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Signaling in the Internet craze of initial public offerings☆

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Abstract

We explain the clustering of underpricing in initial public offerings (IPOs). The model features an industry with aggregate demand uncertainty and asymmetric information about firms' quality. In the IPO market, firms can signal quality by underpricing or under-issuing new shares. Expected aggregate demand for the industry's products increases with the publicity that the industry creates through IPO underpricing. We show that asymmetric information and expectations on aggregate product demand interact with each other to generate multiple equilibria. Underpriced IPOs cluster in one equilibrium but not in the other. We use these results to explain why the clustering often occurs in particular industries, is short-lived, and is sensitive to economic conditions.

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1. Introduction

Shares in initial public offering (IPO) are said to be underpriced when they have large price gains shortly after IPO. Such underpricing clusters sporadically and occurs in particular

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industries. In this paper, we construct a signaling model to explain the clustering as an equilibrium phenomenon and explore the common features of the clustering.

The clustering of IPO underpricing is an important phenomenon because it generates boom-and-bust fluctuations. Since the IPO market is a key source of capital for young firms, these fluctuations hinder the market's ability of providing capital to the firms. The extent of the fluctuations can be best illustrated by the Internet "craze" during the period 1999–2000. At the height of the craze, the average first-day return on IPOs shot up to a staggering 65%. Most of those "hot issues" were concentrated in the dot.com industry, while concurrent IPOs in other industries had lackluster performances.[1] The boom soon turned into bust near the end of 2000, when the number of underpriced IPOs and the magnitude of underpricing both dropped. As a result, the overall IPO activity fell dramatically — the total number of IPOs decreased from 496 in 1999 to 91 in 2001 (Peristiani and Hong, 2004, Table 1).

The Internet craze is not the only episode of clustering. Clustering also occurred in biotech IPOs in the early 1990s and other hot-issue markets (see Ritter, 1984). Common in all those episodes, the clustering was concentrated in particular industries and was short-lived. Why do firms underprice their IPOs at roughly the same time? Why does such clustering occur in particular industries? Why is the clustering short-lived? Answering these questions is important for understanding the common features of clustering. Surprisingly, very little theoretical modeling is on IPO clustering. Instead, the focus has been on a single firm's IPO behavior.[2]

We construct a theoretical model to explain clustering as a result of the interaction between aggregate demand uncertainty in the industry and asymmetric information about the quality of the IPO firms. We define a firm's quality through consumers' preferences for its product. The quality is private information before IPO. Our model features an industry facing an uncertain aggregate demand for its products. The market's expectations on such demand increase with the industry's publicity created in the IPO market. We model the industry's publicity as the average amount of IPO underpricing in the industry. As a positive externality, this industry-wide publicity yields a higher benefit to high-quality firms than to low-quality firms. When the quality is publicly known, a high-quality firm can attract higher demand for its product than a low-quality firm. Moreover, as the total expenditure on the industry's products increases, consumers increase the share of expenditure on high-quality products. Thus, the differential in expected earnings between the two types of firms increases with the industry's publicity.

A high-quality firm likes the market to know its quality because only after the quality is known can the firm attract more customers in the product market. However, this potential benefit also gives low-quality firms the incentive to mimic. To prevent mimicking, a high-quality firm must take costly actions such as under-issuing or underpricing the shares in IPO. Underpricing is more costly than under-issuing because in the event of underpricing, the firm must increase the number of shares in IPO in order to raise the required amount of capital,

[1] In fact, there was an increase in cancellations and withdrawals from the IPO market by non-Internet firms in 1999. As the chief executive of a large dry pet food company complained, "If you look at the IPO market, there's large-capitalization activity and dot.com activity, but little else. I feel sorry for small-cap companies that are nondot.com, and which need to complete their deals." (Prial, 1999).

[2] Well-known signaling models of IPO include Allen and Faulhaber (1989), Grinblatt and Hwang (1989) and Welch (1989). Rock (1986) emphasizes the winner's curse. Others attribute underpricing to underwriters' reputation building behavior (e.g., Beatty and Ritter, 1986; Benveniste and Spindt, 1989), to a firm's concern for liquidity in the secondary market (e.g., Mauer and Senbet, 1992), or to behaviors that are not Bayesian rational (Loughran and Ritter, 2000). For more references, see Michaely and Shaw (1994) and Loughran and Ritter (2000).

which reduces the original owner's claim on the firm's future earnings. As such, underpricing is also more effective in signaling quality than under-issuing. A high-quality firm chooses to underprice when low-quality firms' temptation to mimic is strong, and to under-issue when the temptation is weak.

IPO underpricing clusters when individual firms' incentive to underprice interacts with expectations on the industry's publicity. Industry-wide underpricing cannot be sustained in the absence of incentive to underprice by individual firms. On the other hand, underpricing will not arise at the firm level without expectations of the industry-wide underpricing and its positive externality on individual firms' expected earnings. However, when the industry-wide underpricing is expected, high-quality firms will underprice and IPO underpricing will cluster.

To illustrate this mechanism, suppose that all firms expect the industry's publicity to be high. In this case, the aggregate demand for the industry's products will be high, which will increase the benefit to high-quality firms by increasing the differential in expected earnings between the two types of firms. But low-quality firms will also have strong temptation to mimic in this case. To signal successfully, a high-quality firm will greatly underprice IPO. As all high-quality firms underprice, post-IPO gains in share prices will cluster. This clustering will fulfill the initial expectations that the industry's publicity will be high. Similarly, low expectations of the industry's publicity are also self-fulfilling. In this case, low-quality firms' temptation to mimic is weak and every high-quality firm signals quality by under-issuing instead of underpricing.[3] If firms' quality were public information, instead, then all firms would issue IPO at the full price to raise the required amount of capital so that neither underpricing nor under-issuing would occur.

The main contribution of our paper to the IPO literature is to combine asymmetric information in the IPO market and aggregate uncertainty in the product market to generate the clustering of underpriced IPOs. The mechanism can explain why underpriced IPOs often cluster in particular industries and why the clustering is short-lived (see the concluding section). Another contribution is that the industry's publicity makes each firm's expected earnings endogenous. This endogeneity induces large underpricing even when we deliberately restrict the intrinsic differences in quality to be small. In contrast, most of previous models cannot examine the clustering or generate underpricing under the same restrictions, because they focus on a single firm's IPO decision.

Two exceptions are Hoffmann-Burchardi (2001) and Benveniste et al. (2002), who examine the clustering.[4] Our model shares with these models the feature that the clustering relies on a common factor among different firms' values. However, we illustrate a different mechanism of the clustering, i.e., the interaction between the industry's publicity and individual firms' private information. By generating multiple equilibria at the industry level, this mechanism helps to explain why all hot-issue markets are short-lived and why they are sensitive to economic conditions. The above models cannot answer these questions clearly. In addition, there are two other differences. First, we explicitly link the clustering to the features in the industry's product market. The above models do not have an explicit role of the product market. Second, our model generates the clustering regardless of whether firms go to the IPO market simultaneously or

[3] Multiple equilibria arise here at the industry level rather than at the firm level. For each individual firm, the industry's publicity is given and there is a unique equilibrium in the signaling game. Also, all equilibria are separating equilibria refined by the criterion of Cho and Kreps (1987). We are not interested in pooling equilibria.

[4] These papers were written concurrently with our paper and we became aware of these papers after completing the first version of our paper in 1999.

sequentially. In contrast, a sequential structure is essential for the clustering in the above models. Although sequential moves may be realistic, the time interval between some underpriced IPOs is too short to allow for investors to acquire sufficient information during the interval.[5]

To economize on space, we omit the proofs of all propositions in this paper. They can be found in the working paper (Cao and Shi, 2001).

2. The model

The key ingredients of the model are industry-wide uncertainty and asymmetric information regarding individual firms' quality. We describe them in this section.

2.1. Industry uncertainty and private information

Consider an industry facing an uncertain aggregate demand for its products. The expected demand is susceptible to the industry-wide IPO underpricing. To be specific, let Y be consumers' aggregate expenditure on the industry's products and $\bar{D}$ the industry-wide average price gain per new share immediately after IPOs. The expected aggregate demand is:

$$E\left(Y|\bar{D}\right) = Y_0 + \rho\bar{D}, \qquad 0<\rho<1, \tag{1}$$

where $Y_0>0$ is a constant and the expectations are investor's at the time of IPOs. We refer to $\bar{D}$ as the industry's publicity. This is an externality because individual firms take $\bar{D}$ as given. The assumption $\rho>0$ means that the externality is positive. The auxiliary assumption $\rho<1$ ensures that the externality is not overwhelming in determining the aggregate demand.

The characterization in Eq. (1) is realistic for an immature industry. For such an industry, the forecast on the product demand is imprecise and sensitive to the industry's publicity. Spectacular price gains in IPO in the industry can increase publicity and consumer awareness of the industry, thus benefiting the industry as a whole. For example, if Internet firms that sell books, auction goods, or provide market information have large price gains in IPOs, their collective publicity can attract businesses away from traditional firms that provide similar services. One can formalize a mechanism to support our characterization, for example, by adapting the argument in Stoughton et al. (2001) to our environment. However, we remain agnostic about such formalizations. It is important to bear in mind that the assumption $\rho>0$ does not automatically lead to the clustering of underpriced IPOs (see Section 3).

The industry consists of two types of firms. A fraction α are H firms and a fraction $1-\alpha$ are L firms. H firms produce high-quality products while L firms produce low-quality products. A firm's quality is private information prior to IPO. In order to produce, a firm must have enough funds or capital. Let a firm's total amount of required funds be $k_0>1$, and the firm's internal funds be (k_0-1). Thus, a firm must raise one unit of external fund. This can be done by issuing shares in IPO or seeking alternative financing such as loans and venture capital. Of course, a firm can combine the two financing methods, as described later. Let k_i be a type i firm's total cost

[5] In contrast to some models in the literature, including Benveniste et al. (2002), our analysis does not rely on the role of underwriters. A model that places underwriters at the center of the story has certain realism, but it can only explain some aspects of the clustering. For example, such a model predicts that the clustering and underpricing of IPOs are both more pronounced with a large underwriter than with a small underwriter. This is not obviously the case in a hot-issue market like the Internet IPO market in 1999.

of capital (including the firm's internal funds), which will be determined in the equilibrium. Because external capital is at least as costly as internal funds, $k_i \geq k_0 > 1$ for i=H, L.

All firms issue IPOs at the same time.[6] If a firm's IPO revenue falls short of the required amount (1 unit), the firm seeks alternative financing such as debt. Once the external funds are obtained, firms produce and compete in the product market. Then, each firm repays the alternative funds first and the shareholders second.

A firm's quality is modeled through consumers' preferences for its products: a product of publicly known high quality yields higher marginal utility than a low-quality product. In Cao and Shi (2001), we describe the product market in detail and derive each firm's earnings. For brevity, we only summarize these earning functions. Let r_i be a type i (i=H, L) firm's earnings that is distributed to its lenders and shareholders. Suppose that the IPO market successfully separates the two types of firms, then the ensuing competition in the product market yields:

$$r_L = k_L \tag{2}$$

$$r_H - r_L = \frac{1}{\alpha}(Y - k_L). \tag{3}$$

The first equation states the intuitive result that competition drives an L firm's earnings to the level of its capital cost so that the firm's profit is zero. In comparison, an H firm can obtain higher earnings from its quality advantage. To ensure that this earnings' differential is indeed positive, we assume $Y_0 > k_L$ throughout this paper so that $Y > k_L$ for all $\bar{D} \geq 0$.

An important feature of the above results is that an H firm's earnings increase with the aggregate demand for the industry's products, Y ,while an L firm's earnings are independent of Y. This is intuitive. When the aggregate expenditure on the industry's products rises, consumers will increase the share of expenditure on high-quality products and reduce the share on low-quality products. All H firms benefit from this increased demand, and so each H firm's earnings increase. For an L firm, however, competition drives the earnings down to the cost of capital.

At the time of IPO, investors and firms are concerned with the firms' expected earnings, rather than ex post earnings r_i. These expected earnings are denoted R_i for a type i firm. To calculate R_i, continue to suppose that the IPO market successfully separates the two types of firms. Anticipating the result that only H firms will underprice IPOs in such separating equilibria, we have $\bar{D} = \alpha D$, where D denotes the average amount of underpricing per share by H firms. Then, $R_i = E(r_i|D)$ for i=H, L. Using Eqs. (1), (2) and (3), we have $R_L = k_L$ and $R_H = xR_L + \rho D$, where $x \equiv 1 + \frac{1}{\alpha}(Y_0/k_L - 1) > 1$. Thus, $R_H > R_L$ for all $D \geq 0$. More importantly, an H firm's expected earnings increase in the industry-wide underpricing while an L firm's expected earnings are independent of such aggregate underpricing.

Two facts are worthwhile emphasizing. First, only after an H firm successfully signals its high quality can it obtain R_H; if the firm fails to signal its quality, its expected earnings are lower than R_H. Second, the earnings differential between the two types of firms is endogenous in the equilibrium and it depends on the industry-wide underpricing. This endogeneity is important for

[6] We do not mean literally that firms in reality have the same IPO date, but rather that firms' IPO dates are so close to each other that one firm cannot change the IPO decision after observing other firms' IPO actions. This assumption simplifies the analysis. The results under sequential moves are similar (see Cao and Shi, 2001).

the clustering of underpricing. In contrast to our specification, most previous models of IPO underpricing assume that the earnings' differential is exogenous.

To emphasize the endogenous component in expected earnings, we separate it from the exogenous component and call the latter the *intrinsic earnings* of a firm. Thus, the intrinsic earnings are R_L for an L firm and xR_L for an H firm. Denote $x_H = x > 1$ and $x_L = 1$. We simply refer to x_i as the *quality* of a type i firm, where i = H, L.

2.2. Financing methods

A firm can obtain external funds by combining IPO and alternative financing. In the IPO market, a firm chooses the offer price s and the number of shares f to be offered.[7] Normalize the total number of a firm's shares to 1, so that $f \in (0, 1]$. The firm's original owners keep $1 - f$ shares after IPO. The market price of shares is p. The gain to IPO investors is $d \equiv p - s$ per share. The firm is said to *underprice* IPO if $d > 0$. The IPO revenue is $q \equiv sf$. If $q < 1$, then the firm either underpriced or under-issued shares in IPO. In either case, the firm raises the remaining required capital through alternative methods.

To be specific, let us suppose that firms obtain alternative funds through the following realistic mechanism. The financiers of alternative funds do not know a firm's quality and only have an *imperfect* technology to screen the firm. The technology gives a noisy signal that is positively correlated with the firm's quality. That is, the signal is more likely to correctly reflect the firm's true quality. When the signal indicates high quality, the financiers provide loans to the firm at a low rate. Otherwise, the financiers charge a high loan rate.

The above mechanism has two important features. First, because the screening signal is positively correlated with the firm's true quality, an H firm will more likely get a low loan rate than an L firm. That is, the expected (unit) cost of alternative funds will be lower for an H firm than for an L firm. This cost differential is necessary for an H firm to signal by underpricing. To capture the differential, we assume that the expected unit cost of alternative funds for a type i firm is $(1 + bx_i^{-1})$, where $b > 0$ is a constant and x_i is the true quality of the firm. Thus, if a type i firm raises only a revenue $q < 1$ in IPO, the total cost of alternative funds is $(1 + bx_i^{-1})(1 - q)$.[8]

Second, because the screening technology is imperfect, the financiers may not know a firm's true quality even after screening the firm. In particular, an H firm may be wrongly labeled as an L firm. Thus, seeking alternative financing does not resolve the problem of asymmetric information regarding the firms' quality.[9] This feature implies that the order in which a firm uses the two financing methods is not critical for the analysis. Even if a firm seeks alternative financing before IPO, the loan rate it obtains does not indicate the firm's quality perfectly, and so the firm may still have incentive to signal its quality in IPO. Nevertheless, it is convenient to assume that firms go to IPO first before seeking alternative funds.

[7] By allowing a firm to choose f as well as s, we achieve some realism and conform with the literature. More importantly, we can distinguish a separating equilibrium with underpricing from a separating equilibrium with under-issuing. Since f responds to the industry's publicity quite differently in these two equilibria, fixing f may artificially constrain a firm's incentive to underprice.

[8] All analytical results in this paper continue to hold for a more general cost function $(1 + b/x)\, C(1 - q)$ that satisfies $C(0) = 0$, $C'(0) \geq 1$ and $C'' > 0$.

[9] Empirical evidence seems to support this feature. For example, James and Wier (1990) and Slovin and Young (1990) find that firms with previously established borrowing relationships can still experience IPO underpricing, although they may underprice by less than other IPOs.

2.3. Payoffs to IPO firms and the investors

Consider an individual firm that goes to IPO. We specify the payoffs to this firm and to investors who purchase the IPO shares. For convenience, we describe the firm's choices as the IPO revenue q (rather than the issuing price s) and the number of IPO shares f. Denote $a=(f,q)$. The payoff to the firm is defined as the expected return to the firm's original owners. Let $I\in[0,1]$ be the posterior probability with which investors believe that the firm is of high quality, after observing all firms' financing activities. Given this belief, the firm's expected earnings are:

$$R_{\rm I} = R_{\rm H}I + R_{\rm L}(1-I). \tag{4}$$

From such earnings, the firm repays the alternative financiers and then distributes the rest to the shareholders. Since the original owners hold onto $(1-f)$ shares after IPO, the firm's payoff is:

$$V(f,q;R_{\rm I},x_{\rm i})\equiv(1-f)\left[R_{\rm I}-\left(1+bx_{\rm i}^{-1}\right)(1-q)\right]. \tag{5}$$

The firm chooses a to maximize V, taking D (and hence $R_{\rm H}$) as given.

Notice that we use the market's expected earnings of the firm to calculate the firm's payoff. This is because consumers have the same beliefs about the firm's quality as investors. If the firm does not signal its quality successfully in IPO, the firm cannot be sure that its high quality will attract a high demand for its product. The purpose of signaling in IPO is to affect the expected earnings, $R_{\rm I}$, by affecting the market's belief of the firm's type.

Investors care about the expected rate of return per share. To simplify the analysis, we assume that investors are risk neutral and that the risk-free (gross) rate of return is one. Let $p_{\rm I}$ be the market price of the shares conditional on investors' belief after IPO, I. This price must be equal to the expected return to the shares; otherwise, there would be profitable arbitrage in the post-IPO market as the rate of return to the shares would exceed the risk-free rate. Thus,

$$p_{\rm I} = R_{\rm I}-\left(1+bx_{\rm I}^{-1}\right)(1-q), \tag{6}$$

where $x_{\rm I}^{-1}\equiv x^{-1}I+(1-I)$. The rate of return to buying an IPO share is $p_{\rm I}/s$, where $s=q/f$. For investors to participate in IPO, this rate must be at least equal to the risk-free rate (one). Thus, $0\le s\le p_{\rm I}$.

We say that an IPO action $a=(f,q)$ is feasible under the belief I if $f,q\in[0,1]$ and $0\le s\le p_{\rm I}$. For convenience, let us use Eq. (6) to rewrite the requirements $p_{\rm I}\ge 0$ and $p_{\rm I}\ge s$ as

$$q\ge M_{\rm I}\equiv 1-\frac{R_{\rm I}}{1+bx_I^{-1}} \qquad \text{and } f\ge S_{\rm I}(q), \tag{7}$$

where the function $S_{\rm I}(\cdot)$ is defined as follows:

$$S_{\rm I}(q) = q/\left[R_{\rm I}-\left(1+bx_{\rm I}^{-1}\right)(1-{\rm q})\right]. \tag{8}$$

For all $q\ge M_{\rm I}$, IPO is sold at the full price if $f=S_{\rm I}(q)$ and underpriced if $f>S_{\rm I}(q)$.

3. Public information versus private information

In this section, we first analyze the case where the quality of firms is publicly known and show that underpricing does not occur in this case. This result establishes the earlier claim that Assumptions 1A and 1B themselves do not generate the clustering of underpriced IPOs.

Then, we discuss firms' incentive to signal in the presence of private information and lay out some assumptions.

Consider a type i firm, where i is either H or L, and suppose that the type is publicly known. Then, the firm's expected earnings are equal to R_i, regardless of what the firm does in the IPO market. In this case, underpricing only wastes resources without any gain. So, it is optimal for the firm to issue its IPO at the full price, i.e., at $s = p_i$. Moreover, it is optimal to raise all external funds through IPO, i.e., to set $q = 1$. If the firm used alternative financing to raise a positive amount of funds, δ, the benefit would be δ, the cost $(1+b/x_i)\delta$, and so the firm's payoff would be reduced. Thus, we have established the following proposition:

Proposition 1. *If quality is public information, no firm underprices IPO in equilibrium, despite the influence of the industry's publicity on the aggregate product demand. Moreover, every firm raises all external capital through IPO. Thus, a type i firm's optimal choice is* $(f_i, q_i) = (1/R_i, 1)$ *and the payoff is* $(R_i - 1)$*, where* $i = H, L$.

Industry-wide underpricing cannot be sustained without asymmetric information. This result arises from the free-rider problem. Although the industry's publicity benefits all H firms, it is a public good. Every firm likes to enjoy this public good, but no firm wants to contribute to the public good by underpricing its own IPO. Instead, every firm waits for other firms to underprice. As a result, underpricing does not occur and the industry's publicity is low. This outcome can be a collective loss to the H firms. When the industry's publicity has a strong influence on the aggregate demand, all H firms would gain if all of them could somehow be coerced to underprice their IPOs. Of course, such coercion is not a market outcome.

Let us now return to the case of private information. An H firm may have incentive to signal its quality even if other H firms do not signal. Signaling enables the firm to obtain a higher demand for its product and hence higher expected earnings. If the firm does not signal, on the other hand, consumers may believe that the firm is an L firm. The benefit from signaling can be strong enough to overcome the free-rider problem described above.

Moreover, the benefit from signaling increases with the industry's publicity, because the earnings differential increases in D. Thus, if all other H firms underprice IPOs by more, an H firm is also likely to underprice its own IPO by more. This dependence of individual firms' incentive to underprice on the industry-wide underpricing will be key to the clustering of IPO underpricing. Ironically, it is the same dependence of the earnings differential on D that induces free-riding.

An H firm can signal by either underpricing or under-issuing IPO. Both actions reduce the firm's IPO revenue. The ability to signal comes from the feature that an H firm has a lower expected unit cost of alternative funds than an L firm. This cost differential enables an H firm to refrain more from the IPO revenue than an L firm can.[10] By refraining from raising as much IPO revenue as it desires, the firm forces itself to go through costly alternative financing. This tends to increase investors' belief that the firm is an H firm, because investors know that alternative funds are more costly to an L firm than to an H firm. The more the firm refrains from the IPO revenue, the larger the total expected cost of alternative funds will be, and the more likely investors will treat the firm as an H firm.

Although underpricing and under-issuing both reduce the IPO revenue, they differ in how they change the original owners's claim on the firm's future earnings. By under-issuing, the firm

[10] More precisely, the payoff function R has the single-crossing property which is necessary for signaling (see Fudenberg and Tirole, 1993, p.259). Here, the property appears in the form $\partial\left(-\frac{\partial V/\partial R}{\partial V/\partial z}\right)/\partial z<0$ for $z = q, f$.

increases the fraction of shares, $(1-f)$, that the original owners retain after IPO. If the firm underprices, however, the firm must increase the number of shares in IPO in order to raise the same amount of IPO revenue. This reduces the original owners' claim on the firm's future earnings. Thus, underpricing is more costly than under-issuing to the original owners. As such, underpricing is more credible in signaling the firm's quality.

To emphasize the interplay between the industry-wide underpricing and individual firms' incentive to underprice, we impose the following assumption:

Assumption 1A. The difference in intrinsic earnings between the two types of firms is not too large, i.e., $R_L(x-1) < b$.

Assumption 1B. When the quality is publicly known and the external capital comes entirely from alternative funds, an H firm can make a positive return but an L firm cannot; i.e., $xR_L > 1 + b/x$ and $R_L < 1 + b$.

Assumption 1A is opposite to the ones made in signaling models of a single firm's IPO (see the references in the Introduction). For those models to generate underpricing, the intrinsic difference between the two types of firms must be large. Our assumption seems realistic for the firms in a new industry, because the intrinsic difference between those firms does not seem large at the beginning. Moreover, by deliberately restricting the intrinsic difference to be small, we sharpen the focus on how the industry-wide publicity can induce individual firms to underprice. Nevertheless, a small difference in intrinsic earnings does not always imply a small difference in expected earnings, since the later depends on the industry's publicity which is endogenous.

In order to signal, H firms must have some (albeit small) advantage over L firms in intrinsic earnings. Assumption 1B specifies this advantage in the case of public information. This is a weak assumption: because the quality is private information, this assumption alone implies neither that signaling will necessarily occur nor that signaling will entail underpricing.

4. Signaling equilibrium and separation

In this section we characterize an individual firm's strategy under private information, taking the industry's publicity D (and hence R_H) as given. This strategy is the firm's best response to the industry's publicity. We refer to this best response of a single firm, together with the market belief, as a signaling equilibrium. Of course, we must also determine the industry's publicity in a market equilibrium, which we will do in the next section.

For any given R_H, a Bayesian signaling equilibrium consists of market beliefs I and the firm's decisions (f, q) that satisfy the following conditions: (i) Given the beliefs, the firm's decisions maximize the payoff; (ii) With the firm's choices, the beliefs are rational according to Bayes updating. We will focus on those equilibria in which H firms successfully signal their quality and hence separate themselves from L firms.[11]

To examine when and how an H firm can signal successfully, let us first describe a reference point — the case where IPO actions do not separate the two types of firms. This "pooling" outcome happens when the two types of firms take the same action in IPO. Consider any such pooling action $a_0 \equiv (f_0, q_0)$. After observing this action, the market does not gain any new

[11] More precisely, we use the intuitive criterion of Cho and Kreps (1987) to restrict the beliefs off the equilibrium path. Thus, the term "equilibrium" in this paper stands for an equilibrium that satisfies this criterion.

information about a firm's quality. Thus, the market's belief of every firm is $I=\alpha$. The market price of a share after IPO is p_α, given by Eq. (6) with $I=\alpha$. A type i firm's payoff from pooling is $V^0(x_i)\equiv V(f_0, q_0; R_\alpha, x_i)$, where the function V is defined in Eq. (5).

Now we analyze possible actions that an H firm can take to signal its quality. Consider such an action $a=(f,q)$, where $a\neq a_0$. For this action to signal quality successfully, it must be a credible signal in the sense that it satisfies the following intuitive requirements (see Cho and Kreps, 1987). First, the action must be feasible for an H firm, i.e., $f,q\in[0,1]$, $q\geq M_H$ and $f\geq S_H(q)$ (see the end of Section 2.3). Second, the action must be unattractive to an L firm; otherwise, L firms would mimic the action. Since the payoff to an L firm from mimicking the action a is $V(f,q; R_H, 1)$, the action is unattractive to an L firm if $V(f,q; R_H, 1)\leq V^0(1)$. Third, the action is attractive to an H firm if taking the action induces the market to believe the firm's high quality. That is, $V(f,q; R_H,x)>V^0(x)$. Because an L firm does not gain from the action but an H firm does, investors should naturally interpret any firm taking the action as an H firm.

To depict the set of credible signals, let us rewrite the second requirement above as:

$$f\geq \mathrm{IND_L}(q)\equiv 1-V^0(1)/[R_H-(1+b)(1-q)]. \tag{9}$$

Define a critical level, Q_1, as follows:

$$Q_1\equiv 1-\frac{R_H-V^0(1)}{1+b} \tag{10}$$

We consider two cases: $Q_1=0$ and $Q_1>0$, which are depicted in Fig. 1a and b.

The curve $f=S_H(q)$ in these figures is the *full-price curve* for an H firm when separation occurs. Underpricing occurs if an H firm chooses an action above this curve. For a reference, we also depict the full-price curve under pooling, $f=S_\alpha(q)$. The curve $f=\mathrm{IND_L}(q)$ is the set of actions which generate the same payoff to a mimicking L firm as the pooling action (f_0,q_0) does. Actions above this curve generate strictly lower payoffs to an L firm even if the firm is viewed as an H firm as a result of mimicking. Thus, the shaded area in each diagram is the set of actions that are feasible to an H firm and that will never be taken by an L firm. Credible signals are actions in this shaded area that give an H firm a higher payoff than under pooling.

Among credible signals, an H firm chooses the one that maximizes its payoff. To find the best choice, the following features can be verified. First, an H firm prefers the actions on the lower boundary of the shaded area to the actions in the interior of the area in Fig. 1a and b, because for each action in the interior of the shaded area there is an action on the lower boundary of the area that raises the same IPO revenue but with a fewer number of shares. Second, an H firm's payoff is an increasing function of q along the full-price curve $f=S_H(q)$. Third, an H firm's payoff is a decreasing function of q along the curve $f=\mathrm{IND_L}(q)$.

These features imply that the optimal signal for an H firm is to choose point A depicted in Fig. 1a and b. Denote the choices at point A as $a_b=(f_b,q_b)$.Let Q_A be the IPO revenue at the intersection between the curve $f=S_H(q)$ and the curve $f=\mathrm{IND_L}(q)$. Then,

$$\left.\begin{array}{llll} f_b=1-\dfrac{V^0(1)}{R_H-1-b} & \text{and} & q_b=0, & \text{if } Q_1\leq 0 \\ f_b=S_H(Q_A) & \text{and} & q_b=Q_A, & \text{if } Q_1>0. \end{array}\right\} \tag{11}$$

Separation occurs when the action a_b yields a higher payoff than the one under pooling. In this case, investors can perfectly infer every firm's quality from their IPO actions. The best

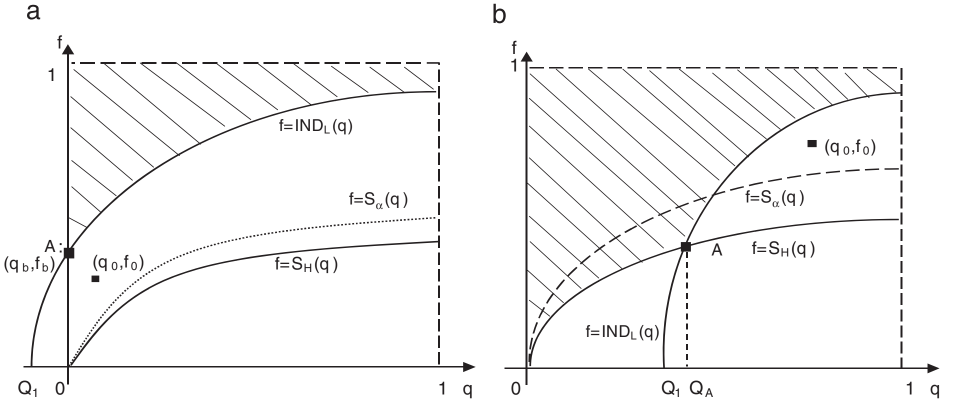

Fig. 1. a) Deviation by an H firm when $Q_1 \leq 0$. b) Deviation by an H Firm when $Q_1 > 0$.

action for an L firm is then $(f,q)=(1/R_L, 1)$ and the payoff is $V^0(1)=R_L-1$ (see Proposition 1). With this value of $V^0(1)$, the condition $Q_1 \leq 0$ becomes $R_H \geq R_L + b$. Denote the values of a_b under this value of $V^0(1)$ as $a^*=(f^*,q^*)$. Then, for $R_H \geq R_L + b$, Fig. 1a applies and

$$f^* = 1 - \frac{R_L - 1}{R_H - (1+b)}, \qquad q^* = 0 \tag{12}$$

For $R_H < R_L + b$, Fig. 1b applies, in which case the action (f^*,q^*) solves:

$$f^* = S_H(q^*) \quad \text{and} \quad \frac{q^*}{R_H - (1+bx^{-1})(1-q^*)} = 1 - \frac{R_L - 1}{R_H - (1+b)(1-q^*)} \tag{13}$$

We have the following proposition:

Proposition 2. *There exists* $\underline{\alpha} \in (0, 1]$ *such that, if* $\alpha < \underline{\alpha}$, *there exists a unique signaling equilibrium. This equilibrium is a separating equilibrium. When* $R_H - R_L \geq b$, *an H firm's action is described by* Eq. (12) *which entails underpricing. When* $R_H - R_L < b$, *an H firm's action is described by* Eq. (13), *which entails under-issuing but not underpricing. In both cases, an L firm's action is* $f=1/R_L$ *and* $q=1$. *If* $\alpha \geq \underline{\alpha}$ *and* $R_H - R_L < b$, *the separating equilibrium is still the unique equilibrium. However, if* $\alpha > \underline{\alpha}$ *and* $R_H - R_L \geq b$, *a pooling equilibrium can exist.*

An H firm can successfully signal its quality when either the differential in expected earnings or the fraction of H firms in the market is small. In the remainder of this paper, we require $\alpha < \underline{\alpha}$ so that all equilibria are separating equilibria. The difference is whether separation is achieved by underpricing or under-issuing.

Whether an H firm underprices or under-issues IPO depends on the differential in expected earnings between the two types of firms, $(R_H - R_L)$. As explained in Section 3, underpricing is more costly to the firm's original owners than under-issuing, but more effective in signaling quality. When $R_H - R_L < b$, the benefit to an L firm from mimicking is small. In this case, under-issuing is sufficient to deter mimicking. When $R_H - R_L \geq b$, however, an L firm has strong temptation to mimic, which can no longer be deterred by under-issuing. In this case, an H firm must underprice in order to signal quality.

Because an individual firm's underpricing depends on the differential in expected earnings, it depends on the industry's publicity. To express this result explicitly, denote the amount of underpricing by an individual H firm as $d(D)$. Then, $d(D)=p_H-q^*/f^*$. Denote $D_0\equiv[b-R_L(x-1)]/\rho$. Note that $D_0>0$ (by Assumption 1A). Since $R_H-R_L\geq b$ if and only if $D\geq D_0$, we can write the two cases of the separating equilibrium in Proposition 2 as follows:

$$d(D)=\begin{cases}0, & \text{if } D<D_0\\ p_H=\rho_D+xR_L-1-bx^{-1}, & \text{if } D\geq D_0.\end{cases} \tag{14}$$

The higher the industry's publicity, the more likely individual H firms will underprice and, when they underprice, the larger the amount of underpricing will be. This interplay between individual firms' incentive to underprice and the industry-wide underpricing is a powerful mechanism that can generate the clustering of large underpricing, as we will show in the next section.

5. Market equilibrium and clustering

Although the signaling equilibrium is unique for each firm under any given amount of the industry's publicity, the industry's publicity is endogenous in the market equilibrium. In this section we determine the market equilibrium.

5.1. Market equilibrium and self-fulfilling expectations

A *market equilibrium* is defined as a pair $(d(D),D)$ such that $d(D)$ is the best response of each H firm to D, given by Eq. (14), and that $d(D)=D$. The condition $d=D$ is required because all H firms are symmetric. We say that a market equilibrium is an underpricing equilibrium if $D>0$ and a no-underpricing equilibrium if $D=0$. In both equilibria, H firms separate from L firms successfully, as shown in the previous section.

Substituting $d(D)$ from Eq. (14) and invoking the requirement $d(D)=D$, we can solve for D. Then, the following proposition can be easily established.

Proposition 3. Define $\underline{\rho}\in(0,1)$ as follows:

$$\underline{\rho}\equiv\frac{b-R_L(x-1)}{b(1-x^{-1})+R_L-1}. \tag{15}$$

When $0\leq\rho<\underline{\rho}$, only the no-underpricing equilibrium exists. When $\underline{\rho}\leq\rho<1$, both the underpricing equilibrium and the no-underpricing equilibrium exist. In the underpricing equilibrium, the amount of underpricing increases in ρ.

Fig. 2 depicts the case $\underline{\rho}<\rho<1$, where the two market equilibria co-exist. In the diagram, the underpricing "curve" depicts the best response (Eq. (14)). Point EN is the no-underpricing equilibrium, in which H firms separate from L firms by under-issuing. Point EU is the underpricing equilibrium, in which H firms separate by underpricing.

This proposition contains the following interesting features. First, no underpricing occurs in the equilibrium when the industry's publicity has only a weak effect on the industry's expected product demand, i.e., when $0\leq\rho<\underline{\rho}$. This result can be seen in Fig. 2. When ρ is small, the level D_0 is large and the underpricing curve lies below the 45-degree line for all $D>0$. It is easy to explain this result. When ρ is small, the differential in expected earnings between the two types of firms is small, and hence it does not pay for an H firm to underprice. At the same time, the temptation for L firms to mimic is weak. For an H firm to signal its quality, it suffices to under-issue rather than to underprice.

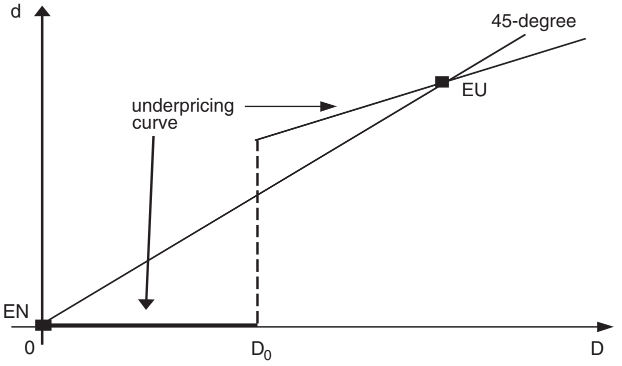

Fig. 2. Multiple market equilibria.

Second, underpricing can occur when the industry's publicity has a strong effect on the aggregate demand for the industry's goods, i.e., when $\rho \geq \underline{\rho}$. This result is intuitive. When firms believe that the industry's publicity will be high, the expected aggregate demand for the industry's products will be high. Benefiting from this high demand, each H firm will have high expected earnings, which will widen the earnings' differential between the two types of firms. To obtain this large benefit, an H firm must signal its quality to the market. This cannot be achieved by only under-issuing IPO, because the large differential in expected earnings creates strong temptation for L firms to mimic. To deter this mimicking behavior, an H firm must resort to the more costly action — underpricing. As every H firm underprices, underpricing clusters in the industry. This generates a large amount of aggregate underpricing which supports the belief that the industry's publicity will be high.

Third, even when $\rho \geq \underline{\rho}$, underpricing is not an inevitable outcome. On the contrary, no-underpricing is also a market equilibrium in this case. All that is needed to generate no-underpricing is that firms believe that the industry's publicity will be low. Under this belief, the differential in expected earnings between the two types of firms will be small. This small benefit does not justify the costly action of underpricing. At the same time, L firms' temptation to mimic will be weak, and so under-issuing will be sufficient for signaling quality. The absence of underpricing supports the belief that the industry's publicity will be low.

The above exposition shows that multiple, self-fulfilling equilibria arise from the interplay between individual firms' incentive to signal and the industry-wide underpricing. Since each firm is small in the industry, it has very little effect on the industry's publicity. However, the industry's publicity affects an individual firm's expected earnings and underpricing decisions. If all other H firms choose not to underprice, an individual H firm also finds it optimal not to underprice, even when all H firms collectively prefer underpricing to no-underpricing. This interplay cannot be appreciated in a model with only one firm, which has been the focus of most models in the literature on IPO underpricing.[12] When a firm is the only one in the industry, it will either underprice or not underprice, whichever gives the higher payoff. The two outcomes cannot both be an equilibrium for given parameters, in contrast to the multiple equilibria in our model.

[12] This literature has examined multiple equilibria in a single firm's signaling game. We have deliberately eliminated this type of multiplicity by imposing Assumption 1A and the restriction $\alpha < \underline{\alpha}$. In our model, the signaling equilibrium is unique for any given $D \geq 0$.

Finally, the interplay between individual firms' underpricing and the industry's publicity can produce large underpricing. In the underpricing equilibrium, H firms offer their shares free of charge! When expected industry's publicity passes over the critical level D_0, the offer price of and H firm's IPO drops to 0 and the percentage of discount to IPO investors jumps from 0% to 100%.[13] This large underpricing is a reminiscent of the phenomenal price gains observed in some Internet IPOs in 1999. Considering that the intrinsic difference between high-quality and L firms is small (Assumption 1A), the large magnitude of underpricing is remarkable.

Another way to understand the large underpricing is to notice that the market price of an individual H firm's IPO varies with the industry's publicity, even when the firm's type becomes publicly known. Despite the small intrinsic difference between the two types of firms, the industry's publicity can magnify it into a large difference in the market price of IPO, and hence into large underpricing. In contrast, previous signaling models deal with only one firm and assume that the market price of shares is exogenous once the firm's type is known. Those models cannot generate underpricing when the difference between firms' intrinsic earnings is small.

5.2. Extensions

The main results of the model are robust to three extensions (see Cao and Shi, 2001). First, we can require that the minimum IPO revenue be positive, rather than zero as in the benchmark model. Because alternative financiers are more likely to supply funds to a firm whose IPO has a large price gain, a reasonable specification is that the minimum IPO revenue decreases in the amount of underpricing. Under this specification, underpricing can still be large and can still cluster. The quantitative predictions of the model will be more realistic: in the underpricing equilibrium, the offer price can be positive and the number of shares offered in IPO will not necessarily increase with expected earnings.

Second, we can allow a firm to benefit directly from its underpricing, as well as from the industry's publicity. For example, the expected revenue R_H can be an increasing function of both the firm's own underpricing and the industry-wide underpricing. Then, the clustering and multiple equilibria can occur even when a firm benefits more directly from its own publicity than from the industry's publicity, provided that the direct benefit is not overwhelming.

Finally, we can allow firms to go to the IPO market sequentially, rather than simultaneously as in the benchmark model. In this case, a firm's underpricing decision is still affected by the externality generated by other firms' underpricing. In particular, underpricing by firms that go to IPO first increases the incentive to underprice by firms that go to IPO later. Thus, again, large underpricing and clustering can occur. Moreover, being a first mover is costly because it must underprice sufficiently in order to entice the other firm to underprice. If firms can choose when to go to the IPO market, they have incentive to go to the market at dates that are very close to each other in order to explore the great externality.

6. Conclusion and empirical implications

We construct a theoretical model to explain the clustering of underpriced IPOs. The model integrates aggregate uncertainty in an industry with asymmetric information regarding the

[13] Zero offer price is unrealistic but, as we will discuss later, the model can be easily extended to generate a positive offer price in the underpricing equilibrium.

quality of individual firms. Expected earnings of each firm increase with the publicity that the industry generates in IPO underpricing. By signaling quality in the IPO market, a high-quality firm can benefit more from this publicity of the industry than a low-quality firm can. We show that two market equilibria exist. In one equilibrium, large underpricing clusters, which is supported by self-fulfilling expectations that the industry's publicity will be high. In the other equilibrium, there is no underpricing, which is supported by self-fulfilling expectations that the industry's publicity will be low.

Our emphasis on the clustering is a marked shift from the literature's emphasis on a single firm's underpricing. We uncover a powerful mechanism to generate the clustering of IPO underpricing — the interplay between individual firms and the industry's expected performance. Even when the intrinsic difference between the two types of firms is small, high expectations of the industry's publicity can magnify it into a large difference in expected earnings and induce the clustering of large underpricing by high-quality firms.

Our analysis can explain three common features of hot-issue markets. First, the clustering of underpricing is industry specific. It occurs more often in industries that are uncertain in product demand, susceptible to the influence of publicity, and with severe private information regarding firms' qualities. These features seem to describe well the Internet industry in 1999 and the Biotech industry in the early 1990s, where phenomenal IPO price gains clustered. Second, the clustering is fragile and short-lived. Even adverse news about a single firm in the industry can greatly affect all IPO performances by switching expectations from underpricing to no-underpricing. An example is the Biotech industry at the beginning of the 1990s. The heat over biotech stocks cooled down considerably when the US Food and Drug Administration rejected several promising drugs such as Centocor Inc.'s Centoxin, a medicine meant to fight a deadly bacteria infection common in surgery patients. Third, the clustering is more likely to occur in economic upturns than in downturns, because the opportunity cost of underpricing is lower in economic upturns.

These features suggest that a "hot-issue" market, such as the one in the dot.com industry in 1999, and the subsequent cooling-off could both be outcomes of rational expectations about the new industry's performance. However, the clustering will become rare as the industry matures, because forecasts about earnings will become more reliable and less susceptible to the influence of the industry's publicity. Finally, a tight monetary policy can reduce the exuberance in the IPO market by increasing the cost of loanable funds and the opportunity cost of underpricing.

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