or to a large number of small investors in the IPO market if he chooses to take the firm public, thus lowering the fraction of equity that he holds in the firm. At time 1, the project pays off a certain cash flow, which depends on project (firm) quality  $q$  or “type,” about which the entrepreneur has private information. We assume that the risk-free rate of return is zero.

### 1.1 The Entrepreneur’s Private Information and Investment Technology

Projects are of two types: “good” ( $q = G$ ) or “bad” ( $q = B$ ); type G projects have a greater expected value of time 1 cash flow than type B projects. The time 1 cash flow from the project, denoted by  $v_q(\iota)$ , depends on project quality as well as on the amount invested in the project at time 0, denoted by  $\iota$ . This cash flow is given by the following investment technology:

$$v_q(\iota) = k_q \iota + \tilde{\varepsilon} \quad \text{for } \iota < I, \quad v_q(\iota) = k_q I + \tilde{\varepsilon} \quad \text{for } \iota \geq I; \quad (1)$$

where  $\tilde{\varepsilon} \sim (0, \sigma_\varepsilon^2)$ ,  $q \in \{G, B\}$ , and  $k_G > k_B > 1$ .

From Equation (1), we can see that the firm’s technology is such that any amount invested at time 0 lower than or equal to a certain upper limit  $I$  yields a time 1 cash flow  $k_q$  times  $\iota$ ,  $q \in \{G, B\}$ . However, for investment amounts above  $I$ , the cash flow generated remains at  $k_q I$ , so that no entrepreneur will choose an investment level above this amount  $I$ . Further, for any given level of investment, type G firms yield a greater expected cash flow compared to type B firms. Finally, while entrepreneurs privately observe the type of their own firm, even they have some uncertainty about their firm’s time 1 cash flow realization [this cash flow “surprise”  $\tilde{\varepsilon}$  is distributed with mean 0 and variance  $\sigma_\varepsilon^2$ ;  $\sigma_\varepsilon^2$  measures the uncertainty in the firm’s investment technology]. For convenience, denote by  $V_G$  and  $V_B$  the entrepreneur’s time 0 expectation (for the type G and the type B firm, respectively) of his firm’s time 1 cash flow, at the full investment level  $I$  (i.e.,  $V_G \equiv k_G I$ , and  $V_B \equiv k_B I$ ). We will assume that  $k_G$  and  $k_B$  are large enough (i.e., the firm’s project has a sufficiently large net present value) that, even if the entire capital required for investment in the project has to be obtained from the (risk-averse) venture capitalist, it is worthwhile for the entrepreneur to invest up to the full investment level  $I$ . Since the entrepreneur is risk neutral, his objective in making the firm’s financing and investment decisions is to maximize the expected value of the time 1 cash flow accruing to him.

### 1.2 The Outsiders’ Evaluation Technology

Outside investors, be they venture capitalists or small investors in the IPO market, have less information than entrepreneurs about the true quality or

type of the firm approaching them for capital. However, when offered equity in any firm, they can choose to expend additional resources and produce more information about the firm, in order to reduce their informational disadvantage relative to firm insiders. We model this information production by outsiders as follows. At a cost  $c$ , outsiders can obtain a noisy “evaluation” ( $e$ ) of the firm, which can have one of two outcomes: “good” ( $e = g$ ) or “bad” ( $e = b$ ). Further, we assume that the precision of the outsiders’ evaluation technology is such that, for any one investor producing information:

$$\Pr\{e = g \mid q = G\} = 1, \quad \Pr\{e = g \mid q = B\} = y, \quad 0 < y < 1. \quad (2)$$

Thus all good firms get good evaluations; however, bad firms may also get good evaluations with a certain probability  $y$ , so the evaluation is noisy (the precision of the evaluation increases as the magnitude of the error probability  $y$  decreases). We also assume that, when a number of investors produce information about a type B firm, a fraction  $y$  of these investors obtain good evaluations, while the remaining fraction  $(1 - y)$  obtain bad evaluations.<sup>7</sup>

The outsiders’ evaluation cost  $c$  depends on several factors. Of these, two very important ones are as follows. First, the magnitude of  $c$  will depend on the amount of information already available in the public domain about the firm and its management (e.g., a software firm such as Microsoft, with a track record of successfully developing and implementing new products would be easier to evaluate, and hence have a lower  $c$ , than a start-up software firm). Thus one can expect the evaluation cost  $c$  to come down steadily as a firm becomes older and more information about the firm becomes easily accessible to the public. Second, the size of  $c$  will depend upon the firm’s industry membership: the projects of firms belonging to certain industries may be intrinsically more complex and therefore difficult to evaluate than those of firms in other industries. Thus, other things remaining the same, a firm running a chain of grocery stores may be easier for outsiders to evaluate (and therefore have a smaller  $c$ ) than one engaged in research on the next generation of supercomputers or in the production of some other product making use of as yet unproven technologies. In summary, we assume that larger values of the evaluation cost  $c$  are associated with younger firms or (holding age constant) those belonging to industries where projects are intrinsically more complex and difficult to evaluate.

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<sup>7</sup> If we were to assume instead that investors producing information about a type B firm obtain independent signals, the expected value of the fraction of these investors obtaining good evaluations would still remain  $y$ . However, in this case, many of our expressions would involve the distribution of this fraction of investors who obtain good evaluations for a bad firm. Clearly this adds unnecessary computational complexity to the model without generating any commensurate economic insights, and we have therefore adopted the correlated information structure above.

### 1.3 The Venture Capitalist

If the entrepreneur decides to use private equity financing, he offers the venture capitalist an equity stake in the company in exchange for the capital, at a certain price per share. We assume that the venture capitalist's wealth is large enough to fund the firm's project in full.<sup>8</sup> This means that if the terms offered to him by the entrepreneur are sufficiently favorable, the venture capitalist will take a large equity position in the firm, and in return fund the firm's project. Such a concentrated equity stake in the firm has two potential consequences. First, since a relatively large portion of the venture capitalist's wealth is tied up in the firm's equity, the venture capitalist will not be fully diversified, and will therefore demand a nondiversification premium from the firm.<sup>9,10</sup> Second, being the sole supplier of capital to the firm, he will have considerably more bargaining power relative to the entrepreneur than the numerous competing investors in the public equity market, and will therefore be in a position to extract a fraction of the net present value of the firm's project. In practice, these two factors may complement each other, and together drive the pricing of the firm's equity when the entrepreneur deals with the venture capitalist. However, in the interest of simplicity, we model each of these factors separately. Thus, in the main body of this article, we assume that the venture capitalist is risk averse but has no bargaining power relative to the entrepreneur. In Appendix B we will go to the other extreme, assuming that the venture capitalist is risk neutral but has sufficient

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<sup>8</sup> It is straightforward in our setting to allow the firm to raise private equity financing by selling equity simultaneously to several such large investors (venture capitalists). The benefit to the firm from selling equity in this manner to more than one large investor is that each investor will be better diversified (so that the return required to be provided to each large investor as a compensation for bearing the firm's idiosyncratic risk will be correspondingly lower); however, the cost of doing this is that there will be duplication in information production, so that the aggregate information production cost (ultimately borne by the firm through a lower share price) will be correspondingly greater. The number of large investors to which the firm sells equity privately will then be determined endogenously from the trade-off between these two effects. However, to keep our analysis simple and focused on the firm's choice between private and public equity financing, we have chosen not to incorporate this additional level of complexity here.

<sup>9</sup> In their empirical study of venture capital financing, Barry et al. (1990) document that the lead venture capitalist averaged a 19% ownership stake in the firm. Even when the venture capitalist is organized as a partnership where a significant fraction of the funds invested is provided by outside limited partners, the agency relationship that prevails between such limited partners and the general partners managing the venture capital firm would lead to compensation contracts for these managing partners that involve significant penalties for investment failures by them, thereby inducing risk-averse decision making [see, e.g., Diamond (1984) for a similar discussion of risk-averse investment behavior by banks]. Further, the success or failure of a particular project can significantly affect the reputation (and therefore the fortunes) of the venture capital partner who made the decision to invest in that project, again leading to risk-averse investment behavior. Consistent with this, Sahlman (1990) notes that when valuing a company, venture capitalists compute the present value of the firm's cash flows by applying a high discount rate, usually in the range of 40% to 60%.

<sup>10</sup> An important alternative to venture capital financing available to private firms consists of wealthy individuals or "angels." It is estimated that angel financing is a much greater source of private equity financing than venture capitalists [see, e.g., Wetzel (1983) and Fenn, Liang, and Prowse (1995)]. Our assumption that the provider of private equity financing is risk averse is perhaps even more appropriate when the source is an angel rather than a venture capital firm; we will therefore not distinguish between these two sources of private equity financing.



bargaining power to enable him to extract a positive fraction  $\gamma$  of the net present value of the firm's project. We demonstrate that almost all our results go through essentially unchanged even in that scenario. Thus our results hold provided that any one of these two assumptions hold.<sup>11</sup>

Given that he is risk averse, the venture capitalist's objective is to maximize the expected utility of his time 1 wealth. For tractability, we assume that the venture capitalist's utility function for wealth has the following simple form:

$$U(W) = \mu_W - \rho\sigma_W^2, \quad (3)$$

where  $\mu_W$  is the mean and  $\sigma_W^2$  the variance of his time 1 wealth  $W$ , and  $\rho$  is his coefficient of risk-aversion. We denote the magnitude of venture capitalist's total wealth at time 0 by  $W_0$ , and assume that any part of the venture capitalist's wealth not invested in the firm at time 0 will be invested in the risk-free asset.

We model the notion that the venture capitalist may or may not engage in producing information about the firm [using the evaluation technology of Equation (2)], as follows. Depending on the cost and precision of the evaluation technology available to outsiders, the entrepreneur offers the venture capitalist *one* of two possible contracts: an unconditional price contract (where the venture capitalist invests in the equity of the firm without conducting a costly evaluation of the firm), or a contract with information production (where the venture capitalist conducts a costly evaluation of the firm, with the price paid for each share by the venture capitalist depending on the outcome of this costly evaluation). In response to the entrepreneur's offer, the venture capitalist may decide either to invest in the entrepreneur's firm or to reject his offer. Together, the above assumptions imply that the venture capitalist will invest in the firm if and only if the entrepreneur offers him equity at a price which leaves him at least as well off at time 1 as investing in the risk-free asset.

#### **1.4 Investor Strategies in the New Issues Market**

If the entrepreneur decides to take the firm public, he offers a certain number of newly issued shares at a fixed price in an IPO. We assume that each investor in the new issues market will buy at most one share in the firm, which translates into each investor holding only a small fraction of the equity in the post-IPO firm (since the number of shares  $m$  has been assumed to be large). Consequently there is no significant loss of generality (but considerable gain in analytical simplicity) from assuming that all investors in the new issues market act as risk-neutral agents, and we therefore make this assumption

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<sup>11</sup> It is easy to see that our results will be qualitatively unchanged even if both these assumptions are made simultaneously (i.e., we assume that the venture capitalist is risk averse and has some bargaining power relative to the entrepreneur). Doing so, however, only adds complexity to the model without generating commensurate insights.

here.<sup>12</sup> We assume that any amount of an investor's wealth not invested in the firm's equity, or devoted to evaluating the firm, is invested in the risk-free asset. Each investor has, therefore, three alternatives when a firm makes an IPO: ignore the IPO altogether and invest in the risk-free asset; engage in uninformed bidding for shares in the IPO; or conduct a costly evaluation of the firm, and depending on the outcome, bid (if he gets a good evaluation) or not bid (if he gets a bad evaluation) for a share.<sup>13</sup> Among these alternatives, each investor chooses the one that maximizes the expected value of his time 1 cash flow.

The proportion of those investors participating in the IPO who choose to become informed about the firm, denoted by  $\alpha$ , is determined as follows. After observing the price and number of shares offered by the firm in the IPO, each investor chooses between not participating in the IPO at all or participating as an informed investor, with a probability  $\alpha$ . In other words, if an investor decides to participate in the IPO, he conducts a costly evaluation of the firm with a probability  $\alpha$  (and follows the optimal bidding strategy depending on its outcome) or makes an uninformed bid for a share in the IPO with the complementary probability  $(1 - \alpha)$ . We will see later that the equilibrium value of  $\alpha$  chosen by each participant depends on the number of shares offered in the IPO and the price per share, the investors' prior probability assessment about the firm's true value, and the cost and precision of the information production technology [Equation (2)] available to them. The probability  $\alpha$  thus measures the extent of information production among the participants in the firm's IPO: in equilibrium, a fraction  $\alpha$  of the participants in the IPO produce information, while the remaining fraction  $(1 - \alpha)$  bid uninformed (participants in the IPO will be indifferent between producing and not producing information in equilibrium).<sup>14</sup>

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<sup>12</sup> None of our results are driven by the differences between the venture capitalist and the small investor in their attitude toward risk. Our results go through qualitatively unchanged even if IPO investors and the entrepreneur were as risk averse as the venture capitalist. The crucial difference here between the venture capitalist and the investors in the IPO market is that the venture capitalist has a more concentrated shareholding in the firm, which results in his being less well-diversified and having significantly greater bargaining power (relative to the entrepreneur) compared to the IPO investors.

<sup>13</sup> Clearly it is never optimal for any investor to produce information and then choose to bid for a share in the IPO even after getting a bad evaluation (since, for any investor to produce information, the information produced must yield him some benefit in terms of discriminating between type G and type B firms).

<sup>14</sup> Since, in equilibrium, each investor will be indifferent between informed and uninformed bidding in the IPO, and investors have identical information production costs, the exact identity of those who produce information and those who engage in uninformed bidding is irrelevant here. Formally, we assume that investors follow a randomized strategy, with a fraction  $\alpha$  choosing to produce information and the remaining fraction  $(1 - \alpha)$  choosing to bid uninformed in the IPO, based on the outcome of a collectively observed randomization device. This way of modeling the investors' choice between informed and uninformed bidding, where investors choose to produce information with a certain probability (rather than confining them to pure strategies) seems to be the most elegant modeling approach here, since it yields a symmetric equilibrium (where identical agents make identical choices). An alternative modeling approach, involving only pure strategies, would measure the extent of information production in the new issues market by the number of investors producing information in equilibrium [Chemmanur (1993) uses this alternative approach in a model of IPO underpricing]. However, this alternative approach would require that some

## 2. Equilibrium

An equilibrium consists of (i) a choice of financing method by the entrepreneur at time 0 (between private equity financing and going public), along with a combination of prices and the number of shares to be offered to outsiders in each case; (ii) a choice by the venture capitalist (in the case where the entrepreneur chooses to use private equity financing) about whether or not to invest in the firm; and (iii) a decision by each investor in the new issues market (in the case where the entrepreneur chooses to take the firm public) about whether or not to participate in the IPO, and if the decision is to participate, a choice by each investor about the probability of his producing information. Each of the above choices must be such that (a) the choices of each party maximizes his objective, given the equilibrium beliefs and choices of others; (b) the beliefs of all parties are consistent with the equilibrium choices of others; further, along the equilibrium path, these beliefs are formed using Bayes' rule; (c) any deviation from his equilibrium strategy by any party is met by beliefs by other parties which yield the deviating party a lower expected payoff compared to that obtained in equilibrium.

Given the rich strategy space for all agents (the entrepreneur, the venture capitalist, and the investors in the new issues market) in this model, we can think of three broad categories of equilibria that may exist (depending on parameter values): (i) separating equilibria, where type G and type B firms behave differently in equilibrium, thus revealing their type; (ii) pooling equilibria without information production, where either the venture capitalist, or investors in the new issues market, or both, invest in the firm seeking capital without conducting a costly evaluation of the firm; (iii) pooling or partially pooling equilibria with information production, where there is some degree of information production both by IPO investors and by the venture capitalist. Since our main objective in this article is to study the importance of costly information production by outsiders on the firm's going-public decision, we focus here on the equilibrium belonging to category (iii), and characterize the conditions for the existence of such an equilibrium.<sup>15</sup>

To facilitate exposition, we present the equilibrium in reverse order: we first discuss the equilibrium behavior of various parties assuming a given financing choice (in Section 2.1, that the firm has chosen to use private equity financing, and in Section 2.2, that the firm has decided to go public), and then go on to discuss, under Proposition 5, the overall equilibrium (where

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members of an otherwise identical cohort of investors choose to produce information, while others do not, so that the equilibrium would be asymmetric. [See also Milgrom (1981), who uses both of these approaches to model auctions with information production, and demonstrates the essential equivalence of these alternative approaches.]

<sup>15</sup> However, conditions for the existence of equilibria belonging to categories (i) and (ii) are available to interested readers from the authors.

we characterize the conditions under which the firm chooses to make use of one form of financing or the other). We will demonstrate there that the equilibrium behavior characterized earlier for a given financing choice is indeed part of the overall equilibrium where the firm first makes the choice between private equity financing and going public.

### 2.1 The Case Where the Firm Chooses Private Equity Financing

If the entrepreneur decides to use private equity financing, he chooses the kind of financing contract to offer the venture capitalist (a contract with information production, or an unconditional price contract), as well as the price of the equity and the number of shares to be offered. Consider first the case where the entrepreneur decides to offer the venture capitalist a contract with information production. In this case, after observing the outcome of the venture capitalist's evaluation of the firm, the entrepreneur makes a take it or leave it offer to the venture capitalist of a certain fraction of equity, depending on the outcome of the venture capitalist's evaluation, in return for the investment amount required. The venture capitalist's choices are restricted to only accepting or rejecting this offer.<sup>16</sup> If the venture capitalist conducts a costly evaluation of the firm using the evaluation technology of Equation (2), he will use the outcome of this evaluation to update (using Bayes' rule) his prior probability assessment  $\phi$  of the firm being of type G, as follows:

$$\begin{aligned} \Pr(q = G \mid e = g) &= \frac{\phi}{\phi + y(1 - \phi)} > \phi, \\ \Pr(q = G \mid e = b) &= 0. \end{aligned} \quad (4)$$

Now, denote the venture capitalist's expectation of the firm's time 1 cash flow, at the full investment level  $I$ , conditional on the outcome of his evaluation, by  $V_e \equiv E(k_q \mid e)$ , for  $e \in \{g, b\}$ ; denote the corresponding variance of the *determinate* part of the firm's cash flow,  $\text{var}(k_q \mid e)$ , by  $\sigma_e$ , for  $e \in \{g, b\}$ . We will refer to  $\sigma_g^2$  and  $\sigma_b^2$  as the venture capitalist's "information-based uncertainty" about the firm conditional on a good or bad evaluation, respectively (since this is the uncertainty arising solely from the fact that the venture capitalist does not have as much information about firm quality as the entrepreneur himself). Since, using the evaluation technology of Equation (2), all bad firms get a bad evaluation with probability 1, the updated

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<sup>16</sup> We assume that the outcome of the venture capitalist's evaluation is observable by the entrepreneur as well, though not verifiable (i.e., this outcome cannot be contracted upon). Further, the entrepreneur commits up front to compensate the venture capitalist for the cost incurred for conducting his evaluation of the firm, regardless of whether the entrepreneur and the venture capitalist eventually agree on the terms of financing the firm's project. We will show later that, in equilibrium, the entrepreneur offers the venture capitalist a certain fraction of equity  $s_g^*$  [given by Equation (5)] if the outcome of the evaluation is  $e = g$ , or a fraction  $s_b^*$  [given by Equation (6)], if the outcome is  $e = b$ ; the venture capitalist accepts this offer in equilibrium.

probability of a good firm conditional on a bad evaluation is zero, so that  $V_b = V_B$ , and  $\sigma_b^2 = 0$ .

Let  $s_g^*$  and  $s_b^*$  denote the lowest share of the firm's equity that the venture capitalist will accept in return for contributing the investment amount  $I$  to the firm, conditional on the outcome of his evaluation of the firm being good or bad, respectively. Since these fractions of equity have to leave the venture capitalist as well off, in terms of expected time 1 utility, as investing his entire wealth  $W_0$  in the risk-free asset,  $s_g^*$  and  $s_b^*$  can be shown, using the venture capitalist's objective of Equation (3), to be those values of  $s_g^*$  and  $s_b^*$  that satisfy Equations (5) and (6), respectively:

$$s_g V_g - \rho s_g^2 (\sigma_g^2 + \sigma_\varepsilon^2) = I + c. \quad (5)$$

$$s_b V_b - \rho s_b^2 \sigma_\varepsilon^2 = I + c. \quad (6)$$

Consider now the situation where the entrepreneur decides to offer the venture capitalist an unconditional price contract. In this case the venture capitalist will price the equity of the firm using his prior probability  $\phi$  about the firm being of type G (in the absence of any additional inferences about firm type that he may be able to draw from the kind of contract that the entrepreneur chooses to offer him). Denote the venture capitalist's expectation of the firm's time 1 cash flow (at the full investment level  $I$ ), under an unconditional price contract, by  $V_u \equiv E(k_q I \mid \phi)$ ; denote the variance of this cash flow,  $\text{var}(k_q I \mid \phi)$ , by  $\sigma_u$ . Now, working as in Equations (5) and (6), the minimum fraction  $s_u^*$  of the firm's equity that the venture capitalist will accept in return for the investment amount  $I$  in this case satisfies

$$s_u V_u - \rho s_u^2 (\sigma_u^2 + \sigma_\varepsilon^2) = I. \quad (7)$$

Given the above pricing rules, each type of entrepreneur chooses that contract which yields him the required investment amount by giving up the lowest possible fraction of equity to the venture capitalist. The type G entrepreneur will therefore choose the information production contract if  $s_g^* < s_u^*$ , and the unconditional price contract if  $s_g^* > s_u^*$ . The advantage of an information production contract to the type G entrepreneur is that it enables him to minimize the extent of pooling with the type B. This yields a price advantage for the type G firm's equity under the information production contract on two counts: first,  $V_g > V_u$ ; second, the venture capitalist's information-based uncertainty about his time 1 cash flow is lower in this case ( $\sigma_g^2 < \sigma_u^2$ ), so that he needs to be compensated only for a lower degree of uncertainty (risk). The only disadvantage of the information production contract relative to the unconditional price contract for the type G entrepreneur is that the information production contract requires that the venture capitalist spend an evaluation cost  $c$ , which is ultimately borne by the entrepreneur through a lower price for the firm's equity. Thus the type

G entrepreneur will prefer the information production contract as long as the firm's evaluation cost is not too high.

In contrast, the type B entrepreneur's incentives are to maximize the extent of his pooling with the type G, since this will allow him to obtain the highest possible price for his firm's equity. However, he has to worry about the inferences that the venture capitalist may draw in equilibrium from the kind of contract offered to him. In particular, if a firm (entrepreneur) offers the venture capitalist an unconditional price contract in a situation under which a type G entrepreneur would have chosen the contract with information production, the venture capitalist will be able to infer (with probability 1) that the firm making the offer is of type B, even without conducting a costly evaluation of that firm. Denote the minimum fraction of equity that has to be offered to the venture capitalist in this eventuality by  $s_B^*$  [this is given by that value of  $s_u$  which satisfies Equation (7) after setting  $V_u = V_B$ , and  $\sigma_u^2 = 0$ ]. If, however, the type B entrepreneur adopts the alternative strategy of mimicking the type G firm by offering an information production contract, his firm will obtain a good evaluation with a probability  $y$ , and a bad evaluation with the complementary probability  $(1 - y)$ , so that his expectation of the fraction of equity that he has to be provided to the venture capitalist in return for the investment amount  $I$  is  $ys_g^* + (1 - y)s_b^*$ . Thus the type B entrepreneur will choose the information production contract when  $ys_g^* + (1 - y)s_b^*$  is less than  $s_B^*$ , and the unconditional price contract otherwise. We now characterize the case where both type G and type B entrepreneurs offer a contract with information production to the venture capitalist.

**Proposition 1.** *If the coefficient of risk aversion  $\rho$  of the venture capitalist and the outsiders' evaluation cost  $c$  are not too large (i.e.,  $\rho < \rho_P$  and  $c < c_P$ , with  $\rho_P$  and  $c_P$  as defined in Appendix A), then the equilibrium in the case where the firm chooses private equity financing involves both types of entrepreneurs offering the venture capitalist a financing contract with information production (involving the equity fractions  $\{s_g^*, s_b^*\}$ ), and the venture capitalist accepts the contract.<sup>17</sup>*

The intuition behind the existence of the above equilibrium is clear from the preceding discussion. If the cost of evaluating the firm is not too high, the benefits of a contract with information production to the type G firm outweighs its only disadvantage, namely the fact that the evaluation cost needs to be incurred; the type G firm offers such a contract to the venture capitalist in equilibrium. Given this, the type B firm finds it advantageous to mimic the type G firm by offering a similar contract. Further, given that their projects

<sup>17</sup> The above equilibrium is supported by the out-of-equilibrium belief that if any entrepreneur (firm) offers the venture capitalist an unconditional price contract, or an information production contract with parameters other than those specified in the equilibrium contract, then the venture capitalist infers the firm to be of type B with probability 1.

have a sufficiently large positive net present value, both types of firms fund their projects up to the full investment level  $I$  in this equilibrium. (The condition specified on the extent of the venture capitalist's risk aversion simply serves to rule out the extreme case where the venture capitalist is so risk averse that he is unwilling to contribute the investment amount  $I$  to the firm, regardless of how high his expected return is on this investment amount.)

**Proposition 2 (Comparative Statics).** *The fraction of equity that has to be offered to the venture capitalist in return for the financing required is (a) increasing in the capital intensity of the firm,  $I$ ; (b) increasing in the uncertainty in the firm's investment technology,  $\sigma_\varepsilon^2$ ; (c) increasing in the cost of evaluating the firm,  $c$ ; and (d) increasing in the venture capitalist's coefficient of risk aversion  $\rho$ .*

Result (a) above follows from the fact that the risk-averse venture capitalist demands a greater expected rate of return for tying up a larger fraction of his wealth in a given firm (which occurs as  $I$  is larger). Result (b) follows from the fact that the venture capitalist, being risk-averse, needs to be compensated for greater variability in the firm's time 1 cash flow with a larger expected return. Further, as  $\rho$  increases, the compensation in terms of return per unit of uncertainty increases, which gives result (d). Finally, as the venture capitalist's cost of evaluating the firm is greater, the compensating return the entrepreneur provides him has to increase as well, yielding (c).

## 2.2 The Case Where the Firm Chooses to Go Public

We now study the situation where the entrepreneur chooses to raise the capital required for the firm by taking it public in an IPO. In this case, the firm issues a certain number  $n$  of additional shares which it offers to the public at a price  $p$ , thereby diluting the entrepreneur's original equity stake in the firm.<sup>18</sup> The entrepreneur's objective is therefore to raise the required external financing by issuing the minimum number of new shares (in other words, to raise the capital required while retaining the largest possible equity stake in his firm). We assume that the equity issue is such that the offering goes forward even if the firm is unable to sell out all the shares offered to investors (i.e., the firm is unable to raise the entire investment amount desired). We now characterize the equilibrium in the new issues market.

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<sup>18</sup> We abstract away from the role of the investment bank in marketing equity in the IPO. It has been argued that one economically important role of the investment bank is that of an information producer, who uses his reputation to convey this information to investors in the IPO market [see, e.g., Chemmanur and Fulghieri (1994)]. If this is the case, even if the firm uses an investment bank to market its equity, the trade-offs we model here will continue to be important as long as the investment bank is unable to dispel the asymmetric information between firm insiders and outsiders completely. Consequently the main difference in that situation will be that the adverse selection that is relevant for our analysis will be the residual adverse selection that remains after the investment bank has performed its role as an information producing and disseminating intermediary, so that the intuition behind our model goes through essentially unaltered.

**Proposition 3.** *There is an equilibrium in the new issues market involving the following:*

*The type G firm: It issues  $n_H$  shares, each at a price  $p_H$ , raising a total amount  $I$  for investment.*

*The type B firm: With probability  $\beta$ ,  $0 < \beta \leq 1$ , it pools with the type G firm by issuing  $n_H$  shares at the price  $p_H$ , of which only a number  $x n_H$  are bought by investors in equilibrium ( $0 < x < 1$ ), thus raising only an amount  $x I$ ; with probability  $(1 - \beta)$ , it separates from the type G firm, by issuing  $n_L$  shares at a lower price  $p_L$  ( $n_L > n_H$ ,  $p_L < p_H$ ), thus raising the entire amount  $I$  required for investment.*

*Investors: A fraction  $\alpha$  of the investors in the IPO market produce information, bidding for a share if and only if they get a good evaluation; the remaining fraction  $(1 - \alpha)$  engage in uninformed bidding.<sup>19</sup> Such an equilibrium will always exist if the outsiders' cost of evaluating the firm is not too high, so that:*

$$c < c_s \equiv (1 - \phi)(1 - y) \left[ \frac{1}{\bar{n}_H} - \frac{k_B - 1}{m} \right] I, \quad (8)$$

*(where  $\bar{n}_H$  is defined in Appendix A), and the information available to them is precise enough, so that  $y < \bar{y}$  (defined in Appendix A).*

In the above equilibrium, the type G firm always sets the high price  $p_H$ , since it is confident of always being able to raise the full amount  $I$  required for investment (since all investors who conduct an evaluation of the firm obtain a good evaluation for a type G firm). The type B firm, on the other hand, has to pay a price if it mimics the type G firm by setting the price  $p_H$ : among the informed investors, only a fraction  $y$  will obtain a good evaluation for the firm, while the remaining fraction  $(1 - y)$  obtain a bad evaluation and do not bid for shares. This means that some of the firm's shares will go unsold, leading the firm to scale back the investment in its positive net present value project, thus wasting value. Denoting by  $N$  the total number of participants (potential investors) in the firm's IPO, this implies that if the type B firm adopts the pooling strategy by offering  $n_H$  shares at a price  $p_H$  per share, the fraction  $x$  of these shares that will actually be sold will satisfy

$$x n_H = N[(1 - \alpha) + \alpha y], \quad (9)$$

since the investors who bid for shares in the IPO will consist of the fraction  $(1 - \alpha)$  of the total number of investors who engage in uninformed bidding,

<sup>19</sup> The out-of-equilibrium beliefs supporting the above equilibrium are that outsiders infer that any firm setting a share price other than  $p_H$  or  $p_L$ , or offering a number of shares other than  $n_H$  (at the price  $p_H$ ) or  $n_L$  (at the price  $p_L$ ) is a type B firm with probability 1.



and the fraction  $y$  of the  $\alpha$   $N$  information producers who (erroneously) receive good evaluations.<sup>20</sup> Denote by  $\theta$  the probability assessed by an uninformed investor that a firm offering  $n_H$  shares at a price  $p_H$  per share is a type B firm (taking into account the type B firm's equilibrium strategy of pooling with the type G firm with a probability  $\beta$ ). This is given by

$$\begin{aligned}\theta &\equiv \Pr\{q = B \mid p = p_H, n = n_H\} = 1 - \frac{\phi}{\phi + \beta(1 - \phi)}; \\ \Pr\{q = G \mid p = p_H, n = n_H\} &= 1 - \theta.\end{aligned}\quad (10)$$

Further, for any uninformed investor to find it worthwhile to bid for a share in the IPO, the following weak inequality has to be satisfied:

$$p_H \leq (1 - \theta) \frac{1}{m + n_H} V_G + \theta \frac{x}{m + xn_H} V_B. \quad (11)$$

In other words, an uninformed investor must at least be able to recoup the price paid (in terms of expected value). At the same time, for any participant to have an incentive to incur the additional cost  $c$  of producing information, the cost of producing information must be less than or equal to the expected value of the benefit from doing so (which arises from the ability to avoid bidding for a share in a bad firm if the informed investor gets a bad evaluation). Thus any equilibrium with information production must satisfy

$$c \leq \theta(1 - y) \left[ p_H - \frac{x}{m + xn_H} V_B \right]. \quad (12)$$

Note that both Equation (11) and Equation (12) incorporate the effects of the investors' information production strategy on the investment level adopted by the type B firm (recall that when the type B firm pools by setting the price  $p_H$ , it is able to sell only a fraction  $x$  of the  $n_H$  shares it offers investors, and will therefore invest only  $xI$ ).<sup>21</sup>

It now remains to be seen how the fraction of investors producing information,  $\alpha$ , and the probability of the type B firm pooling with the type G firm,  $\beta$ , are determined in equilibrium. We first discuss how  $\alpha$  is determined. To see this, consider first the extreme case where most investors in the IPO market engage in uninformed bidding. In this case, the cost imposed on the type B firm (in terms of having to scale back its investment) is very low, so that it has an incentive to mimic the type G firm by setting the high price  $p_H$

<sup>20</sup> Throughout this article we will ignore any integer problems associated with the number of bidders in the IPO.

<sup>21</sup> Some readers may wonder whether it is possible for the type B firm to offer for sale a number of shares larger than  $n_H$ , at a price of  $p_H$  each, in the hope of raising an amount greater than  $xI$  for investment. Clearly such an out-of-equilibrium strategy will not be adopted, since it will reveal that the firm is of type B with probability 1.

very often (thus creating an incentive for more investors to produce information). At the other extreme, if most investors in the IPO market choose to become informed, the cost to the type B firm from pooling with the type G firm will then be very high, so that it rarely mimics the type G (thus creating an incentive for more investors to remain uninformed). Thus the equilibrium  $\alpha$  will be such that the type B firm is indifferent between selling  $xn_H$  shares at price  $p_H$ , and selling  $n_L$  shares at price  $p_L$ . In other words, in equilibrium, the type B entrepreneur is indifferent between owning a smaller fraction of the larger firm with expected time 1 cash flow  $V_B$  (which will result if it sells  $n_L$  shares at price  $p_L$ ), and a larger fraction of the smaller firm with expected time 1 cash flow  $xV_B$  (which will result if it sells  $xn_H$  shares at a price  $p_H$ ). Thus Equation (13) will hold as an equality:

$$\frac{m}{m + n_L} V_B = \frac{m}{m + xm_H} xV_B. \quad (13)$$

At the same time,  $\beta$ , the probability with which the type B firm sets the high price  $p_H$ , is determined such that each investor is indifferent between producing and not producing information. To see the relationship between the equilibrium values of  $\beta$  and  $\alpha$ , consider first the extreme case where  $\beta$  is close to 1. In this case, since the type B firm mimics the type G most of the time, the expected benefit to investors from producing information is very high, thereby creating an incentive for a large fraction of investors in the IPO market to produce information (thus imposing a high cost on the type B firm for mimicking the type G, and inducing it to reduce the probability  $\beta$ ). At the other extreme, if  $\beta$  is close to zero (implying that the type B firm almost never mimics the type G), there is almost no benefit to outsiders from producing information about the firm, thus driving down the fraction of investors who produce information (thereby reducing the cost imposed on the type B firm if it mimics the type G, and inducing it to increase the probability  $\beta$ ). Therefore the equilibrium value of  $\beta$  will be such that all investors are indifferent between producing and not producing information, so that Equations (11) and (12) hold as equalities. In summary, the values of  $\alpha$  and  $\beta$  are determined simultaneously in equilibrium, such that Equations (11), (12), and (13) hold as equalities.

The equilibrium number of shares issued at the price  $p_H$  must also satisfy

$$p_H n_H = I. \quad (14)$$

Further, the separating price  $p_L$ , and the corresponding number of shares issued,  $n_L$ , must satisfy

$$p_L = \frac{1}{m + n_L} V_B; \quad p_L n_L = I. \quad (15)$$

Thus the equilibrium variables  $p_H^*$ ,  $p_L^*$ ,  $n_H^*$ ,  $n_L^*$ ,  $x^*$ ,  $\alpha^*$ ,  $\beta^*$ , and  $\theta^*$  satisfy Equations (9)–(15) simultaneously. In the above equilibrium, the price conveys information across investors so that many investors are able to engage in uninformed bidding, being aware of the existence of a large number of

informed bidders. At the same time, the presence of informed bidders ensures that the “noisiness” in the price of equity in the IPO market cannot be too large, in the sense that, on average, the pooling price  $p_H$  cannot be too far away from the true value of the firm’s equity. Thus, while there is some degree of duplication in information production by outsiders when a firm raises capital in the public equity market (in contrast to the case when it raises private equity financing from a single large investor, when there is no such duplication), the extent of such duplication is minimized by the considerable degree of free riding by uninformed investors on the information produced by the informed investors. Since evaluation costs are borne in equilibrium by the firm, the fact that the firm is able to obtain a significant part of its financing from uninformed investors in the public equity market considerably reduces its cost of capital.

It is instructive to compare the equilibrium in the IPO market above with that in Rock (1986). As in our model, there also the market consists of both informed and uninformed investors (though in Rock (1986) the informed investors are simply endowed with their information, so that there is no information production in that model, and the fraction of investors who are informed is exogenous). The crucial difference, however, between the IPO market in our model and that in Rock (1986) is that there the entrepreneur himself is uninformed. Therefore the IPO offer price set by him cannot depend on firm type. This, in turn, means that the offer price is not informative to any investor in the IPO, so that uninformed investors face severe adverse selection in the Rock (1986) setting.<sup>22</sup> In our setting, however, since the entrepreneur is informed about true firm value, he sets the IPO offer price optimally, anticipating the market response from informed investors. Consequently the IPO offer price is partially informative about firm type in our setting, so that the price serves to convey information across investors. Thus, in our model, uninformed investors do not face the kind of adverse selection present in the Rock (1986) model, and they do not invest in a disproportionately large fraction of type B firms (relative to the fraction of such firms in the pool approaching the IPO market).<sup>23,24</sup>

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<sup>22</sup> Since, in Rock (1986), the entrepreneur, who sets the offer price, is uninformed, all IPOs have to be either underpriced or overpriced from the point of view of an informed outsider. This allows the informed to bid selectively for shares in underpriced IPOs, leaving the uninformed with disproportionately large allocations of shares in overpriced IPOs. Rock argues that IPO underpricing is meant to compensate uninformed investors for this adverse selection, thus enabling them to break even from their participation in the IPO market.

<sup>23</sup> The incentive for a certain fraction of investors to produce information remains, however, since informed investors benefit from being able to distinguish between good and bad firms with some additional precision (compared to the uninformed). Thus, in equilibrium, the expected value of the benefit from producing information equals the cost of doing so, so that each investor is indifferent between uninformed and informed bidding for a share of stock in the IPO.

<sup>24</sup> As noted in the introduction, it is our assumption that the entrepreneur has private information about firm type that makes the fixed price informative to outsiders. In the alternative setting where the entrepreneur himself is uninformed about the type of his own firm, two kinds of equilibria would emerge. In the first kind, which prevails when the outsiders’ information production cost  $c$  is large (for a given precision), no

**Proposition 4 (Comparative Statics).** *The equilibrium pooling price  $p_H^*$  is (a) decreasing in the outsiders' cost of information production (i.e.,  $\partial p_H^* / \partial c < 0$ ); (b) decreasing in the error probability in the outsiders' evaluation technology (i.e.,  $\partial p_H^* / \partial y < 0$ ); and (c) increasing in the capital intensity of the firm (i.e.,  $\partial p_H^* / \partial I > 0$ ).*

As the cost of information production goes up (or the precision of the information goes down), there are less informed investors in the IPO market in equilibrium, so that the equilibrium frequency of the bad firm pooling by setting the price  $p_H$  increases. This, in turn, leads to a larger value of  $\theta^*$  (the equilibrium probability assessment of uninformed investors that a firm setting a share price  $p_H$  is a type B firm), and a lower value of the equilibrium pooling price,  $p_H^*$ . Thus the equilibrium pooling price  $p_H^*$  becomes a noisier indicator of the firm's true value as the outsiders' cost of evaluating the firm increases or the precision of their evaluation technology decreases.

The intuition behind part (c) is as follows. In equilibrium, mimicking the type G firm by setting the same offer price is costly to the type B firm. This mimicking cost arises from the need of the type B firm to scale down its project, since it is unable to obtain the full amount it wishes to raise in the IPO if it mimics the type G firm (given that only a fraction of information producers buy equity in this case). Clearly the larger the desired external financing amount  $I$ , the greater the magnitude of the shortfall in the amount actually raised by the type B firm, and therefore the greater the net present value foregone from the firm having to scale down its project. In other words, as the capital intensity  $I$  increases, the cost imposed on the type B firm when it mimics the type G firm also increases. This, in turn, implies that the equilibrium frequency with which the type B firm pools with the type G (by setting the price  $p_H$ ) decreases as  $I$  increases, resulting in a smaller equilibrium value  $\theta^*$  and a greater equilibrium pooling price  $p_H^*$ .

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outsider produces information, and the entrepreneur sets the offering price at the *unconditional* expected value of time 1 cash flows accruing to each share in the firm (i.e., expected value computed using his prior probability). The notion of type is irrelevant in the above kind of equilibrium, since no agent (the entrepreneur himself, or outsiders) knows firm type. In the second kind of equilibrium, which prevails when  $c$  is small, all outsiders produce information. Consistent with this, the entrepreneur sets the offering price at the *conditional* expected value of the time 1 cash flows accruing to each share in the firm (with the expectation taken across type G and type B firms) minus the outsiders' cost  $c$  of producing information. In other words, the entrepreneur prices the equity such that outsiders' expected payoff from producing information, net of information acquisition costs, is zero. In this equilibrium, the type G firm's project is fully funded, while the type B firm's project is only partially funded. Notice that a crucial difference between this second kind of equilibrium and the one prevailing in our model (where the entrepreneur knows his own type) is that, since the price is not informative about firm type when the entrepreneur is uninformed, all the funds raised in the equity market are raised from informed outsiders. Therefore, compared to that in our model, the extent of duplication in information production (and consequently, firms' cost of capital) would be significantly greater in such an alternative setting.

### 2.3 The Choice Between Private Equity Financing and Going Public

We now discuss the overall equilibrium of the model, involving the entrepreneur's choice between private equity financing and going public.

**Proposition 5 (Overall Equilibrium).** *Let the venture capitalist's risk aversion be less than a certain value  $\rho_M$  (with  $\rho_M < \rho_P$ ), and let the initial number of shares in the firm,  $m$ , exceed a certain minimum number  $m_0$ . Then there is a certain threshold value of the evaluation cost, denoted by  $c_A$  ( $c_A < c_s$ ), such that (a) if the evaluation cost of a firm is less than  $c_A$ , then the firm finances its project by going public; (b) if the evaluation cost exceeds  $c_A$  (but is less than a certain upper bound  $c_B$ ), then the firm finances its project using private equity financing in equilibrium ( $\rho_M$ ,  $m_0$ ,  $c_A$ , and  $c_B$  are defined in Appendix A).*

The advantage of private equity financing over going public is that the entrepreneur can use a single source to finance his project, thereby saving a large amount in the aggregate evaluation cost. However, the use of a single financing source automatically means that this financing source, the venture capitalist, will be less than fully diversified, and will have considerably more bargaining power relative to the entrepreneur compared to the numerous small investors whose financing the firm can tap into in the public equity market. Now, if the firm is relatively young (so that the outsiders' evaluation cost  $c$  is significantly large), the benefit from minimizing the outsiders' aggregate evaluation cost outweighs the disadvantage of providing the venture capitalist a greater return (either as compensation for the idiosyncratic risk he bears by tying up a substantial portion of his investment in the firm, or due to his ability to extract a fraction of the net present value from the firm's project using his greater bargaining power with the entrepreneur). However, as the firm ages, and establishes a track record of successful operation, its evaluation cost falls, and at these smaller magnitudes of the evaluation cost, the ability to tap numerous small investors by going public outweighs the disadvantage of the duplication in evaluation costs which occurs in the public equity market. The parametric restrictions on  $\rho$  and  $c$  in this proposition merely ensure that the overall equilibrium involves the behavior by outsiders (i.e., either the venture capitalist or investors in the new issues market) characterized in Propositions 1 and 3, respectively.<sup>25,26</sup> We now develop some comparative static results.

<sup>25</sup> The upper bound on  $\rho$  ensures that the venture capitalist is not so risk averse as not to invest in the firm regardless of the fraction of equity he is offered in the firm; the bounds of  $c$  serve to rule out the case where the information available to outsiders is so prohibitively expensive (for a given precision of the information) that it does not pay any outsider to engage in information production (see the proof of Proposition 5 for details). If this parametric restriction is not satisfied, so that  $c$  is prohibitively large, we obtain the rather uninteresting equilibrium in which the two types of firms pool with probability 1, with no information production by outsiders.

<sup>26</sup> The out-of-equilibrium beliefs supporting such an equilibrium are as follows: if investors (or the venture capitalist) observe a firm with  $c > c_A$  going public, they believe the firm to be of type B with probability

**Proposition 6 (Capital Intensity and Technological Uncertainty).**

(a) Firms which have greater capital intensity  $I$  go public earlier; and  
(b) firms characterized by greater technological uncertainty (i.e., which have a larger value of  $\sigma_\varepsilon^2$ ) go public earlier.

As a firm's capital requirement  $I$  is larger, there are two effects. First, the expected return used by the venture capitalist to evaluate the firm's equity increases (as discussed under Proposition 2), thus lowering the price of each share the firm sells to the venture capitalist. At the same time, the pooling price per share of equity sold by the type G firm in the public equity market increases [as discussed under Proposition 4(c)]. Therefore, as the capital intensity increases, the threshold value  $c_A$  at which firms choose to go public (rather than sell equity privately) becomes larger, so that firms with greater capital intensity will go public earlier. The intuition behind part (b) is that for firms in industries characterized by greater technological uncertainty, the risk premium demanded by the venture capitalist is larger, driving the firm to choose to go public at an earlier stage in its life.

**Proposition 7 (Hot Issue Markets).** Let the initial number of shares in the firm,  $m$ , exceed a certain minimum number  $m_1$  [defined after Equation (A8)]. Then, if there is a productivity shock in an industry such that  $k_G$  increases, the firms in that industry will go public earlier.

As the productivity parameter  $k_G$  increases,  $V_G$  increases. Therefore, if a firm in that industry chooses to go public, the benefit to a participant in its IPO from producing information is larger, so that the proportion of informed investors in equilibrium will also be larger, yielding a lower value of  $\theta$  and a correspondingly greater equilibrium equity price,  $p_H^*$ . This results in the cutoff value of the information production cost,  $c_A$  (at which firms prefer to go public rather than use private equity financing) to be larger, implying that firms in that industry will go public earlier. This proposition provides an explanation for why many firms in industries where there has been a relatively sudden technological advance (recent examples are the biotech and computer networking industries) tend to go public almost simultaneously ("hot" IPO markets): in the setting of our model, such a technological advance will lead to a fall in the threshold going-public value  $c_A$  for firms in that industry, resulting in a number of firms in that industry going public almost simultaneously.<sup>27</sup>

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1; similarly, if investors or the venture capitalist observe a firm with  $c < c_A$  using private equity financing, they believe that it is a type B firm with probability 1. The beliefs of outside investors supporting this overall equilibrium in response to out-of-equilibrium actions by the entrepreneur further along the game tree are discussed in Notes 17 and 19.

<sup>27</sup> To see this argument in more detail, assume (for concreteness) that the evaluation costs of various firms in a particular industry are distributed uniformly over a certain interval. In the normal course of events (i.e., absent a productivity shock), firms in that industry will go public at a uniform rate (as each firm ages, its evaluation cost decreases, until it falls below the threshold value  $c_A$ , at which point the firm goes public).

### 3. Empirical and Policy Implications

We highlight some of the empirical and policy implications of our model below.

(i) *Differences in the average age and size between private and public firms.* Our model implies that public firms will be older on average; further, it implies that (holding everything else constant) public firms will be larger, in terms of market value, than private firms.

(ii) *Cross-sectional variations across industries in the average age of firms going public.* Our model suggests that there will be systematic variations across industries in the average age at which firms go public. First, if we compare two industries where the difficulty in evaluating projects is similar (so that the evaluation costs of firms of the same age in the two industries is also similar), firms in the more capital intensive industry will go public earlier (Proposition 6). Second, if we compare two industries in which the capital intensity is similar, but the difficulty in evaluating projects is different, our prediction is that firms in the industry where projects are intrinsically more difficult to evaluate, and therefore have a larger evaluation cost at any given age, will go public later (since the evaluation cost of firms in that industry will fall to its threshold going-public value only later).

(iii) *Differences across markets in the average age of firms going public.* In many European countries, the number of financial intermediaries (investment banks and financial analysts) engaged in working with and producing information about companies, especially about smaller ones, is significantly lower than that in the United States.<sup>28</sup> Therefore the cost to investors of evaluating firms of any given age will be larger in such economies than in the United States. Consequently our model predicts that, on average, firms in these European countries will go public at a much later age compared to those in the United States. Consistent with this prediction, Pagano, Panetta, and Zingales (1998) document that the average age for Italian companies that went public during 1982–1991 was 33.4 years, compared with a U.S. average age of 6.7 years for venture-backed firms, and 11 years for non-venture-backed firms [see Gompers (1993) or Lerner (1994)].<sup>29</sup>

(iv) *Hot issue markets.* Several authors [see, e.g., Ritter (1984)] have noted that firms tend to go public in waves, with many firms in the same industry going public around the same time. In our setting, such “hot” IPO markets arise when there is an unanticipated increase in the productivity

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However, if the threshold value  $c_A$  falls suddenly as the result of a productivity shock, all the firms falling in the interval between the new and the old values of  $c_A$  will find it optimal to go public, creating a hot IPO market.

<sup>28</sup> See, for example, the discussion in Lerner (1995), regarding the paucity in Europe (in general) of investment banks working primarily with small firms.

<sup>29</sup> Rydqvist and Hogholm (1994) document an average age of firms going public in other European countries roughly similar to that in Italy.

parameter  $k_G$  in a particular industry (perhaps due to a relatively sudden technological advance), so that many firms in that industry will go public simultaneously in a short span of time subsequent to such a productivity shock (Proposition 7).<sup>30</sup> This generates the testable prediction that hot IPO markets will coincide with those periods when stocks of firms already listed in a given industry yield abnormally high returns (since, as  $k_G$  goes up, the equity market values of listed firms go up on average as well).

(v) *The rationale behind stock exchanges imposing stringent listing restrictions.* Clearly, an important question that exchanges must decide in the context of going public is the stringency of listing restrictions. For instance, in the context of the example quoted earlier (Note 1) about the London Stock Exchange waiving certain listing restrictions for some biotech firms, one question that arises is why restrictions (such as that requiring firms going public to have a 3-year profitability record) should exist in the first place. In the context of our model, such restrictions can be interpreted as a requirement about the minimum amount of information about the firm that has to be available to the public before the firm can be listed, thus imposing an upper bound on the outsiders' cost of information production.<sup>31</sup> We have shown here that the noisiness in the price of equity in the new issues market increases with the outsiders' cost of evaluating the firm. Imposing such an upper bound on the evaluation cost  $c$  leads to an upper bound on the variance (conditional on the equity offering price) of the true value of the firm whose equity is listed, and is consequently desirable for exchanges seeking to control this variance.

(vi) *Why firms need to go public before shares can be sold to a large number of investors.* Casual discussions of a firm's motivations for going public usually point to a need to improve the liquidity of the firm's equity, so that firm insiders can diversify their portfolios. Yet in a full information setting, it should be no more difficult for a private than for a public firm to sell shares to a large number of shareholders, thus allowing each investor (including insiders) to be fully diversified. Our model indicates why this is not possible in practice: selling equity privately to a large number of

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<sup>30</sup> Another way in which such hot IPO markets can arise in our setting is due to an exogenous reduction in the evaluation cost  $c$  of firms in a given industry again resulting in a number of firms in that industry going public during a relatively short span of time. Such an exogenous reduction in  $c$  for firms in a given industry may occur due to a few products from that industry becoming extremely successful (thus focusing media and other attention on the industry, thereby leading to a large amount of otherwise costly information about the industry becoming freely available in the public domain). Outsiders may also be able learn various lessons about evaluating firms in a given industry (especially in the case of industries employing very new technologies) from their experience with firms going public earlier, so that their cost of evaluating firms from the same industry going public later may be significantly reduced [see Benveniste, Busaba, and Wilhelm (1997) for a model, driven by motivations altogether different from ours, incorporating this feature].

<sup>31</sup> Other listing restrictions on most exchanges include minimum requirements on the firm's assets, net worth, and the total market value of the shares floated in the initial public offering. Clearly these restrictions also tend to contribute toward imposing an upper limit on outsiders' costs of evaluating firms.



shareholders means that each investor has to evaluate the firm independently, so that the aggregate evaluation cost (borne by the firm in equilibrium through a lower share price) will be prohibitively large.

#### **4. Conclusion**

We have developed a rigorous theoretical analysis of the going-public decision of a firm. Our model can be extended easily in several directions. One interesting extension of our model would be to allow for the reduction in the extent of outside shareholder monitoring that may occur after a firm goes public. Since, in our model, the entrepreneur does not suffer from moral hazard, there is clearly no role for the monitoring of firm management by outside shareholders. However, if we allow for such entrepreneurial moral hazard (e.g., by allowing for the possibility that the entrepreneur-manager may divert resources from the firm, or may slack off, thus reducing the firm's output), and incorporate the role of shareholder monitoring in controlling such value-reducing actions by firm management, then it seems to be the case that the extent of such monitoring would decrease significantly after a firm has gone public. This is because, since the share ownership in public firms is more dispersed, the free-rider problem in monitoring (which arises from the fact that while the costs of monitoring are incurred by one or a small group of shareholders, the benefits have to be shared with all shareholders) reduces, and may perhaps even eliminate, the incentive of any single shareholder or group to engage in the costly monitoring of the firm's managers. If, then, we make the extreme assumption that only private firm managers will be monitored, it follows that only firms whose entrepreneurs have accumulated a significant track record for successful operation (and thereby a reputation to lose if they engage in value-reducing actions) will find it optimal to sell shares in the public equity market, while those without such a track record will raise capital from private equity investors.<sup>32</sup> Thus, while allowing for moral hazard accentuates some of the problems associated with the existence of incomplete information, it seems to be the case that our results will continue to hold in a slightly modified form even in such a setting.

A second extension relates to the possibility of delay in undertaking the firm's project. One can think of situations where such delay is possible at a certain finite cost per unit of time by which the project is delayed (in our model, the implicit assumption is that the firm's investment opportunity is extinguished by delay). If we incorporate this feature, the entrepreneur will be faced with a three-way choice rather than a two-way choice between

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<sup>32</sup> This argument is analogous to the Diamond (1991) analysis of firms' choice between bank loans and publicly traded debt in the presence of entrepreneurial moral hazard and reputation acquisition.

private and public equity financing, the third possibility being to delay investment. However, the analysis we have developed above will go through in a modified form even in that case, with the additional complication that the entrepreneur now has to solve for the optimal point in time at which to implement his firm's project. Assuming that he knows how the magnitude of the outsiders' evaluation cost  $c$  will evolve over time (for instance, a smooth decrease with time), the entrepreneur can accomplish this readily as follows. He first solves for the equilibrium choice between private and public financing for the various values of  $c$  that will prevail in the future, yielded by our analysis above. He then solves for the value of his objective at various points in the future, assuming in each case that the optimal form of financing (i.e., corresponding to the value of  $c$  that prevails at the time) is adopted at any time. The optimal time to implement the project, and therefore to undertake the financing as well, will be when the entrepreneur's objective (expected cash flow from implementing the project net of the cost of waiting to implement it) is maximized.

## Appendix A

*Proof of Proposition 1.* In the proposed equilibrium both types of entrepreneurs pool by offering the same contract and the venture capitalist (VC) performs an evaluation according to Equation (2). Both types of entrepreneurs offer to the VC a contract  $\{s_g, s_b\}$  specifying the share of the firm accruing to the VC contingent on the result of the evaluation,  $e = g, b$ . We determine these shares as follows. If  $e = b$ , the entrepreneur is revealed to be of type B with certainty. Given the VC's utility of Equation (3), the fraction of the firm required by the VC,  $s_b^*(c, \rho)$ , is determined by taking the smallest  $s_b^*$  that satisfies Equation (6). Note that  $s_b^*$  does not depend on  $y$ . To ensure that  $s_b^* < 1$  and that the VC is willing to finance the entrepreneur, we assume that  $\rho < \rho_1 \equiv (V_B - I - c)/\sigma_\epsilon^2$ . It may immediately be verified that  $\partial s_b^*/\partial c > 0$ . If  $e = g$ , by Bayes' rules, the ex post probability that a firm is of type G is given by Equation (4). Let  $V_g = E(V | e = g)$  and  $\sigma_g^2 = \text{var}(V | e = g)$  the conditional mean and variance for this residual uncertainty. Let  $s_g^*(c, \rho)$  be the fraction of the firm that a VC requires if  $e = g$ . This is determined by taking the smallest root of Equation (5). We assume that  $\rho < \rho_2 \equiv (V_g - I - c)/(\sigma_\epsilon^2 + \sigma_g^2)$ . Note that  $\partial s_g^*/\partial c > 0$  and  $\partial s_g^*/\partial y > 0$ . Finally, given the out-of-equilibrium beliefs, an entrepreneur may deviate from the pooling contract and identify himself as a type B entrepreneur by offering a contract  $\{s_b\}$  which does not require information production. The share offered  $s_B^*(\rho)$  is now determined by setting  $V_u = V_B$  and  $\sigma_u^2 = 0$  in Equation (7).

Under the proposed pooling contract, a type G entrepreneur will be identified as such, and will always give the VC a share  $s_g^*$ . Hence he will prefer the pooling contract to the deviating contract  $s_B^*$  if and only if  $s_g^*(c, \rho) = s_B^*(\rho)$ . Note that  $s_g^*(0, 0) = I/V_g < I/V_B = s_B^*(0)$ . Let  $\rho_3$  be minimum  $\rho$  such that  $s_g^*(0, \rho) = s_B^*(\rho)$  (if there is no such a  $\rho$ , set  $\rho_3 = \infty$ ). Since  $s_g^*$  is an increasing function of  $c$  and  $\rho$ , given any  $\rho < \rho_3$  there is a  $c_g(\rho)$  such that  $s_g^*(c_g, \rho) = s_B^*(\rho)$ , and  $s_g^*(c, \rho) \leq s_B^*$  for all  $c \leq c_g(\rho)$ . Hence, for all  $c \leq c_g(\rho)$ , with  $\rho < \rho_3$ , a type G prefers the pooling contract  $\{s_g^*, s_b^*\}$  to the deviation  $s_B^*$ . Consider now a type B entrepreneur. Under the pooling contract, the expected share that a type B must give to a VC is equal to  $s^*(c, \rho) \equiv y s_g^*(c, \rho) + (1 - y) s_b^*(c, \rho)$ . This

type prefers the pooling contract if and only if  $s^*(c, \rho) < s_B^*$ . By an argument similar to the one developed earlier, note that  $s^*(0, 0) < s_B^*$ . Let  $\rho_4$  be the minimum  $\rho$  for which  $s^*(0, \rho) = s_B^*(\rho)$  (if there is no such  $\rho$ , set again  $\rho_4 = \infty$ ). Monotonicity in  $c$  of  $s_g^*$  and  $s_b^*$  implies that, given a  $\rho < \rho_4$ , there is a  $c_b$ , defined by  $s^*(c_b, \rho) = s_B^*(\rho)$ , such that  $s^* \leq s_B^*$  for all  $c \leq c_b$ . Hence also a type B prefers a pooling contract. The proof is then concluded by setting  $\rho_P \equiv \min\{\rho_1, \rho_2, \rho_3, \rho_4\}$ , and  $c_P(\rho) \equiv \min\{c_g(\rho), c_b(\rho)\}$ . ■

*Proof of Proposition 2.* Properties (a)–(d) follow from the definitions of  $s_g^*$  and  $s_b^*$ , and from implicit function differentiation of Equations (5) and (6). ■

*Proof of Proposition 3.* Consider first the conditions for the existence of a semi-separating equilibrium, given by Equations (9)–(15), where Equations (11) and (12) hold now as an equality. After simplification and rearranging, Equation (13) becomes  $m + xn_H = x(m + n_L)$ . Substituting this and Equation (14) into Equations (11) and (12), after noting that  $k_B/(m + n_L) = (k_B - 1)/m$ , we can simplify Equations (11) and (12) into

$$\begin{aligned} \text{(a)} \quad H(\theta, n_H) &\equiv (1 - \theta) \frac{n_H}{m + n_H} k_G + \theta n_H \frac{K_B - 1}{m} - 1 = 0, \\ \text{(b)} \quad G(\theta, n_H, c/I) &\equiv \theta(1 - y)[1/n_H - (k_B - 1)/m] - c/I, \end{aligned} \quad (\text{A1})$$

with  $0 \leq \theta \leq 1 - \phi$ . A solution to Equation (A1), with  $0 \leq \theta \leq 1 - \phi$ , will give the desired pair  $(n_H^*, \theta^*)$  (if there are multiple solutions, choose the one with the minimum value for  $n_H$ ). Using these values, Equation (13) may be solved for  $x^*$ , which gives  $\alpha^* = (N - x^*n)/(1 - y)N$ . Note that  $y < \bar{y}$ , where  $\bar{y} \equiv mn_H/[N(m + n_L - n_H)]$  guarantees that  $\alpha^* < 1$ . Bayes' rule [Equation (10)] may then be used to obtain  $\beta^*$ . Finally, Equation (15) yields  $p_L^*$  and  $p_n^*$ . Consider now Equation (A1b), which may be rewritten as

$$n_H = g(\theta) \equiv \theta[c/(1 - y)I + \theta(k_B - 1)/m]^{-1}. \quad (\text{A2})$$

After some algebra, it may be verified that  $g(\theta)$  is an increasing and concave function of  $\theta$ . Note that  $0 = g(0)$  and define  $\hat{n}_H = g(1 - \phi)$ . Note next that Equation (A1a) may be rewritten as

$$\theta n_H^2(k_B - 1) + n_H[1 - \theta]k_G + \theta(k_B - 1) - 1]m - m^2 = 0. \quad (\text{A3})$$

Solving Equation (A3) for  $n_H$ , define  $n_H = h(\theta)$  as the root where the positive sign is taken. Note that the discriminant of Equation (A3) is always positive and a solution exists. Also, implicit differentiation of Equation (A1a) implies that  $h'(\theta) = -(\partial H/\partial \theta)/(\partial H/\partial n_H) > 0$ , since it may be verified that  $H/\partial \theta < 0$ , and  $\partial H/\partial n_H > 0$ . Finally, let  $n_H \equiv h(0) = m/(k_G - 1)$  and  $\bar{n}_H \equiv h(1 - \phi)$ . Since  $g(0) = 0 < n_H = h(0)$ , we have that  $\hat{n}_H > \bar{n}_H$  and continuity of Equation (A2) together ensure existence of a solution to Equation (A1). From Equation (A2), condition  $\hat{n}_H > \bar{n}_H$  holds if and only if  $c < c_s \equiv (1 - \phi)(1 - y)I[1/\bar{n}_H - (k_B - 1)/m]$ . ■

*Proof of Proposition 4.* From implicit function differentiation of Equation (A1), we have

$$\frac{\partial n_H}{\partial(c/(1 - y)I)} = \frac{\partial H/\partial \theta}{\partial H/\partial \theta \cdot \partial G/\partial n_H - \partial H/\partial n_H \cdot \partial G/\partial \theta} > 0, \quad (\text{A4})$$

since  $\partial H/\partial \theta < 0$ , and  $h'(\theta) < g'(\theta)$  implies that the Jacobian determinant of Equation (A1) is negative. Properties (a)–(c) follow then from Equation (14). ■

*Proof of Proposition 5.* Note first that by substituting Equation (12) into Equation (11), the equilibrium price  $p_H^*$  in the IPO subgame is to  $p_H^* = V_G/(m + n_H^*) - c/(1 - \theta^*)(1 - y)$ . Let  $f_G^* \equiv n_H^*/(m + n)$ . A type G entrepreneur is indifferent between using a VC and selling to the market when

$$s_g^*(\rho, c) - f_G^* = s_g^*(\rho, c) - I/V_G - cn_H^*/(1 - \theta^*)(1 - y)V_G = 0. \quad (A5)$$

Let  $\rho_G(c)$  be implicitly defined by Equation (A5). Implicit differentiation gives that  $\partial \rho_G/\partial c = -[\partial s_g^*/\partial c - \partial f_G^*/\partial c]/(\partial s_g^*/\partial \rho)$ . Note that  $\partial s_g^*/\partial c \geq 0$ ,  $\partial s_g^*/\partial \rho \geq 0$ , and from Proposition 4 that

$$\frac{\partial}{\partial c} \left( \frac{cn_H^*}{(1 - \theta^*)(1 - y)V_G} \right) = \frac{n_H^* + c \frac{\partial n_H^*}{\partial c} + \frac{cn_H^*}{1 - \theta^*} \frac{\partial \theta^*}{\partial c}}{(1 - \theta^*)(1 - y)V_G} > 0. \quad (A6)$$

Since,  $n_H^* > \underline{n}_H \equiv m/(k_G - 1)$ , there is a value  $m_0 \equiv (k_G - 1)\partial s_g^*/\partial c$  such that for  $m > m_0$  we have that  $\partial \rho_G/\partial c > 0$ . Finally, note that for  $\rho = c = 0$ ,  $s_g^* > f_G^*$ , which implies that  $\rho_G(0) < 0$ . Consider now a type B. As a proportion of the full-scale firm (that is when  $\iota = I$ ), he must sell on the market a share  $f_B^*$  equal to  $f_B^* = I/V_B$ . Hence a type B is indifferent between the VC and the market if  $s_b^*(\rho, c) - I/V_B = 0$ . Let now  $\rho_B(c)$  be implicitly defined by the latter equality. It may be verified that, from Proposition 2, it is  $\partial \rho_B/\partial c < 0$ . Finally, note that for  $c = 0$  we have that  $f_B^* > \underline{s}^*$ , which implies that  $\rho_B(0) > 0$ . Let  $(\hat{\rho}, \hat{c})$  be defined by the intersection of  $\rho_G$  with  $\rho_B$ , that is,  $\rho_G(\hat{c}) = \rho_B(\hat{c}) = \hat{\rho}$ . Assume that  $\hat{\rho} > 0$ . Set  $\rho_M \equiv \min\{\hat{\rho}, \rho_P\}$ . For  $\rho < \rho_M$ , define values  $c_A$  and  $c_B$  such that  $\rho_G(c_A) = \rho_B(c_B) = \rho$ . From the previous discussion, it may be verified that for  $c_A < c < c_B$ , both types prefer the VC. If instead  $0 < c < c_A$ , type G prefer the market. Under these parameter values, and the specified out-of-equilibrium beliefs, if a type B uses the VC rather than the market, he is identified as such, and the VC would require a share  $s_b^* > f_B^*$ . Hence a type B prefers the market so as to pool with type G ones.

*Proof of Proposition 6.* The proof proceeds in a way similar to the proof of Proposition 5, after noting that  $\partial s_g^*/\partial I \geq 0$ ,  $\partial s_g^*/\partial \rho \geq 0$ , and that from Proposition 4 it is also

$$\frac{\partial}{\partial I} \left( \frac{cn_H^*}{(1 - \theta^*)(1 - y)V_G} \right) = \frac{c \frac{\partial n_H^*}{\partial I} + \frac{cn_H^*}{1 - \theta^*} \frac{\partial \theta^*}{\partial I} - \frac{cn_H^* k_G}{V_G}}{(1 - \theta^*)(1 - y)V_G} < 0. \quad (A7)$$

Hence  $\partial \rho_G/\partial I < 0$ ,  $\partial c_A/\partial I > 0$ , and, for any  $\rho$ , firms choose to go public for larger  $c$ . Following a similar procedure, we have that  $\partial \rho_G/\partial \sigma_\varepsilon^2 = (\partial s_g^*/\partial \sigma_\varepsilon^2)/(\partial s_g^*/\partial \rho) < 0$ , since  $\partial s_g^*/\partial \rho > 0$  and  $\partial s_g^*/\partial \sigma_\varepsilon^2 > 0$ . Hence  $\partial c_A/\partial \sigma_\varepsilon^2 > 0$ , and for any given  $\rho$ , firms choose to go public for larger  $c$ . ■

*Proof of Proposition 7.* The proof proceeds in a way similar to the proof of Proposition 5, after noting that  $\partial s_g^*/\partial k_G \leq 0$ ,  $\partial s_g^*/\partial \rho \geq 0$ , and using Equation (A4) that

$\partial n_H^*/\partial k_G < 0$  and  $\partial \theta^*/\partial k_G < 0$ . Hence

$$\frac{\partial}{\partial k_G} \left( \frac{cn_H^*}{(1-\theta^*)(1-y)V_G} \right) = \frac{c \frac{\partial n_H^*}{\partial k_G} + \frac{cn_H^*}{1-\theta^*} \frac{\partial \theta^*}{\partial k_G} - \frac{cn_H^* I}{V_G}}{(1-\theta^*)(1-y)V_G} < 0. \quad (A8)$$

Again, since  $n_H^* > \underline{n}_H$ , there is a  $m_1 \equiv -(V_G/cI)\partial s_G^*/\partial k_G$  such that  $\partial \rho_G/\partial k_G < 0$  for  $m > m_1$ . ■

## Appendix B: The Case of a Risk-Neutral Venture Capitalist with Positive Bargaining Power $\gamma$

In this appendix we show that the main results of the article hold also in the case of a risk-neutral venture capitalist (VC) holding some bargaining power over the entrepreneur. Consider the case of private equity financing, discussed in Section 2.1. The structure of the model is the same, except that now the VC is risk neutral and he is able to extract from the entrepreneur a fraction  $\gamma$  of the NPV of the project. Since the VC and the entrepreneur bargain after joint observation of the outcome of the evaluation, the fractional shares  $\{s_g^*, s_b^*\}$  are now determined as follows:

$$s_g^* V_g = c + I + \gamma(k_g - 1)I, \quad (5')$$

$$s_b^* V_B = c + I + \gamma(k_B - 1)I, \quad (6')$$

replacing Equations (5) and (6), respectively. We then have

**Proposition 1' (Private Equity Financing).** *If  $c < \bar{c}$ , then the equilibrium of the private placement subgame involves both types of entrepreneurs offering the VC a financing contract with information production involving equity fractions  $\{s_g^*, s_b^*\}$ , and the VC accepts the contract.*

Hence, if the information cost is not too large, firms of both types pool by offering a contract with information production. This contract is costly to the firm in that the VC is able to extract a fraction  $\gamma$  of the net present value of the project. Furthermore, implicit differentiation of Equations (5') and (6') yields

**Proposition 2' (Comparative Statics).** *The shares  $s_e^*$ , for  $e = g, b$ , increase with information production cost  $c$ , with the bargaining power  $\gamma$  of the VC and decrease with capital intensity  $I$ : (a)  $\partial s_e^*/\partial c > 0$ , (b)  $\partial s_e^*/\partial \gamma > 0$ , and (c)  $\partial s_e^*/\partial I < 0$ .*

The properties of the equilibrium in the IPO case (Section 2.2) will remain the same here. Hence we can characterize the equilibrium in the overall game as follows:

**Proposition 5' (Overall Equilibrium).** *Let  $\gamma < \hat{\gamma}$  and let  $m > \hat{m}_0$ ; then there is a pair  $\{\hat{c}_A; \hat{c}_B\}$ , with  $\hat{c}_A < \hat{c}_B$ , such that if  $0 \leq c \leq \hat{c}_A$  then the firm finances the project on the public market, and if  $\hat{c}_A < c < \hat{c}_B$  the firm finances the project with the VC.*

The predictions of this modified version of the model derive from the following propositions:

**Proposition 6' (Capital Intensity).** *Let  $m > \hat{m}_2$ , then  $\partial \hat{c}_A / \partial I > 0$ .*

**Proposition 7' (Hot Issues Markets).** *Let  $m > \hat{m}_1$ , then  $\partial \hat{c}_A / \partial k_G > 0$ .*

Propositions 6' and 7' imply that firms with greater capital intensity  $I$  and firms in industries experiencing a positive productivity increase  $k_G$  will go public earlier. Thus the main results of the article hold also in this alternative setting.

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