Technological Innovation and Initial Public Offerings

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This article shows how both technological and competitive risks affect the timing of private and initial public offerings in an emerging industry. Early private financing occurs in industries that are perceived to be risky, with high development costs and low probability of being displaced by technologically superior rivals. Early public financing occurs in industries perceived to be viable, with low development costs and low probability of displacement. Due to feedback effects between financial and product markets, the value of investors' proprietary information is greater in private than in initial public offerings. This has implications for underpricing.

> Very rapid change often creates entrepreneurial opportunity: it also creates risk. Analysis of the hard drive industry reveals the dark side of rapid technological evolution and of customer instability. Early players are often preempted by changes in technology and in customer needs. Early birds are not always winners in product markets, but late comers are almost always losers. [Sahlman and Stevenson (1985, p. 8)]

In industries undergoing rapid technological change, the optimal timing, pricing, and success of a securities offering depend not only on the individual firm but also on the competitive environment in the industry. Firms pioneering a new technology face a trade-off. A pioneering firm that invests early may gain an advantage in the product market. However, the firm faces the risk that it does not have the winning technology and may be subsequently forced out by rivals who turn out to have a better technology.[1] Moreover, the

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[1] As an example, Christensen (1993) has identified two distinct strategies used by entrants in the computer disk-drive industry, one of the most active for initial public offerings (IPOs) in the 1980s. Christensen shows that through three revolutions of technology and waves of entry, 25 of the 28 IPO firms that adopted an established technology eventually failed, and 16 of the 40 firms that adopted a new, unproven technology succeeded.

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firm risks revealing valuable information to potential entrants by its investment and financing decisions.[2]

In this article, we analyze how firms time their investment and choose a financing method in an industry that is undergoing technological change. We address the following questions: How do technological risks affect the choice between private and public financing? When will a firm choose to postpone external financing? When should we expect IPOs to be clumped together in time? Do privately and publicly financed firms have the same risks?

To answer these questions we model an industry in which investment is made in two stages: an initial stage, in which the firm acquires the technology and finds out whether it is viable, and a second stage, in which firms finance production facilities. The model considers a number of existing (pioneering) firms that require capital to finance the second stage and many potential entrants who have not yet invested in the first stage. New entrants can invest in the same technology as the pioneering firms or in a potentially superior technology. New entrants discover whether a technology is viable directly after they have acquired it. But even before deciding whether to invest in the first stage, potential entrants can make inferences from the pioneering firms' financing decisions.

We first determine how external financing decisions of pioneering firms affect both their initial profits and the entry into the industry by potential rivals. The risk of encouraging new entry occurs with both public and private offerings but is higher with the former. Our model shows how the new-entry risk and the risk of displacement by superior technology (technology risk) interact with each other. We show that a key determinant of the sizes of the two risks is the cost of the initial investment in research and development of technology (first-stage investment) relative to the total investment required to compete in the industry.[3] This first-stage investment cost is a sunk cost for pioneering firms already in the industry, but it is the initial cost of entry for potential entrants. Pioneering firms in industries where first-stage investment costs are high relative to later investment costs face a relatively high new-entry risk of external financing and relatively lower technology risk.

Our model shows that early private financing occurs in industries that are perceived by the market to be risky (the viability of the industry itself is uncertain) and where the relative first-stage cost is high but the probability of being displaced by more technologically advanced rivals is low. Early

[2] These interactions have been noted in the business press. For example, in a cover article on IPOs, *Business Week* (December 18, 1995, p. 67) pointed out that an IPO by a pioneering firm in an emerging industry can set up a chain reaction as rivals and potential entrants raise capital to position themselves in the industry: "By the late 1970s, medical researchers and academic scientists had made great strides in genetic science. Yet it was unclear whether or not a biotechnology industry was a sustainable business proposition. In 1980, the tremendous market reception given Genentech's IPO unlocked financial purse strings and persuaded many scientists to start up companies."

[3] One may alternatively refer to this as the relative growth option cost or the cost of obtaining a toehold into the industry, relative to the total cost of preparing for full-scale production.

public financing occurs in industries that are perceived to be viable, in which there are low relative first-stage costs and where the probability of being displaced by more technologically advanced rivals is also low. Predictions for the timing and type of financing for industries that do not fit all of these criteria depend on more detailed trade-offs.

We develop a condition for describing the relative magnitudes of the new-entry and technology risks faced by pioneering firms. We show that in industries where the new-entry risk is the more significant risk there will be herding of IPOs. That is, the first public offering in an industry will cause other pioneers to go public around the same time. On the other hand, if technology risk is more significant, the industry may only be able to support a small number of early IPOs. Those who are not first or second will have to wait until the uncertainty about the new technology is resolved.

We show that the variance of returns realized by the initial purchasers of firms' securities is higher when the firm is financed privately than when the firm is financed publicly. This is because when a pioneering firm goes public it creates a secondary market in its own shares in which investors who hold proprietary information about the new technology may partially reveal their information to potential industry entrants. The information affects the competitors' entry decisions in such a way as to reduce deviations of the returns on investment.[4] Such informed investors' information is less likely to be revealed to potential competitors in the absence of a public secondary market. As a result, there will not be feedback from the financial market to the product market and the realized rates of return for pioneering firms that seek private financing will deviate more from the opportunity cost of capital than if the same firms had sought public financing. We show that this difference is increasing in the relative cost of the first-stage financing, the probability of technological displacement, and the public perception of the riskiness of the industry.

An implication of this feedback between the financial market and the product market is that the value of proprietary information that some investors may possess is reduced. As a result, the adverse selection risk faced by investors when a firm issues securities is also reduced, making a public offering more attractive relative to private financing. To the extent that underpricing of initial offerings depends on adverse selection, our model can be used to make predictions about the magnitude of underpricing in different industries.

Interactions between product and financial markets have been studied by Maksimovic and Zechner (1991), Maksimovic et al. (1995), and Williams

[4] Positive (negative) information about the long-run prospects of the issuing firm induces additional (decreased) entry of competitors using the same technology, thus dampening the positive (negative) effect of the information on the valuation of the issuing firm.

(1995), who examine the relationship between leverage, risk, and technology choice. The trade-off between disclosures to investors and product market competition was first explored by Bhattacharya and Ritter (1983). Our model differs from theirs in that we allow for the interaction of two types of information concerns that affect decisions in different ways, and we demonstrate how the relative first-stage cost plays an important role in determining the sequence in which firms go public. We also develop testable propositions about how technological options affect the market for IPOs and private offerings, as well as short-term and long-term failures. A review of the literature on the interactions between product and financial markets is given in Maksimovic (1995).

The timing of IPOs has been examined in a single-firm context by Yosha (1995), Zingales (1995), and Chemmanur and Fulghieri (1999). This article is also somewhat related to work on IPO performance across industries. Mauer and Senbet (1992) show that underpricing varies by industry. Ritter (1991) suggests that long-run performance of IPOs may also vary across industries and raises the possibility that the market's reception of an IPO may predict long-run performance. But existing theories of IPO pricing and performance do not explain the relation between the market's reception of IPOs and subsequent financing activity and investment in an industry.

The rest of the article is organized as follows. Section 1 describes the basic model. Section 2 characterizes the evolution of the industry and the timing of IPOs and private financing. In Section 3 we summarize our basic results on the timing and choice of financing in emerging industries. Section 4 generalizes the model to the case of asymmetrically informed investors. In Section 5 we discuss further implications and possible extensions of this work. A list of the notation and proofs of the propositions are in the Appendix.

1. The Model

To examine the financing timing decision, we assume that a project is funded in two stages. We focus on "pioneering" firms that have already successfully completed the first stage and are deciding whether to finance the second stage immediately or wait. Once a pioneering firm has decided to seek external financing, the firm must also decide whether to seek private or public financing.

There is an unlimited pool of "potential entrants" who have not as yet made any investment. Assuming that the pool of potential entrants is unlimited means that new entry will occur up to the point where the cost of entry is equal to the expected profit for entry. If these potential entrants wish to enter the industry and compete with the pioneers, they will need to purchase the first stage in the near future. The entry decisions of these potential entrants will be affected by any information released by a pioneer's early financing. Thus, pioneering firms that are considering early second-stage financing will take into account the "cost" of releasing positive information to potential entrants.

In addition to these firms, there exist firms that are developing new technology. The pioneering firms that have already successfully completed stage 1 have done so using an established (E) technology. If the new (N) technology is successful, then all firms with the established technology will be supplanted. Thus, pioneering firms that do early financing of the second stage risk misallocating funds. The risk of misallocation can be avoided by postponing expansion. The N technology firms are not modeled in detail because they do not make any decisions in the model. Decisions will be made by pioneering E firms (wait, public, or private) and by potential entrants (enter or not). These decisions, however, are made taking into account the existence of a new technology with an exogenously given probability of success.

For ease of modeling we assume that the two technologies differ only in production costs. If the N technology succeeds, then the unit cost using this technology will be lower than the unit cost using the E technology. We will only consider parameter values such that the unit cost for firms employing the N technology, if it succeeds, is sufficiently low such that firms with this technology will displace all firms that have adopted the E technology. However, if the innovation fails, firms that have chosen the N technology will have costs sufficiently higher than the E technology firms such that they cannot successfully compete in the industry.[5]

Entrepreneurs who have completed the first-stage investment learn their own production costs and the costs of rivals who have chosen the same technology. They may not learn the costs of rivals who have chosen a different technology. Further detail on the sequence of events is provided in Figure 1 and the description that follows.

The model focuses on two periods during which firms can enter and install production capacity. Each of the periods is broken into three subperiods. At time $1a$ pioneering firms enter the industry by investing in the first stage of the project. Each firm chooses one of two possible technologies, N (new) or E (established), to produce a homogeneous product. Regardless of the choice, the cost of the first-stage investment is kG and the additional investment required to purchase the second stage of the project and initiate full production is $(1-k)G$ where k is strictly less than one. The number of pioneering firms with prototypes of each technology type is taken as exogenous in the model and is assumed public knowledge.

Technology E firms learn their production costs at time $1b$ and, in doing so, learn whether the industry is viable. Technology N entrepreneurs may

[5] The model can be generalized to allow a proportion of firms choosing both technologies to fail due to idiosyncratic factors, such as inability to successfully implement a technology in their plants. It is also possible to ease the parameter restrictions so that success of the new technology would result in loss of value rather than complete failure of established firms. This would greatly complicate the analysis without changing the qualitative results.

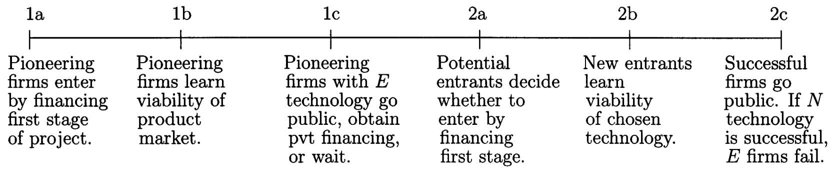

Figure 1
Timeline

also learn at this time whether their new technology will be successful. At this time the public believes that with probability θ $(0 < \theta < 1)$ the industry is viable and with probability λ $(0 < \lambda < 1)$ the N technology will prove to be successful. The public probability that the E technology will prove successful in the long run is thus $\theta(1 - \lambda)$ and that the N technology will prove successful in the long run is $\theta\lambda$. The actual viability of the industry is known only by the pioneering entrepreneurs. The success or failure of the N technology, if it is known at this time, is known only by the pioneering entrepreneurs who are using the N technology.

If the industry is viable, then the E technology can be implemented immediately by raising additional funds from external financing and completing the second stage of the project. We assume that the N technology firms, even if they have learned good news, are not yet ready to expand into the second stage. At time $1c$ technology E firms decide whether or not to finance a full-scale plant and, if so, how to finance this expansion. We assume that at the time that a firm obtains external financing, the entrepreneur must fully disclose to investors what has been learned about the viability of the chosen technology. In the case of an IPO this information becomes public and thus known to potential entrants into the industry. This accords with institutional requirements for IPOs in the United States.[6] If a firm issues shares privately, this financing may or may not be publicly observed. With probability z the fact that some firm(s) have obtained private financing becomes known to the market, and thus to potential new entrants, by time $2a$.[7] If such financing is observed, then potential competitors know that the E technology has so far proved viable. Although private financing has the advantage of possibly not releasing information to potential competitors, it also has the disadvantage of being more costly than public financing.[8] We assume an additional fixed cost of F.

[6] The Securities and Exchanges Commission requires that firms proposing an IPO make extensive information disclosures that include audited financial statements and profitability projections [Tinic (1988), Hughes and Thakor (1992)]. Sufficient information revelation may occur even without this regulatory mandate.

[7] We assume that the number of firms obtaining private financing does not affect the probability z. Although it would be straightforward to generalize the model to the case in which z depends on the number of firms obtaining private financing, this would greatly complicate the exposition.

[8] See Maksimovic and Pichler (1999) for an analysis of the adverse effect of limiting sales to a pool of private investors on the pricing of initial offerings. Such effects exist even in the absence of risk aversion and liquidity concerns.

At time $2a$ potential entrants into the industry decide whether to enter and with which technology. New firms enter by making the first stage investment kG. The number of firms that choose to enter will be a function of the information that is publicly available at this time. An increase in the probability of long-run viability of a given technology will lead to an increase in the number of firms that enter with that technology. The exact equilibrium condition that determines the number of entrants is given in the following section. Any pioneering firm that financed their second stage at time $1c$ will also start producing at this time.

At time $2b$ all new firms learn their production costs and whether the industry is viable, if this was not already revealed at time $1c$. If the pioneering N firms did not learn of the success of their technology at time $1b$, then they learn this at time $2b$.

All firms that appear to be viable attempt to go public at time $2c$. Because information release is no longer a concern at this point in time, we can assume without loss of generality that all firms that finance at time 2c do so with a public offering. If the N technology has failed, then only E firms will go public at time $2c$. If the N technology has succeeded, then all private firms will attempt a public offering at time $2c$, but only the N firms will succeed and any E firms that had obtained financing and expanded at time $1c$ will cease operations at the end of this period. Thus, if the N technology proves to be successful, then we will see failure of any E technology firms that went public at time $1c$. We may also see turbulent IPO markets at time $2c$, with the failure of E IPOs, if both N and E technology firms are attempting to go public.[9]

Firms that have obtained financing at time $2c$ install their full-scale plants by time 3. All firms with installed capacity that remain in the industry produce in each period in perpetuity. Further entry into the industry is no longer possible.[10]

We assume that without the second-stage investment no cash flows can be generated and a firm is worthless. As in Myers (1977), an entrepreneur may wish to expand even if he is unable to recover the entire sunk cost kG. The entrepreneur may, however, choose to wait and attempt expansion at a later date. Firms that choose to go public are valued by the financial market at the expected present value of future cash flows, given all publicly available information, including the disclosures by all firms selling shares to the public. Firms that choose to obtain private financing are valued by private investors who use information revealed by the selling entrepreneur, together with other publicly available information.

[9] In an a less extreme competitive environment, E firms will have their share prices adjusted significantly downward, either during the premarketing stage of the IPO or soon after the IPO is completed.

[10] This is a tractable way of modeling the observation by Sahlman and Stevenson (1985), quoted in the introduction, that late comers are almost always losers.

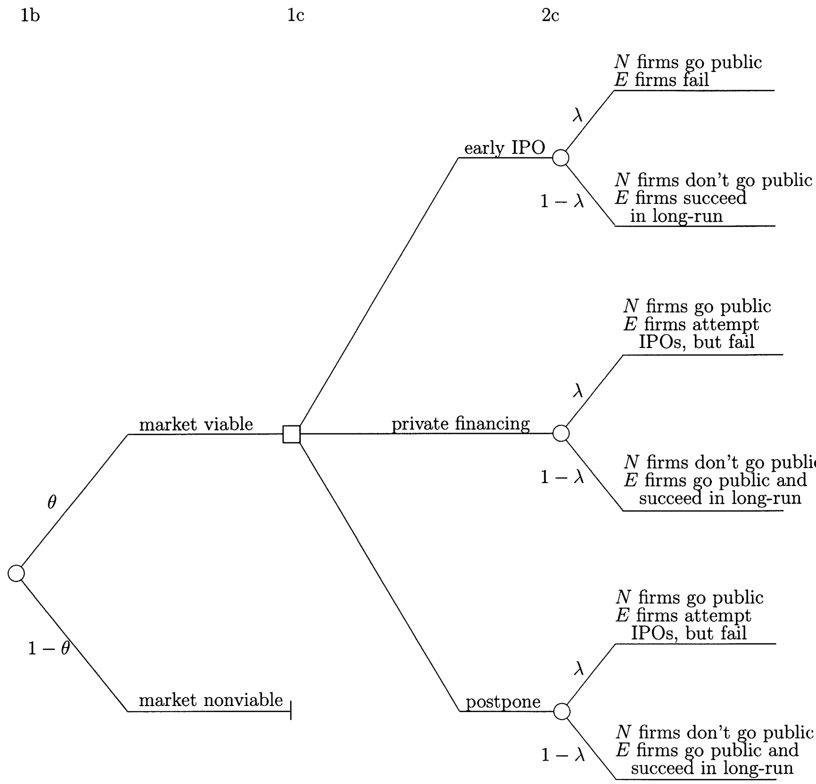

Figure 2
Decision tree for established technology pioneering firms

Our analysis focuses on the decisions made by firms at times $2a$ and $1c$. The decisions made at time $1a$ are taken as given. Figure 2 presents the decision tree for pioneering E firms. The decision tree for potential rival firms is presented in Figure 3.

To further define the model we assume that after funding the second stage, each firm can produce with a constant per-unit variable cost of c_i, $i \in \{N, E\}$. We model the demand for the output as a linear function, so that in each period $p_t = a - bQ_t$, where p_t and Q_t are the market price and the aggregate output at time t and a and b are positive constants. The opportunity cost of capital is r. In the product market firms compete strategically, each setting production quantity to maximize profits given the outputs of other firms. In each period the quantity produced and the single-period profits made by each producing firm depend on the number of other firms producing and on their technologies. The production quantities are derived assuming a Cournot equilibrium.

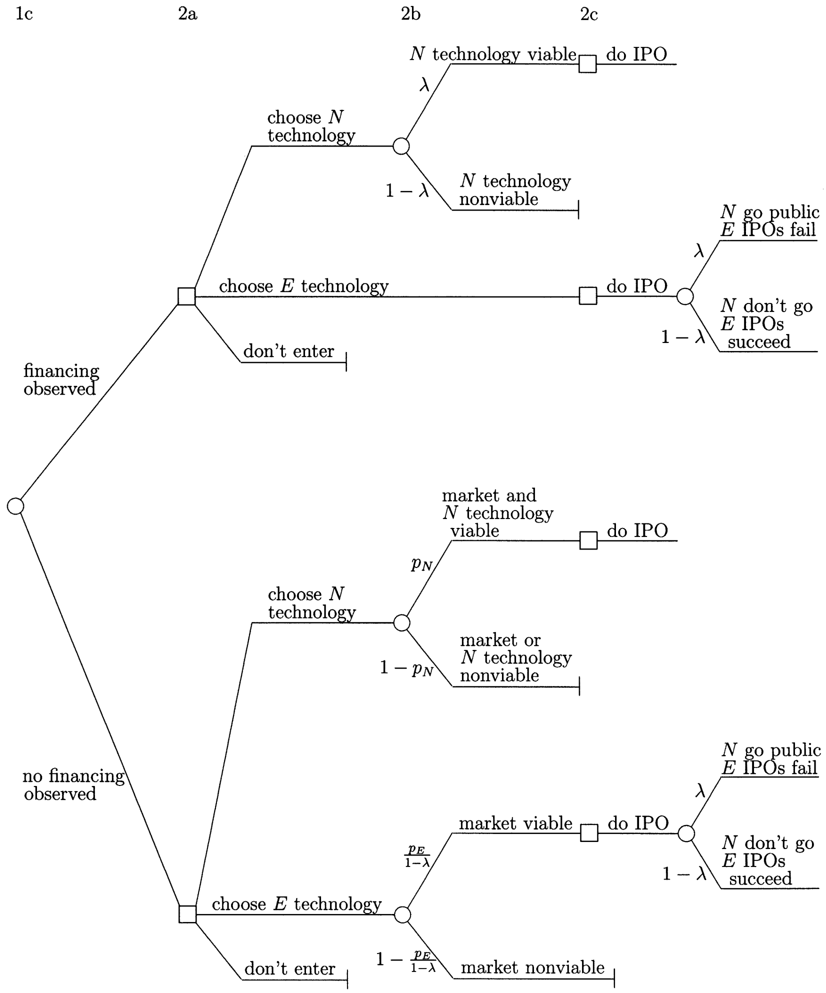

Figure 3
Decision tree for potential rival firms

The key endogenous variables are the numbers of firms utilizing each technology that go public or seek private financing at the ends of the first and second periods and the resulting firm values. The exogenous variables are the industry demand characteristics $\{a, b\}$, technology characteristics $\{k, G, c_N, c_E\}$, the discount rate r, and the a priori common knowledge probabilities of industry viability and of the success of the N technology $\{\theta, \lambda\}$. A summary of the notation is given at the beginning of the Appendix. Most of our results will explore the effects of three of the exogenous variables: k (the relative cost of the first-stage investment), θ (the prior probability that the industry is viable), and λ (the prior probability that the new technology will be successful).

2. Timing of IPOs

In this section we answer three questions: What determines whether firms obtain financing early or late in the industry development cycle? If early financing is obtained, under what conditions is this financing private or public? What industry characteristics are associated with the risk of long-term failure of IPOs?

We identify patterns of financing activity and associate each pattern with a different equilibrium of our industry game. We then characterize the patterns of financing as a function of industry characteristics. An equilibrium consists of three parts: (a) a financing strategy for each pioneering E firm that specifies whether at time $1c$ it goes public, obtains private financing, or waits; (b) the number of new entrants into the industry at time $2a$[11]; and (c) the financial market price of an IPO or private offering. We solve the problem using the perfect Bayes's equilibrium concept, which requires that in equilibrium each agent maximize his payoff, given the equilibrium choices and beliefs of the other agents, and that the beliefs of all agents are consistent with Bayes's rule. Our focus will be on part (a) of the equilibrium, although parts (b) and (c) are also endogenously determined.

We identify and demonstrate the existence of three pure strategy equilibria: All pioneering firms wait until period 2 to obtain financing (W); at least two pioneering E firms do an IPO at time $1c$ (I); and at least two pioneering firms obtain private financing, and no firms do early IPOs (P). In the I equilibrium any pioneering E firms that do not do early IPOs will postpone financing. Other patterns can be ruled out. For example, it is not an equilibrium for some firms to obtain private financing while others obtain public financing. In such cases, the firms obtaining private financing would be paying a higher financing cost, but they would not have a corresponding informational advantage because the firms doing IPOs would release all pertinent information.[12]

If the industry has proved viable, then a pioneering E firm will be interested in financing early to obtain early production profits.[13] However, a

[11] We will concern ourselves only with the number that choose the E technology because this will affect the value of the pioneering E firms.

[12] There are also special cases where it is optimal for only one firm to finance early. We refer to the equilibrium in which only one pioneering firm may do an IPO as I' and the equilibrium in which only one pioneering firm may obtain private financing as P'. These equilibria raise some distinct modeling issues but do not qualitatively affect any of the results that we focus on in the article. We discuss these equilibria briefly in the text but develop them only in the Appendix.

[13] To keep the analysis from becoming too complicated, we model the benefit to early second-stage financing as simply the benefit of producing in the early period. Additional benefits could include possible benefits from being a first mover. The model could also be extended here to allow for the possibility of positive aspects of signaling to rivals. These extensions are reserved for later work.

pioneering E firm may hesitate to finance early due to two concerns: the possibility that early financing will release information that will encourage new entry into the industry, thus adversely affecting the long-run profits earned by all firms, and the possibility that a superior technology will make the current technology obsolete. To address the former concern, we first determine how potential entrants' decisions at time $2a$ depend on the publicly available information concerning the viability of each technology. Next, we discuss each financing pattern and present the trade-offs that pioneering E firms face. Finally, we show how observed patterns of IPOs and private financing depend on industry characteristics.

Subsections 2.1 and 2.2 provide precise descriptions of the equilibria and an outline of the solution method. These sections are necessary for the technical development of the solution, but may be skipped by readers not interested in this development. The results are presented in subsections 2.3 and 2.4. Empirical predictions are summarized in Section 3.

2.1 Potential entrants' decisions and the equilibrium long-run profit

For each technology, at time $2a$ a number of new entrepreneurs will enter and construct prototype plants. Entry occurs until the expected profit from participating in the industry equals kG, the cost of the prototype plant:

$$p_i \times \left(\frac{\pi_{i3}}{r} - (1-k)G\right) = kG, \tag{1}$$

where p_i, $i \in \{N, E\}$, is the potential entrants' probability that technology i is viable in the long run, and π_{i3} is the long-run per-period profit that each firm in the industry earns in that case. We are able to treat each technology separately because we have assumed that the probability of both technologies surviving in the long run is zero. Thus, the left-hand side of Equation (1) is the expected value, net of the expansion cost, of entering the industry. New entrants pay the expansion cost $(1-k)G$ only if the technology proves to be viable. As a result, more new entry occurs when k is low.[14]

We assume that in the long run pioneering firms will have the same annual profits as the newer entrants. Thus, Equation (1) also characterizes the relationship between potential entrants' estimates of the viability of technology i and the realized long-run profit of the pioneering firms, if technology i proves viable. Equation (1) shows that the long-run single period profit π_{i3} is inversely related to p_i for each technology. This is because, as the potential entrants become more certain that a particular technology is viable in

[14] Equation (1) can be rewritten to show the role that an entrant's option to abandon the industry plays in determining the long-run profts: $p_i\pi_{i3}/r = G - (1-p_i)(1-k)G$. The left-hand side is expected discounted present value of future profits. The second term on the right-hand side, $(1-p_i)(1-k)G$, is the value of the option to abandon the industry. The higher the value of this option, as determined by the cost of prototypes, k, and the entrants' estimates p_i, the lower the expected long-term profits of firms in the industry.

the long run (p_i increases), a greater number of entrants choose that technology. The additional entry increases competition and lowers the long-run expected profits of the pioneering firms with that technology. For this reason, in determining the timing of their financing, the pioneering firms take into account the effect of their announcements on potential entrants' information, as represented by p_i.

2.2 Equilibrium financing patterns

At time $1c$ each pioneering firm will either do an IPO, obtain private financing or wait. When determining an action for a pioneering firm we will concern ourselves only with the case in which the industry is viable. Otherwise, the decisions of these firms are irrelevant. When determining the actions of potential entrants, however, we need to keep in mind that they may not know if the industry is viable. At time $1b$ potential entrants into the industry have a prior probability θ that the industry is viable. At time $1c$ the potential entrants update their beliefs, according to what they observe. If potential entrants observe an E firm obtaining financing in period $1c$, then they will know that the industry is viable. As a result they will update the probability that the N technology is viable to $p_N = \lambda$ and the probability that the E technology is viable to $p_E = 1 - \lambda$. If no early financing is observed, then beliefs will depend on the particular equilibrium. These beliefs are given in Table 1 and discussed below.

In equilibrium W potential entrants learn nothing when they do not observe financing at time $1c$, and so they maintain their prior beliefs. In the I equilibrium, if the industry is viable then financing will be observed with probability one. Thus, the probability of industry viability is updated to zero if no financing is observed in this equilibrium. In the P equilibrium, if the industry is viable then financing will be observed with a probability that is less than one. A lack of observed financing may occur either because the industry is nonviable so no financing occurred or because financing did occur but was not observed. If no financing is observed in this equilibrium, then potential entrants revise downward their probability of industry viability, but they

Table 1
Time $2a$ public beliefs, given that no early financing is observed

Time $1c$ equilibrium	The public probability that each technology is viable, given that financing *is not* observed: p_N	p_E
All wait (W)	$\lambda\theta$	$(1-\lambda)\theta$
Pioneering E firms obtain private financing; no IPOs (P)	$\lambda\theta^P$	$(1-\lambda)\theta^P$
Pioneering E firms undertake IPOs (I)	0	0

p_i = probability, given only public information, that technology i is viable.
θ = prior probability that industry is viable.
θ^P = probability that industry is viable, given that no financing is observed and strategy P has been played; $0 < \theta^P < \theta$.
λ = prior probability that new technology succeeds.

do not set the probability to zero. The precise value of θ^P is given in the Appendix.[15]

2.2.1 Equilibrium *W*. W is an equilibrium if and only if no pioneering E firm has a positive incentive to deviate from the equilibrium. In determining whether to deviate, an E firm faces a trade-off. If it obtains financing early, it realizes single-period monopoly profits from producing at a time when other pioneering firms are waiting. However, the firm's decision to finance early may reveal information that is valuable to potential entrants and thus increase the number of firms that enter the industry. In addition, the firm risks losing the new capital invested if the N technology turns out to be viable.

The value of a pioneering E firm that chooses not to seek financing until period $2c$, while all other pioneering E firms also postpone financing, is given by

$$V_W^W = (1-\lambda)\left(\frac{(\pi_{E3}^{(2)}/r) - (1-k)G}{1+r}\right). \tag{2}$$

The expression in the first set of parentheses is the pioneering E firms' probability that they will be viable in the long run. The expression in the second set of parentheses is the present value of the expected operating profit, if they are viable, less the cost of the expansion. Because the firm is postponing full-scale operations, the expansion cost is paid only if the E technology turns out to be viable for the long run. $\pi_{E3}^{(2)}$ is the long-run single period profit for an E firm, given that no information is released until time 2. This profit depends on the total number of entrants that choose to enter with technology E, and will be determined by Equation (1).

By adopting a strategy of waiting, pioneering E firms do not disclose that the industry is viable. Hence, new entry by firms adopting the E technology will occur up to the point that long-run profits $\pi_{E3}^{(2)}$ are given by the equilibrium entry condition (1), with $p_E = (1-\lambda)\theta$. Substituting the expression for long run profits $\pi_{E3}^{(2)}$ into Equation (2), we obtain

$$V_W^W = \frac{kG}{\theta(1+r)}. \tag{3}$$

Consider now the incentive for a pioneering firm to deviate and go public in period $1c$, while the other pioneering E firms postpone financing until $2c$.

[15] There are also two other equilibria, P' and I', that occur when a single pioneering firm may seek early financing. These are discussed in Section 2.2.4. In strategies P and I at least two pioneering firms seek early financing. The exact number is determined as part of the equilibrium but not does affect the probabilities given in Table 1.

The deviating firm's IPO reveals to potential entrants that the industry is viable. The value of the deviating firm is given by

$$V_I^W = \left(\pi_2 + \frac{(1-\lambda)\pi_{E3}^{(1)}}{r}\right)\left(\frac{1}{1+r}\right) - (1-k)G. \tag{4}$$

The first term is the expected operating profit, and the second term is the cost of the expansion. The expected profit now has two components. The cash flow π_2 is the profit that the pioneering firm earns from being the only producer in the second period. The cash flow $\pi_{E3}^{(1)}$ is the long-run single period profit for E firms, given that the public learns at time $1c$ that the industry is viable.

By announcing an early IPO a pioneering E firm discloses that the industry is viable, but not whether the N technology is successful. Hence, an IPO at time $1c$ by an E firm will induce entry by firms adopting the E technology until long-run profits $\pi_{E3}^{(1)}$ are given by the equilibrium entry condition (1), with $p_E = 1 - \lambda$. Substituting the expression for long-run profits $\pi_{E3}^{(1)}$ into Equation (4), we obtain the following expression for the value of a pioneering E firm that proceeds with an IPO at time $1c$, while all other pioneers wait:

$$V_I^W = \frac{\pi_2 + kG - (\lambda + r)(1-k)G}{1+r}. \tag{5}$$

In the above expression, future expected profits are given by $\pi_2 + kG$. To produce at full capacity, a firm must invest an additional amount $(1-k)G$. The term $\lambda(1-k)G$ represents the expected loss from being displaced by the superior technology N after this new investment has been made, and $r(1-k)G$ is the cost of making the investment one period early.

A pioneering E firm may instead choose to deviate from the W equilibrium by obtaining private financing. Private financing has an advantage in that the probability that private financing is observed by potential entrants is z, where $0 < z < 1$. On the other hand, private financing incurs an additional cost of F. Thus, the deviating firm's value is

$$V_P^W = \left(\pi_2 + \frac{(1-z)(1-\lambda)\pi_{E3}^{(2)} + z(1-\lambda)\pi_{E3}^{(1)}}{r}\right)\left(\frac{1}{1+r}\right) - (1-k)G - F, \tag{6}$$

where F is the capitalized additional cost of financing privately. Substituting for the long-run profits $\pi_{E3}^{(2)}$ and $\pi_{E3}^{(1)}$, yields

$$V_P^W = \frac{\pi_2 + \frac{(1-z(1-\theta))kG}{\theta} - (\lambda + r)(1-k)G}{1+r} - F. \tag{7}$$

The present value of the deviating firm's expected long-term profit, $\frac{(1-z(1-\theta))}{\theta}kG$, exceeds the corresponding expected profit for a firm that does an IPO. This is because fewer competing firms will enter if the deviating firms' private financing does not become known to the market. A deviating firm's expected cost of being displaced by superior technology and of financing early, $(\lambda+r)(1-k)G$, is independent of the type of early financing used. Thus, we can see that in choosing the type of financing if early financing is done, the trade-off will be between higher expected long-term profits versus the higher cost of private financing.

The marginal gain from deviating and going public at time $1c$ is given by

$$\Delta_I^W V = V_I^W - V_W^W = \frac{\pi_2 - \left(\frac{1-\theta}{\theta}\right)kG - (\lambda + r)(1-k)G}{1+r}. \tag{8}$$

The marginal gain consists of three components. The first term of the right-hand side of expression (8) is the second period profit that is earned only if the firm expands early. The second term is the decrease in long-term profits due to revealing to potential entrants that the industry is viable. This information is most valuable to potential entrants and costly to the pioneering E firms if the a priori probability of viability, θ, is low. The last term in expression (8) is the cost of expanding early. This includes the cost of financing one period earlier and the expected loss of capital that will occur if the N technology is subsequently revealed to be successful. If $\Delta_I^W V > 0$, then W will not be an equilibrium.

The marginal gain from deviating and financing privately at time $1c$ is given by

$$\Delta_P^W V = V_P^W - V_W^W = \frac{\pi_2 - z\left(\frac{1-\theta}{\theta}\right)kG - (\lambda + r)(1-k)G}{1+r} - F. \tag{9}$$

Equation (9) is similar to Equation (8). The two differences are that the decrease in long-term profits occurs only with probability z, and private financing entails a fixed cost F. As above, if $\Delta_P^W V > 0$, then W will not be an equilibrium.

2.2.2 Equilibrium *I*. In this equilibrium, if the industry is viable, at least two pioneering firms go public at time $1c$. As a result, potential entrants either learn that the industry is viable, or if they do not observe an IPO, they learn that the industry is not viable.

Because at least two firms are going public at time $1c$, the financing decision of any single firm does not disclose any information to potential entrants. Thus, in deciding between an IPO at time $1c$ and waiting, each firm only trades off the gain from producing early against the expected cost of being made obsolete by a superior technology. As the number of firms going public early increases, then the gain from producing early declines and the expected cost remains the same, giving a unique solution for the number of firms that do IPOs at time $1c$. There is no incentive for any firm to deviate and obtain private financing because doing so would only increase its costs. The gain from waiting while $n-1$ ($n \geq 1$) other pioneering firms do public offerings at time $1c$ is

$$\Delta_W^I V = \frac{(\lambda + r)(1-k)G}{1+r} - \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2. \tag{10}$$

As before, π_2 is the single period monopoly profit. It is clear that the benefit to waiting in an I equilibrium is increasing in n. Equation (10) will enable us to determine the equilibrium number of firms that do early IPOs when I is the equilibrium.

2.2.3 Equilibrium *P*. In this equilibrium, if the industry is viable at least two pioneering firms obtain private financing at time $1c$. With probability z, potential entrants observe this private financing and learn that the industry is viable. If they do not observe the private financing, potential entrants do not know whether the industry is nonviable or whether the industry is viable but the financing was not revealed. Accordingly, they revise downward their probability that the industry is viable, to $\theta^P < \theta$.

A pioneering firm that deviates and does an IPO instead of obtaining private financing can save the financing cost F. However, by doing so it reveals with certainty that the industry is viable. In equilibrium, the firm's marginal payoff from deviating in this way is given by

$$\Delta_I^P V = F - \frac{kG}{1+r}\left(\frac{1-\theta}{\theta}\right). \tag{11}$$

The first term in Equation (11) is the savings in financing costs, and the second term is the expected decline in long-run profits that occurs when potential entrants with the E technology learn that the industry is viable.

2.2.4 Other equilibria. There exist two other equilibria that occur for very limited parameter values. These equilibria are not central to the analysis but must be included in the first proposition for completeness. We discuss them briefly here and develop them further in the Appendix. In strategy I' a single firm will do an IPO with probability η_I, while all other pioneering firms wait. In strategy P' a single firm will obtain private financing with probability η_P, and all other pioneering firms wait. These equilibria occur when single-period *monopoly* profits are large enough to overwhelm the risk of loss to a superior technology but single-period *oligopoly* profits are too small. Thus, it is rational for only one pioneering firm to obtain financing early. However, when the equilibrium calls for only one pioneering firm to finance early, then a deviation by this one firm could lead potential entrants to conclude incorrectly that the industry is not viable. Mixing of strategies is necessary so that beliefs will be consistent and the single firm will not have a positive incentive to deviate.

2.3 Equilibrium results

The following proposition characterizes the conditions under which each equilibrium exists.

Proposition 1.

(i) *"All pioneering firms postpone financing" (W) is an equilibrium if and only if $\Delta_I^W V \leq 0$ and $\Delta_P^W V \leq 0$.*

(ii) *If W is not an equilibrium:*

  (a) *If $\Delta_I^P V > 0$, then there is either a unique pure strategy equilibrium: "some pioneering firms do an early IPO" (I); or a unique mixed strategy equilibrium: "a single firm does an early IPO with probability η_I" (I').[16] There does not exist a P or P' equilibrium.*

  (b) *If $\Delta_I^P V \leq 0$, then there exists either an equilibrium in which "some pioneering firms obtain private financing, with no early IPOs" (P), or "a single firm obtains private financing with probability η_P" (P').*

Proposition 1 covers all possible outcomes for the Δ functions that were derived in the previous section. W is an equilibrium if and only if a single pioneering firm will have no positive incentive to deviate from the W equilibrium. There do exist parameter values such that both W and I are equilibria. In these regions if one pioneer goes public, then I will be the equilibrium because the proprietary information has already been released. However, if W (waiting and maintaining the status quo) is an equilibrium, then such an IPO can be thought of as an out-of-equilibrium action. For this reason, we will focus only on the W equilibrium in such parameter regions.[17]

In an I equilibrium, a pioneering firm faces a trade-off, as illustrated in Equation (10), which gives the benefit to waiting while other pioneers do IPOs. Each firm has an incentive to go public early to reap the second-period profits. At the same time, no single firm can affect the release of information to potential competitors. This creates an incentive to "herd," so that one firm

[16] These equilibria are unique in the sense of specifying how many pioneering firms take each action. They are not unique in the sense of identifying which firms take which action.

[17] Similarly, there also exist parameter regions in which both W and P are equilibria and in which we will focus only on W. In any case, if W is an equilibrium, then it is either the unique equilibrium, or it Pareto-dominates all other equilibria. In addition, there are parameter regions in which there exist both a P or P' equilibrium and an I or I' equilibrium. If this occurs then P or P' is the Pareto-dominant equilibrium and the one on which we focus.

doing an early IPO causes all pioneering firms to do early IPOs. However, firms doing early IPOs face the risk of loss of investment due to the entry of a superior technology. In addition, they bear the cost of committing capital one period early. These costs, given by $(\lambda + r)(1 - k)G$, are independent of the number of firms going public early. The second-period profits, however, are decreasing in the number of firms that go public early. If n firms go public early, then each will earn $\frac{4\pi_2}{(1+n)^2}$ in the second period, where π_2 is the single-period monopoly profit. Because the profit from an early IPO is decreasing in the number of firms while the cost is constant, there is a limit on the number of firms that can profitably do early IPOs. The number of firms going public early in an I equilibrium is given in the following proposition.

Proposition 2. *The equilibrium number of early IPOs, given at least one IPO is*

$$n_I = \min\left[n_1, 2\sqrt{\frac{\pi_2}{(\lambda + r)(1 - k)G}} - 1\right], \tag{12}$$

where n_1 is the number of pioneering firms that have completed the first stage.

Proposition 2 clearly demonstrates that the higher the expected loss to a new technology, relative to the value of the period 2 profit opportunity, the smaller the number of firms that go public in an I equilibrium. Thus, we would expect to see more herding of early IPOs occurring in industries with low probability of loss due to new technology (low λ), low cost of capital (r), relatively low costs of going from the prototype stage to full production (high k), and/or high product demand (high π_2). In industries that do not have these characteristics, some pioneering firms will go public early in an I equilibrium, while others wait until more has been learned about the new technology.

2.4 Industry characteristics and timing

In the previous two sections we developed the decision functions that determine the pioneering firms' IPO timing decisions. We now examine how the prior probabilities that the technologies are viable in the long run (θ and λ) and the relative cost of the first-stage investment (k) affect both the incentives of pioneering firms to obtain early financing and the choice of financing method. In the following propositions, the phrase "early financing" refers to both private and public financing.

Proposition 3. Information and timing of second-stage financing.

(i) *As the prior probability of industry viability (θ) increases, early financing becomes more attractive.*
(ii) *As the prior probability that the new technology is viable (λ) increases, early financing becomes less attractive.*

If potential competitors believe that there is a low probability that the E technology is viable, then new entry will be low. As a result, when the value of θ is low, disclosure that the industry is viable causes a larger increase in new entry than a similar disclosure when θ is high. Thus, an increase in θ lowers the signaling cost of early financing. A larger value of λ means that there is a greater probability that E firms will eventually fail and the new investment $(1-k)G$ will be wasted. By postponing, the E firms wait until they learn the outcome of the N technology before sinking the new investment. Thus, a larger value of λ makes waiting more attractive.

Proposition 4. Relative cost of first stage and timing of second-stage financing. *An increase in the relative cost of the first-stage financing* (k) *makes early financing* more *attractive relative to waiting if the cost of capital, adjusted for the risk of displacement by technology N firms, exceeds the cost of disclosing to potential entrants that the industry is viable. For IPOs this occurs when* $\lambda + r > \frac{1-\theta}{\theta}$, *and for private offers this occurs when* $\lambda + r > z\left(\frac{1-\theta}{\theta}\right)$. *If these conditions do not hold, then as k increases early financing becomes* less *attractive relative to waiting.*

The effect of the relative cost of first-stage financing, k, is complicated by the fact that k affects the two concerns of the pioneering E firms, the cost of disclosure and the risk of capital loss, in opposing ways. We can show, using the equilibrium condition (1), that the cost to a pioneering firm of a marginal increase in entry caused by information released by an early IPO is proportional to $\left(\frac{1-\theta}{\theta}\right)kG$. This cost is high for low values of θ and is *increasing* in k. On the other hand, the firms that finance early have a risk-adjusted cost of newly invested capital of $(\lambda + r)(1-k)G$. The total risk-adjusted cost of capital is high for high values of λ and is *decreasing* in k. Thus, the net effect that an increase in the relative cost of first-stage financing has on the timing decision of a pioneering firm depends on whether the higher cost of disclosing information or the lower expected cost of capital loss dominates. If both θ and λ are low so that $\frac{1-\theta}{\theta} > \lambda + r$, then the disclosure concern is the most important concern driving the investment timing decision, and as k increases an early IPO will become less attractive. On the other hand, if both θ and λ are large so that $\frac{1-\theta}{\theta} < \lambda + r$, then the potential loss of newly invested capital is the dominant concern, and as k increases an early IPO will become more attractive. For firms considering private financing, these expressions are adjusted to reflect the fact that the disclosure cost is borne only with probability z.

If a firm chooses to finance early, then regardless of the financing method, new capital is sunk before learning the outcome of the new technology. As a result, although the probability λ that the new technology is viable is important in the timing decision, it does not play a role in determining the best *method* for early financing. The decision of how to finance is affected only by the cost of signaling. In particular, public financing becomes more attractive relative to private financing when the cost of information disclosure decreases.

Proposition 5. *Given that a pioneering E firm chooses to finance the second stage early, an IPO becomes more attractive relative to private financing if:*

(i) *the prior probability of industry viability, θ, increases, or*
(ii) *the relative cost of the first stage financing, k, decreases.*

3. Empirical Predictions on Timing

To summarize, the timing decision is driven by the trade-off between early profits and two concerns: (i) firms that finance early are at risk for long-term failure, due to a superior technology; (ii) revealing to potential new entrants that the industry is viable may be costly. The choice of financing method, if firms choose to finance early, is driven by the trade-off between the cost of doing private financing and an IPO's higher probability of disclosing information to potential competitors. Table 2 summarizes the principal empirical predictions of our model.

Figure 4 illustrates the results presented in Table 2 and in Propositions 3 through 5. Figures 4a through 4d show that firms postpone financing when λ is high or when θ is low and k is high. All of the figures show that when early financing occurs, IPOs dominate private issues when θ is high. Figures 4c through 4f demonstrate that IPOs also dominate private issues for low values of k. The dependence on θ and λ of the effect of k is demonstrated in Figures 4c through 4f. In Figures 4d and 4e, the boundary between postponing and early financing occurs with low values of θ and λ. In these figures waiting becomes *more* attractive as k increases. In Figures 4c and 4f, the boundary between postponing and early financing occurs with high values of θ and λ. In these figures waiting becomes *less* attractive as k increases.

Our results also allow us to make predictions concerning the long-run success and failure of IPOs. Firms using established technology that finance

Table 2
Empirical predictions

When do we expect pioneering firms to wait?	i) λ high or ii) λ low and k high and θ low
When do we expect to see herding of early IPOs?	low λ, high k and/or high product demand
When do we expect to see more failure of IPO firms, not immediately, but after the firms have invested new capital?	high θ and intermediate or high k
Given that pioneering firms finance early, when do we expect firms to choose IPOs for early financing?	higher θ and/or lower k

θ = prior probability that industry is viable.
k = relative cost of first-stage financing.
λ = prior probability that new technology is viable, given industry is viable.

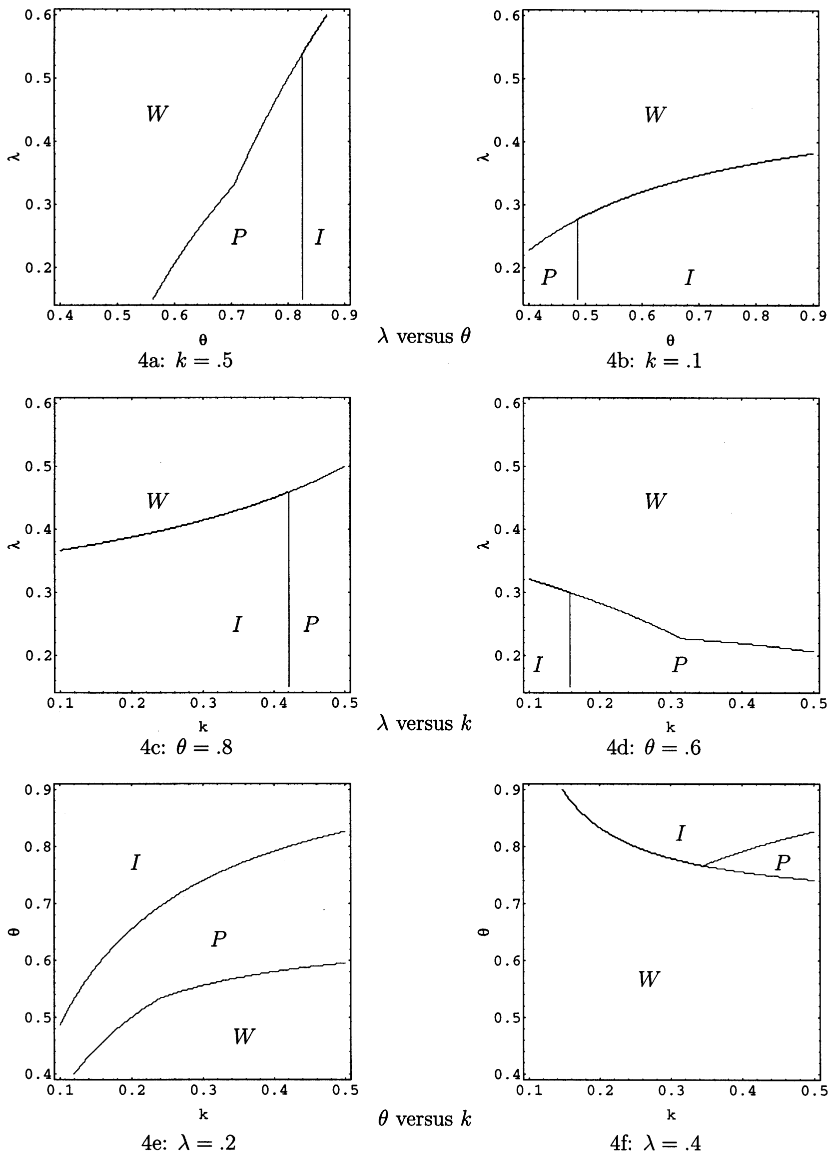

Figure 4
Equilibrium outcomes
In all of the figures: $z = .5$, $F = 10$, $\pi_2 = 40$, $r = .05$, $G = 100$.

early, before learning the outcome of the new technology, place themselves at risk of failing after sinking new resources. We have shown that if the risk of displacement by a superior technology is too high (λ very high), then firms will postpone financing and avoid the risk of failure. However, as illustrated in Figures 4a, 4c, and 4f, we also show that if the industry is established (θ high) and if the relative first-stage cost, k, is not too low, then even with intermediate to high values of λ, early financing will be observed. It is with these industry characteristics that we predict a preponderance of long-term failure of IPOs.

4. Adverse Selection in Public and Private Security Markets

In this section, we explore how asymmetries of information about the success of the new technology can affect the pricing of securities and the incentives of pioneering firms and potential entrants. In the set-up of the model we allowed for the possibility that entrepreneurs using the N technology learn of the the success of their technology early on, at time $1b$. Even though the N technology pioneering firms will not be ready to seek early second-stage financing, information (possibly noisy) about their prospects may be available to some investors at the time that E technology firms are seeking early financing. The existence of such investors has three effects.

First, as modeled by Rock (1986), the existence of potentially informed investors creates an adverse selection problem in the market for newly issued shares and thus decreases the price that firms financing early can obtain for their shares. Second, in the case of IPOs potential entrants will condition their entry and their choice of technology on the secondary market price, which may contain information about the likely success of the N technology. The equilibrium condition of Equation (1) is maintained, but with the new information from the secondary market. This feedback effectively reduces the value of informed investors' information, and thus reduces both the adverse selection risk and the underpricing for pioneering firms. Because this feedback does not occur with private offerings, adverse selection risk and underpricing is higher in private markets. Third, underpricing caused by asymmetries of information about the N technology is a cost to financing early. As such, the existence of this underpricing in both public and private markets for securities affects the timing and method of pioneering firms' financing.

To investigate these effects we add to the model a date, $1d$, on which the secondary market opens for shares of firms which have gone public at time $1c$. This market opens after all the pioneering firms which go public in period one have done so, but before the potential entrants have made their entry decisions. We assume that an IPO firm's decision to purchase the second stage of the project is taken before the aftermarket opens.[18]

[18] The model can be expanded to allow for the possibility that the information learned in the secondary market will be so bad that the IPO firm will choose to postpone expansion. Although such an extension is interesting, it greatly adds to the complexity, due to complications regarding the equilibria.

4.1 Proprietary information and feedback between financial and product markets

When E firms are sold at time $1c$, the value of the shares of E firms will be inversely related to the probability that the N technology is successful. We assume that with probability ϕ some "informed" investors receive an identical signal about the long-run prospects of the N technology. This signal causes them to revise their estimate of the probability that the N technology is successful from λ to λ' . The signal can be either positive (in which case the informed investors revise λ upward to $\lambda' = \lambda + \varepsilon$) or negative (in which case they revise their estimate to $\lambda' = \lambda - \varepsilon$). It is assumed that $0 < \varepsilon < \min(\lambda, 1 - \lambda)$. The informed investors use their proprietary information when placing orders for an E offering (both public and private) and also, in the case of an IPO, when trading in the secondary market at time $1d$. We assume that the trades of the informed at time $1d$ fully reveal their information.

If informed investors receive a positive signal about the N technology, then their valuation of an E firm decreases by an amount v_h, where $h = I$ in the case of an IPO and $h = P$ in the case of a private offering. If the informed receive a negative signal about the N technology, then their valuation of an E firm increases by v_h. Good and bad signals are equally likely. If the informed receive no signal, then the value of the E firm is unchanged. The latter event occurs with probability $1 - \phi$.

The magnitude v_I is a function both of the quality of the information received by informed investors and of the effect that the information has on the decisions of potential entrants who learn the information at time $1d$. To see this, we can write the uninformed investors' and the E firm's own valuation at time $1c$ as

$$V_I + (1 - k)G = \frac{\pi_{I2}}{1 + r} + \frac{G}{1 + r} - \frac{\lambda(1 - k)G}{1 + r}, \tag{13}$$

where π_{I2} is the time 2 single-period profit realized by a public firm. The second term on the right hand side of expression (13) is the value at time $1c$ of expected future cash flows from operations, given that E firms are successful in the long run. This term is determined by the equilibrium entry condition of Equation (1). The third term is the expected loss due to the N technology.[19]

At time $1d$, after proprietary information has been revealed in the market, potential entrants will use the updated estimate λ' in deciding whether or not to enter. By Equation (1) entry will adjust to the new information so that the expected value of future cash flows will remain equal to the total project

[19] Expression (13) is the same as Equation (5) in Section 2, except for two differences. We use π_{I2} instead of π_2 to indicate that an E firm that does an early IPO may not be a monopolist even for the first period of production. We also add here the amount raised in the IPO, $(1 - k)G$. We do this because we are now interested in determining the value of the firm after this amount has been raised from external capital markets.

cost, G.[20] However, the expected loss due to the N technology changes. Thus, the value of an IPO firm after the proprietary information has been revealed is

$$V_I' + (1-k)G = \frac{\pi_{I2}}{1+r} + \frac{G}{1+r} - \frac{\lambda'(1-k)G}{1+r}. \tag{14}$$

The absolute value of the change in valuation of an IPO firm, as a result of proprietary information about the N technology is

$$v_I = \mid V_I' - V_I \mid = \frac{\varepsilon(1-k)G}{1+r}. \tag{15}$$

The expected value of future cash flows for a firm that obtains private financing at time $1c$ differs in two respects from the value of future cash flows for the public firm. First, in a private offering it is only with probability z that potential entrants observe the financing, and thus find out that the industry is viable. Second, because there is no secondary market trading, even if potential entrants do observe the financing, they do not learn the informed investors' valuation, and thus their entry decisions at time $1d$ are conditioned only on the information that is publicly available at time $1c$. As a result, news about λ has a stronger impact on the value of a private firm than a public firm. The absolute value of the amount by which the informed investors' valuation of the private firm differs from that of the uninformed investors is

$$v_P = \mid V_P' - V_P \mid = \frac{\varepsilon G}{1+r}\left(\frac{(1-z+z\theta')k}{(1-\lambda)\theta'} + 1 - k\right) > v_I. \tag{16}$$

By comparing equations (15) and (16) we obtain the following proposition.

Proposition 6. *(i) Proprietary information leads informed investors to revalue the firm to a lesser degree if the firm does an IPO than if the firm finances privately. (ii) This difference is increasing in the relative cost of the first-stage financing, k, and the a priori probability that the new technology is successful, λ. The difference is decreasing in the a priori probability that the industry is viable, θ.*

A direct implication of Proposition 6 is that the value of an informed investor's proprietary information is higher when the firm finances privately. In our model, this is not because the value of information is competed away in public security markets by other informed investors. Rather, it is because the reactions of potential product market competitors to the information attenuate the impact of the information. If the information is good for E

[20] If the aftermarket price reveals that the prospects for technology E are so hopeless that no new entrants use it, then the expected value of future cash can fall below G. We do not address this case formally because the intuition is similar but the derivations differ in detail from the main case.

firms, then more competitors enter with the E technology, thus decreasing long-term profits and lessening the positive impact of the good news. If the information is bad for E firms, then fewer competitors enter with the E technology, thus increasing long-term profits in the case that the E technology succeeds and lessening the negative impact of the bad news. Investors in the product market use the information in a way that lessens the profits accruing to informed investors in the financial market. In a private offering, however, the product market investors do not observe the information and so do not serve this function.

4.2 Underpricing and the timing and method of financing

The existence of proprietary information will affect both the pricing of shares and the financing decisions of pioneering firms. Applying Rock's (1986) model of underpricing, if informed investors observe that the probability of N success is lower than the a priori probability λ, then they will know that the offering is underpriced and they will participate actively in the offering. Conversely, if informed investors observe that the probability is higher than λ, then they will know that the offering is overpriced and will not participate in the offering. As a result, uninformed investors receive the entire offering when the E firms are overpriced and only part of the offering when E firms are underpriced. To ensure the participation of the uninformed investors despite this adverse selection, the offer price of E firms must be reduced below the a priori expected value of the shares. Thus, on average the shares of E firms will be underpriced ex post. For IPOs the immediate secondary market price will on average be higher than the offer price. In the case of a private offering underpricing will be hard to measure, but the value of the issue will on average be higher than the issue price.

The direct implication of the results of the previous subsection is that, *holding the quality of information and the proportion of informed investors constant across public and private financial markets, underpricing is greater in private offerings of private firms than in initial public offerings.* This result adds a new dimension to the choice of financing for a private firm. As shown in Section 2, an IPO may be less attractive than a private offering because an IPO releases, with probability one, information that may be valuable to competitors. However, an IPO may also provide a market in which information that is not known by the IPO firm can be revealed. The revelation of this information is valuable for the IPO firm because it reduces the adverse selection risk it faces at the time of the offering. Thus, the presence of investors who may have information that is not known to the entrepreneur can make a public offering more attractive relative to a private offering.[21] In addition,

[21] Although beyond the scope of this model, an IPO may also be valuable because the revelation of proprietary information can be directly useful for the IPO firm in making resource allocation decisions. See, for example, Titman and Subrahmanyam (1999).

our analysis may well understate the magnitude of the difference in underpricing between private and public offerings. If, as is likely, the proportion of informed investors is higher in a private offering than in a public offering, then private offerings will be even more underpriced.[22]

The presence of informed investors in both the primary and secondary financial markets also affects the timing of offerings and the value of N technology firms. The existence of informed investors reduces the incentives of E firms to obtain financing before the success or failure of the N technology has been revealed because the adverse selection risk requires them to reduce the price of their offering. If there are any successful pioneering N firms, they would prefer that the E firms postpone their IPOs, so as not to reveal valuable information to potential entrants. If such information is not disclosed, fewer new rivals will enter and, as a result, a successful pioneering N firm's long-term profits will be higher. Thus, although adverse selection in the market for E IPOs directly decreases the value of E firms that might otherwise wish to obtain financing early, it may indirectly increase the expected value of N firms.

5. Conclusion

This article analyzes how pioneering firms in an emerging industry choose the timing of financing and decide whether to seek public or private financing. Pioneering firms face both the technological risk that new investment may be made obsolete by a more advanced technology and the risk that entry by new firms that copy their technology will reduce their profits. We show how timing and the choice of financing depend on three key parameters: the public perception that the industry is viable, the prior probability that a superior technology will appear, and the initial cost of research and development that must be paid by new entrants. Each of these parameters affects the technology and new-entry risks differently.

The choice of public or private financing is strategically important because each is associated with a different amount of disclosure of the issuer's proprietary information. Moreover, a public offering creates a secondary market for the firm's securities, which may reveal additional proprietary information not known to the issuer. Potential rivals can condition their entry decisions on such information, thus reducing the probability of either excess or insufficient entry. A result of this feedback between the product and financial markets is that the value of investors' proprietary information and the resultant adverse selection risk in the market for pioneering firms' securities are lower in an

[22] A public offering may be sold to a large number of investors, with possibly only a small fraction of the investors being privately informed. A private offering is typically sold to a limited number of large investors who may also be differentially informed. As such, an investor in a private offering faces the possibility that a large fraction of the other investors are better informed. For this reason the adverse selection risk in a private offering may be as large as or greater than in a public offering.

IPO than in a private placement of the firm's securities. A direct implication of this is that, if we hold the proportion of informed investors constant, expected underpricing will be lower in an IPO than in a private placement of shares of a private firm.

Our model generates predictions about the timing of private offerings and IPOs, as well as the success of IPOs both in the short and long run. For example, optimal early private financing occurs in industries whose viability is uncertain and where the cost of research and development is high but the probability of being displaced by more technologically advanced rivals is low. On the other hand, early public financing occurs in industries that are perceived to be viable, in which there are low relative first-stage costs, and where the probability of being displaced by more technologically advanced rivals is also low. We develop trade-offs that predict the timing and type of financing for industries that do not fit all of these criteria.

Our model predicts herding of IPOs in industries where new-entry risk is significant. By contrast in industries where the technology risk is the more significant risk (according to a condition developed in the article), we expect to observe some pioneering firms expanding early while others postpone financing.

A feature of the model is that firms' financing decisions can be interpreted as the optimal exercise of options. The model provides predictions on when these options are exercised and on the resulting financial market price effects, in terms of structural parameters. This gives it a relatively simple dynamic structure in which the parameters, such as the probabilities of success of the technologies and the extent of adverse selection, could be estimated using an optimization model. Such an estimation procedure has an advantage over a simple regression because, as we show, in some parameter ranges the incentive to finance early is increasing in the cost of development, while in other parameter ranges it is decreasing.

Our results also have implications for financial contracting between entrepreneurs in pioneering firms and venture capitalists. Because of the feedback between financial and product markets, we predict that public financing will result in lower variance of initial returns than will private financing. Thus, holders of securities whose payoffs are convex in the value of the firm may prefer to finance expansions privately, whereas claimants whose payoffs are concave may wish to go public. As such, the design of the optimal contract for the party that has the power to determine the timing of the IPO may depend on industry characteristics.

Appendix: Technical Assumptions and Derivation of Results

Notation

N = index for new technology

E = index for established technology

Exogenous variables

G = total amount of investment needed to initiate full production
k = fraction of G required for first-stage investment
θ = prior probability that industry is viable
λ = prior probability that new technology is viable, given industry is viable
r = opportunity cost of capital
n_1 = number of pioneering E firms
c_i = per-unit variable production cost for firms of type i, $i \in \{N, E\}$
a, b = industry demand characteristics
z = probability that private financing reveals that the industry is viable
F = additional cost to private financing
ε = absolute value of revision in beliefs due to private information about N technology
ϕ = probability that some investors have received private information

Equilibrium actions

I ≡ 1 or more firms do IPOs in period 1
P ≡ 1 or more firms obtain private financing in period 1; no early IPOs
W ≡ all wait until period 2 to finance
I' ≡ 1 firm does IPO in period 1, with probability η_I
P' ≡ 1 firm obtains private financing in period 1, with probability η_P; no early IPOs

Endogenous variables

π_2 = single-period monopoly profit (for firm of type E) in period 2
p_i = probability, given only public information, that technology i is viable, $i \in \{N, E\}$
$\pi_{i3}^{(t)}$ = long-run (equilibrium) per period profit for firm of type i (in period 3 and later), given that no information is publicly released until time t, $t \in \{1, 2\}$
V_q^s = expected value of a pioneering firm that takes action q when other pioneering firms take action s; q and $s \in \{I, P, W\}$
$\Delta_q^s V$ = $V_q^s - V_s^s$ = benefit to deviating from s to q
θ^P = probability that industry is viable, given that the equilibrium is "private offering" and no financing has been publicly observed
η_I = probability of early IPO in I' equilibrium, given that industry is viable
η_P = probability of private financing in P' equilibrium, given that industry is viable
n_I = equilibrium number of early IPOs
π_{I2} = period 2 profit (for firm of type E) that does an early IPO with $n_I - 1$ other E firms
λ' = revised (due to proprietary information) probability that N technology is viable
V_h = uninformed value of an E firm just before obtaining early financing through method h, $h \in \{I, P\}$
V_h' = informed value of an E firm just before obtaining early financing through method h, $h \in \{I, P\}$
v_h = $|V_h' - V_h|$

Single-period Cournot equilibrium

The single period profits are consistent with a Cournot equilibrium in which

$$\text{price} = P = a - bQ$$
$$Q = \sum_j q_j = \text{total quantity produced in a single period}$$

(a and b are exogenously given, positive constants.)

The single-period profit for a firm of type i, with unit cost c_i, is

$$\pi_i = (P - c_i)q_i = \left(a - b\sum_{j\neq i} q_j - bq_i - c_i\right)q_i.$$

If only one type of firm produces in a given period, then the solution is

$$\pi_i = bq_i^2 = \frac{(a - c_i)^2}{(1 + m_i)^2 b}$$

where m_i = the number of producing firms of type i.

Thus, the single period monopoly profits for an E firm are $\pi_2 = \frac{(a-c_E)^2}{4b}$.

Additional assumptions. These assumptions are applied throughout the Appendix.

A1: $\pi_2 < (1 - k)G$ It is not possible to recover the cost of expansion in a single period of production, even as a monopolist.

A2: $\pi_2 \geq rG$. An E firm can as a monopolist recover the entire cost G, if the firm is successful in the long run. This assumption along with A1 requires that $k < 1 - r$. Without this condition, it would make no sense for pioneers to enter the industry.

A3: Fractional firms may enter the industry.

A4: The difference in production costs between a successful N firm and an E firm are large enough so that E firms cannot survive in the long run, if N firms enter the industry and their technology is successful. This assumption greatly simplifies the math without qualitatively changing the results. Without this assumption, the value of a public E firm would still drop if N firms are proven to be successful, and early investors in what turns out to be the inferior technology still would stand to lose much of their investment.

A5: $n_1 \leq m_{Ej}$ where n_1 is the number of pioneering E firms and m_{Ej} is the equilibrium long-run number of E firms, given information outcome j in period 1. This assumption is consistent with a general equilibrium approach in which pioneering firms have not invested in negative NPV projects. This assumption can be weakened without qualitatively changing the results. All that is necessary for our results is that the release of a valuable signal about the industry or technology causes more new entry than would occur with no signal.

A6: z (the probability that a private offering releases relevant information) is independent of the number of private offerings.

Derivation of Δ functions and proof of Proposition 1. Assume first that all other pioneering firms postpone. The time $1c$ expected value of an E firm that also postpones financing is

$$V_W^W = \left(\frac{\pi_{E3}^{(2)}}{r} - (1 - k)G\right)\frac{1 - \lambda}{1 + r},$$

where $\pi_{E3}^{(2)}$ is the long-term single period profit for an E firm, given that no information is released until the second period. To determine $\pi_{E3}^{(2)}$: If no E firm finances at time $1c$, Prob{long-run E success | public information} = $\theta(1 - \lambda)$.

$$\text{E\{total entry cost} \mid \text{public information\}} = \text{E\{new } E \text{ firm} \mid \text{ public information\}}$$

$$kG + \theta(1-\lambda)(1-k)G = \theta(1-\lambda)\left(\frac{\pi_{E3}^{(2)}}{r}\right)$$

$$\frac{(1-\lambda)\pi_{E3}^{(2)}}{r} = \frac{kG}{\theta} + (1-\lambda)(1-k)G$$

Thus,

$$V_W^W = \frac{kG}{\theta(1+r)}$$

The time $1c$ expected value of an E firm that deviates and goes public is

$$V_I^W = \left(\pi_2 + \frac{(1-\lambda)\pi_{E3}^{(1)}}{r}\right)\frac{1}{1+r} - (1-k)G,$$

where $\pi_{E3}^{(1)}$ is the long-term single period profit for an E firm, given that the public learns in period 1 that the market is viable. To determine $\pi_{E3}^{(1)}$: If at least one E firm does an IPO at time $1c$, Prob{long-run E success | public information} = $1-\lambda$.

$$\text{E\{total entry cost} \mid \text{public information\}} = \text{E\{new } E \text{ firm} \mid \text{ public information\}}$$

$$kG + (1-\lambda)(1-k)G = \frac{(1-\lambda)\pi_{E3}^{(1)}}{r}$$

Thus,

$$V_I^W = \frac{\pi_2}{1+r} + \frac{kG}{1+r} - \frac{(\lambda+r)(1-k)G}{1+r}.$$

The last term on the right-hand side is the expected loss to a superior technology.

$$\begin{aligned}\Delta_I^W V &= \text{benefit to doing IPO when all others postpone}\\ &= V_I^W - V_W^W\\ &= \frac{\pi_2 - (\lambda+r)(1-k)G}{1+r} - \frac{kG}{1+r}\left(\frac{1-\theta}{\theta}\right)\end{aligned}$$

The time $1c$ expected value of an E firm that deviates and obtains private financing is

$$\begin{aligned}V_P^W &= \left(\pi_2 + \frac{z(1-\lambda)\pi_{E3}^{(1)} + (1-z)(1-\lambda)\pi_{E3}^{(2)}}{r}\right)\frac{1}{1+r} - (1-k)G - F\\ &= \frac{\pi_2}{1+r} + \frac{(1-z+z\theta)kG}{\theta(1+r)} - \frac{(\lambda+r)(1-k)G}{1+r} - F\end{aligned}$$

$$\begin{aligned}\Delta_P^W V &= \text{benefit to doing private financing when all others postpone}\\ &= V_P^W - V_W^W\\ &= \frac{\pi_2 - z\left(\frac{1-\theta}{\theta}\right)kG - (\lambda+r)(1-k)G - (1+r)F}{1+r}.\end{aligned}$$

$\Delta_P^W V < 0$ and $\Delta_I^W V < 0$ together form both a necessary and sufficient condition for "all pioneering firms wait" (W) to be an equilibrium. This may not be a unique equilibrium. For example, as long as the risk of losing the investment $(1-k)G$ is not too high, then all pioneering firms going public early will also be an equilibrium. However, if all firms postponing is an equilibrium, then either it is the unique equilibrium or it Pareto-dominates all other equilibria.

The reason this is true is that the Δ functions were formed assuming monopoly profits for early financing. Thus, these functions give an upper bound on the benefits to early financing. If $\Delta_P^W V < 0$ and $\Delta_I^W V < 0$, then clearly all pioneering firms are better off if all firms wait.

Assume now that some pioneering firms obtain private financing in period $1c$, but none do an IPO. The time $1c$ expected value of an E firm that also obtains private financing is

$$V_P^P = \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2 + \frac{(1-z+z\theta^P)kG}{\theta^P(1+r)} - \frac{(\lambda+r)(1-k)G}{1+r} - F.$$

n $(\leq n_1)$ is the number of firms that obtain private financing, π_2 is the single period monopoly profit for an E firm, and $\pi_2(2/(1+n))^2$ is the single-period profit for a pioneering E firm that produces along with n other firms. θ^P $(\theta^P < \theta)$ is the public probability that the E technology is viable, given that P is the equilibrium and no early financing has been publicly observed.

$$\theta^P = \frac{\theta(1-z)}{1-\theta z} < \theta$$

Adding the term $(2/(1+n))^2$ and replacing θ with θ^P are the only difference between V_P^P and V_P^W.

The time $1c$ expected value of an E firm that deviates and goes public is

$$V_I^P = \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2 + \frac{kG}{1+r} - \frac{(\lambda+r)(1-k)G}{1+r}.$$

The only difference between V_I^P and V_I^W is the term $(2/(1+n))^2$.

$$\begin{aligned}\Delta_I^P V &= \text{benefit to doing IPO when all others do private financing}\\ &= V_I^P - V_P^P\\ &= F - \frac{(1-z)kG}{1+r}\left(\frac{1-\theta^P}{\theta^P}\right) = F - \frac{kG}{1+r}\left(\frac{1-\theta}{\theta}\right)\end{aligned}$$

Note that z cancels out because θ^P is a function of z. If $\Delta_I^P V > 0$, then "private financing" (P) is not an equilibrium. If in addition, $\Delta_I^W V > 0$, then "all wait" (W) is not an equilibrium.

We next check if a pioneering firm may want to postpone, even when other pioneering firms are engaging in private financing. A firm may choose to postpone to save the extra cost F and to avoid the risk of incorrectly sinking the investment $(1-k)G$. The time $1c$ expected value of an E firm that waits, while $n-1$ others obtain private financing, is

$$V_W^P = \frac{(1-z+z\theta^P)kG}{\theta^P(1+r)}$$

and

$$\begin{aligned}\Delta_W^P V &= \text{benefit to waiting when } n-1 \text{ others do private financing}\\ &= V_W^P - V_P^P\\ &= F - \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2 + \frac{(\lambda+r)(1-k)G}{1+r}.\end{aligned}$$

The necessary conditions for "private financing" (P) to be an equilibrium are $\Delta_W^P V < 0$ at $n = 1$ and $\Delta_I^P V < 0$. If $\Delta_W^P V < 0$ for $n \geq 2$ then we also have sufficiency. However, if $\Delta_W^P V(n=1) < 0 < \Delta_W^P V(n=2)$, then the P equilibrium calls for exactly one E pioneer to raise private financing, and we must consider the possibility that this E pioneer may wish to deviate from the P equilibrium and wait. The single firm may wish to do this so that potential entrants will place a low probability on industry viability. Thus, in the case where a single firm should obtain private financing a third necessary (and sufficient) condition for P to be an equilibrium is

$$F - \frac{\pi_2}{1+r} + \frac{(\lambda+r)(1-k)G}{1+r} + \frac{z(1-\theta^P)kG}{\theta^P(1+r)} < 0.$$

Note that the above condition is equivalent to $\Delta_P^W V > 0$, except that we use θ^P here instead of θ. $\theta^P < \theta$, thus $\Delta_P^W V(\theta^P) < \Delta_P^W V(\theta)$. There is a parameter region such that $\Delta_P^W V(\theta^P) < 0 < \Delta_P^W V(\theta)$ and $\Delta_W^P V(n=1) < 0 < \Delta_W^P V(n=2)$. In such a region neither P nor W are equilibria, but there does exist a mixed strategy equilibrium in which a single pioneering E firm obtains private financing with probability η_P and waits with probability $1-\eta_P$, while all other pioneering firms wait. This is the P' equilibrium. There is a similar IPO equilibrium, I', that is discussed following the proof of Proposition 2.

It is possible to have multiple equilibria such that both I (or I') and P (or P') are equilibria. However, for P or P' to be an equilibrium we must have $\Delta_I^P V \leq 0$, which means that all pioneering E firms are better off if the information is not released by an early IPO. Thus, if I (or I') and P (or P') are both equilibria, and W is not an equilibrium, then the private financing equilibrium, P (or P'), will be the Pareto-dominant equilibrium. ■

Derivation of $\Delta_W^I V$ and proof of Proposition 2. The value of a pioneering firm that does an IPO while $n-1$ others do IPOs is

$$V_I^I = \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2 + \frac{kG}{1+r} - \frac{(\lambda+r)(1-k)G}{1+r}.$$

(This is identical to V_I^P in the last proof.) The value of a pioneering firm that waits while others do IPOs is

$$V_W^I = \frac{kG}{1+r}.$$

A firm that waits while others finance does not prevent information from being released but only avoids the risk of loss due to a superior technology. Thus, a firm will not deviate by doing a private offering while others go public. A firm will deviate and wait while others go public if $\Delta_W^I V > 0$, where

$$\begin{aligned}
\Delta_W^I V &= \text{benefit to waiting when } n-1 \text{ others do public offerings} \\
&= V_W^I - V_I^I \\
&= \frac{(\lambda+r)(1-k)G}{1+r} - \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2
\end{aligned}$$

To determine the equilibrium number of early IPOs, given at least one IPO, we merely need to solve for the value of n such that $\Delta_W^I V = 0$. For any n larger than this, firm(s) will have incentives to wait; for any n smaller than this no firm will deviate and wait.

$$\Delta_W^I V = \frac{(\lambda+r)(1-k)G}{1+r} - \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2 = 0 \Longrightarrow$$

$$\left(\frac{1}{1+n}\right)^2 = \frac{(\lambda+r)(1-k)G}{4\pi_2}$$

$$n = 2\sqrt{\frac{\pi_2}{(\lambda+r)(1-k)G}} - 1$$

■

Discussion of I' equilibrium. If $n_I = 1$, then there is a parameter region such that $\Delta_I^W V > 0$, but the single E firm will have a positive incentive to deviate from the I equilibrium if this means that the public belief about the viability of the industry will be updated to probability zero. For this to occur we need the following conditions:

(i) a single E firm will wish to deviate from W: $\pi_2 + kG - \frac{kG}{\theta} > (\lambda + r)(1 - k)G$, and
(ii) at most one firm will do an early IPO: $(\lambda + r)(1 - k)G > \frac{4\pi_2}{9}$, and
(iii) this single firm has a positive incentive to deviate and wait, because the public beliefs resulting from such a deviation lead to no new entry: $(1 - \lambda)((\pi_{E3}^{ne})/r - (1 - k)G) > \pi_2 + kG - (\lambda + r)(1 - k)G$, where π_{E3}^{ne} is the future single period profit for a successful E firm, given no new entry.

If these conditions hold, then there exists no pure strategy equilibrium, but only a mixed strategy equilibrium in which a single E firm does a public offering with probability η_I. If $0 < \eta_I < 1$, then after observing no early IPO the public will revise its probability that the industry is viable to $\theta^{I'}$, where $\theta^{I'}$ is a function of η_I and $0 < \theta^{I'} < \theta$. η_I will be chosen so that $\theta^{I'}$ will cause the E pioneer to be indifferent between doing an early IPO or not.

Summary of Δ functions. These are presented here in summary form as an aid to the reader in following the details of the equilibria.

$$\begin{aligned}
\Delta_I^W V &= \text{benefit to doing IPO when all others postpone} \\
&= \frac{\pi_2}{1+r} - \frac{(\lambda + r)(1-k)G}{1+r} - \frac{kG}{1+r}\left(\frac{1-\theta}{\theta}\right) \\
\Delta_P^W V &= \text{benefit to doing private financing when all others postpone} \\
&= \frac{\pi_2}{1+r} - \frac{(\lambda + r)(1-k)G}{1+r} - \frac{zkG}{1+r}\left(\frac{1-\theta}{\theta}\right) - F \\
\Delta_I^P V &= \text{benefit to doing IPO when all others do private financing} \\
&= F - \frac{kG}{1+r}\left(\frac{1-\theta}{\theta}\right) \\
\Delta_W^P V &= \text{benefit to waiting when } n-1 \text{ others do private financing} \\
&= F + \frac{(\lambda + r)(1-k)G}{1+r} - \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2 \\
\Delta_W^I V &= \text{benefit to waiting when } n-1 \text{ others do public offerings} \\
&= \frac{(\lambda + r)(1-k)G}{1+r} - \frac{\pi_2}{1+r}\left(\frac{2}{1+n}\right)^2
\end{aligned}$$

Let:

$$A = \frac{\pi_2}{1+r} \quad A' = \left(\frac{2}{1+n}\right)^2 A \quad B = \frac{(1-k)G}{1+r} \quad C = \frac{kG(1-\theta)}{(1+r)\theta}$$

$$\begin{aligned}
\Delta_I^W V &= A \quad - (\lambda + r)B \; - C \\
\Delta_P^W V &= A \quad - (\lambda + r)B \; - zC \; - F \\
\Delta_I^P V &= \qquad\qquad\qquad\quad - C \; + F \\
\Delta_W^P V &= -A' + (\lambda + r)B \qquad + F \\
\Delta_W^I V &= -A' + (\lambda + r)B
\end{aligned}$$

Interpretation:

A = single-period monopoly profits, discounted one period

A' = single-period oligopoly profits, discounted one period, $(n \geq 2)$

B = new capital that must be invested, discounted one period

C = cost to future profits of revealing information, discounted one period

F = extra cost of doing private financing

Proof of Proposition 3.

(i)

$$\frac{\partial \Delta_I^W V}{\partial \theta} > 0 \quad \frac{\partial \Delta_P^W V}{\partial \theta} > 0$$

(ii)

$$\frac{\partial \Delta_I^W V}{\partial \lambda} < 0 \quad \frac{\partial \Delta_P^W V}{\partial \lambda} < 0 \quad \frac{\partial \Delta_W^I V}{\partial \lambda} > 0 \quad \frac{\partial \Delta_W^P V}{\partial \lambda} > 0$$

■

Proof of Proposition 4.

$$\left(\frac{1+r}{G}\right)\frac{\partial \Delta_I^W V}{\partial k} = 1+\lambda+r-\frac{1}{\theta}$$

This is positive iff $\theta(1+\lambda+r) > 1$

$$\left(\frac{1+r}{G}\right)\frac{\partial \Delta_P^W V}{\partial k} = z+\lambda+r-\frac{z}{\theta}$$

This is positive iff $\theta(1+(\lambda+r)/z) > 1$ ■

Proof of Proposition 5.

$$\frac{\partial \Delta_I^P V}{\partial \theta} > 0 \quad \text{and} \quad \frac{\partial \Delta_I^P V}{\partial k} < 0$$

■

Derivation of v_I and v_P, and proof of Proposition 6. From the proof of Proposition 1 we know that the expected value of an E firm that does an early IPO and raises an amount $(1-k)G$ is

$$\begin{aligned} V_I+(1-k)G &= \frac{\pi_2}{1+r}\left(\frac{2}{1+n_I}\right)^2+\frac{kG-(\lambda+r)(1-k)G}{1+r}+(1-k)G \\ &= \frac{\pi_{I2}+G}{1+r}-\frac{\lambda(1-k)G}{1+r}, \end{aligned}$$

where $\pi_{I2} = \pi_2(2/(1+n_I))^2$. The actual derivation of the above expression is somewhat different than in Proposition 1 because we must use iterated expectations over the three possible outcomes in the secondary market, but because of symmetry the result is the same.

λ' = the updated probability that the N technology is good. $\lambda' \in \{\lambda+\varepsilon,\ \lambda,\ \lambda-\varepsilon\}$. Using the same methods as applied in the proof of Proposition 1, keeping in mind that potential competitors use the updated value λ' in making their entry decisions, the secondary market value of a public E firm is

$$V_I' + (1-k)G = \frac{\pi_{I2}+G}{1+r} - \frac{\lambda'(1-k)G}{1+r}.$$

It follows directly that

$$v_I = | V_I' - V_I | = \frac{\varepsilon(1-k)G}{1+r}.$$

In a private offering, potential entrants do not observe λ', even if they do observe that financing has occurred. Using an approach similar to that used in the proof of Proposition 1 we know that the expected value of an E firm that does early private financing and raises an amount $(1-k)G$ is

$$V_P + (1-k)G = \frac{\pi_2}{1+r}\left(\frac{2}{1+n_P}\right)^2 + \frac{(1-\lambda)\left(z\pi_{E3}^{(1)} + (1-z)\pi_{E3}^{(2)}\right)}{r(1+r)} - F.$$

Using the proof of Proposition 1, the value of future profits, given that industry viability is revealed in period 1 is

$$\frac{\pi_{E3}^{(1)}}{r} = \frac{kG}{1-\lambda} + (1-k)G$$

and the value of future profits, given that industry viability is not revealed in period 1 is

$$\frac{\pi_{E3}^{(2)}}{r} = \frac{kG}{\theta^P(1-\lambda)} + (1-k)G.$$

Thus,

$$\begin{aligned} V_P + (1-k)G &= \frac{\pi_{P2}}{1+r} + \frac{\left(1-z+z\theta^P\right)kG}{\theta^P(1+r)} \\ &\quad - \frac{(\lambda+r)(1-k)G}{1+r} + (1-k)G - F \\ &= \frac{\pi_{P2}}{1+r} + \frac{G + (1-z)\left(\frac{1-\theta^P}{\theta^P}\right)kG}{1+r} \\ &\quad - \frac{\lambda(1-k)G}{1+r} - F, \end{aligned}$$

where $\pi_{P2} = (\pi_2/(1+r))(2/(1+n_P))^2$. As in calculating the value of an IPO given only publicly available information at time $1c$, we must again employ iterated expectations. However, because of symmetry, and because our equilibrium entry conditions are all linear in λ, the result is the same as in Section 2.

In a private offering, the future equilibrium profits $\pi_{E3}^{(1)}$ and $\pi_{E3}^{(2)}$ are not affected by private information held by some investors. Thus, the valuation of a privately informed investor is

$$\begin{aligned} V_P' + (1-k)G &= \frac{\pi_{P2}}{1+r} + \frac{(1-\lambda')\left(z\pi_{E3}^{(1)} + (1-z)\pi_{E3}^{(2)}\right)}{r(1+r)} - F \\ &= \frac{\pi_{P2}}{1+r} + \frac{(1-\lambda')\left(1-z+z\theta^P\right)kG}{(1-\lambda)\theta^P(1+r)} \\ &\quad + \frac{(1-\lambda')(1-k)G}{1+r} - F \\ &= \frac{\pi_{P2}}{1+r} + \frac{G + (1-z)\left(\frac{1-\theta^P}{\theta^P}\right)kG}{1+r} \\ &\quad - \frac{(\lambda'-\lambda)\left(1-z+z\theta^P\right)kG}{(1-\lambda)\theta^P(1+r)} - \frac{\lambda'(1-k)G}{1+r} - F. \end{aligned}$$

It follows directly that

$$v_P = |V_P' - V_P| = \frac{\varepsilon G}{1+r}\left(\frac{\left(1-z+z\theta^P\right)k}{(1-\lambda)\theta^P} + 1 - k\right) > v_I.$$

The second part of the proposition follows directly from the above equation and the fact that θ^P is increasing in θ. ∎

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