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Equity offerings following the IPO Theory and evidence

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Abstract

This paper presents an IPO signaling model in which some issuers signal their higher quality not only by underpricing their IPO more, but also by waiting more patiently before they sell the remainder of the firm in a seasoned equity offering (SEO). In contrast to earlier models, this model offers empirical predictions (including functional forms) on easily observable variables: the IPO underpricing, after-market returns (reflecting the issuer's actions), and the timing of the SEO. The paper can thus calibrate and better test the theory. The evidence is that [a] signaling high-quality issuers are worth 2–3 times more than non-signaling low-quality firms; [b] the market recognizes the true quality of a firm with probability 30% per year; and [c] patience (i.e. waiting for extra funding) costs issuers about 15% of their value each year.

JEL classification: G32

Keywords: IPO; Seasoned equity offerings; Signaling; Model calibration

The first-day underpricing of initial public offerings (IPOs) is a well-documented empirical regularity. The models in Allen and Faulhaber (1989) and Welch (1989) explain this underpricing as a "money-burning" signal, which informed

[1] Chemmanur (1990) and Grinblatt and Hwang (1989) present similar models that also explain IPO underpricing as signals, but follow a structure different from the one in this paper.

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high-quality firms send to separate themselves from low-quality firms. [1, 2] A major shortcoming of these two models is their assumption that the probability that an issuer's quality is revealed after the IPO and before the seasoned equity offering (SEO) or a dividend distribution is an exogenous constant. [3] This would be appropriate if IPO issuers had no choice but to wait for a fixed time. Yet it is far more realistic to assume the issuer decides when to issue, taking into account a probability of revelation at each moment in time. In addition, permitting SEO timing to be endogenous allows the use of both the observed timing of the SEO and after-market returns – variables that are easily observable by empiricists – in testing the theory.

This paper extends Welch's signaling model (Welch, 1989) by making the IPO issuer's timing of the seasoned equity offering (SEO) endogenous. In the model presented here, the longer a firm waits before it returns for a seasoned offering, the more likely that its quality will be revealed. Therefore, a high-quality firm can wait longer to issue seasoned equity in order to increase the probability that low-quality firms that may try to imitate will be publicly revealed. By waiting longer, however, high-quality issuers lose the full benefit of adequate and timely funding, which in turn reduces the value of the firm. With specific but reasonable functional forms, a separating equilibrium ensues in which the best high-quality issuers optimally underprice more and expect to wait longer for their SEO. According to the model, firms issue unusually early only if their quality is (randomly) revealed. In this case, the expected further capital starvation expected by investors (a necessary signal by unrevealed high-quality firms) can be avoided. Therefore, early reissues should be associated with price runups before the SEO. In contrast, before revelation, IPO issuers should experience post-IPO downward price drifts, which reflect the loss of opportunities due to inadequate funding. The net effect is a U-shaped pattern in after-market returns. Fig. 1 illustrates this intuition. Higher-quality issuers are more willing to wait, and thus tend to issue later. If a firm's quality is revealed early (by chance), the result is both a smaller after-market drop and a more positive seasoned offering announcement effect.

More generally, in the model, high-quality firms can use their willingness to

[2] Used in virtually *all* information models, e.g., in Leland and Pyle (1977), there is ample anecdotal evidence that corporate insiders (e.g., IPO issuers) are better informed about their business than their investors. In response to abuses in the new issue market, the SEC 1933 act established strict legal liability to "restore" investor confidence. To some extent, such legal liability and ex-post contracting (where possible, e.g., through the use of debt instruments) can mitigate inside information concerns. However, when such mechanisms are imperfect and it becomes necessary for issuers to sell additional risky claims, high-quality IPO issuers can improve their outside image with the signaling mechanisms discussed in this paper.

[3] These models apply only to firms without access to internal funds or risk-free borrowing. The IPO is simply on the residual risky component of the firm's financing activities. This is a reasonable assumption for firms in the IPO market.

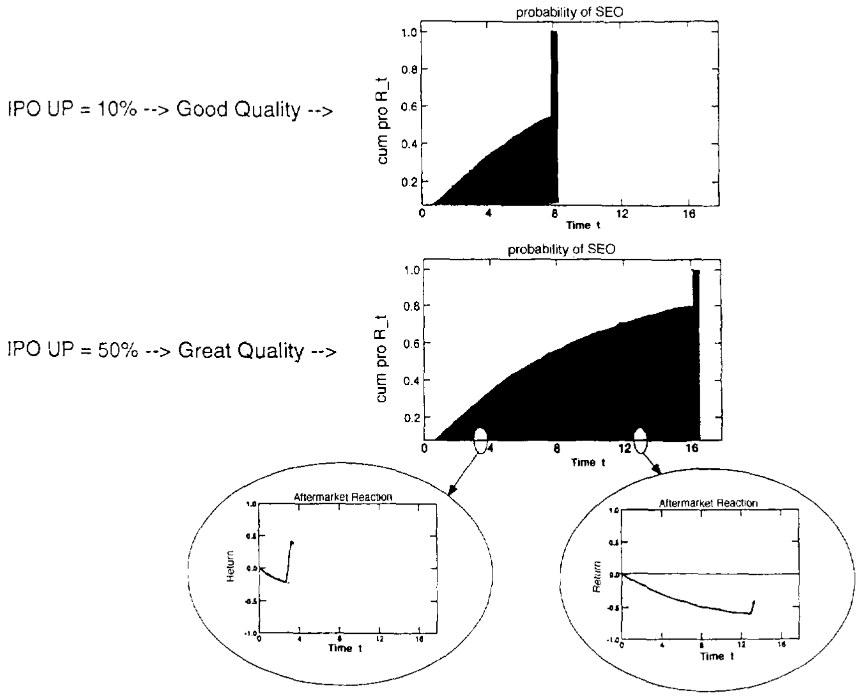

Fig. 1. **Model intuition**. This figure illustrates the model intuition. An IPO firm underpricing by a large amount (great quality) also signals by waiting longer compared to an IPO firm underpricing by a smaller amount (lesser but good quality). The two smaller graphs illustrate the after-market cumulative return for two (randomly) occurring natural quality revelations. If quality happens to be revealed early (good news), the issuer has to no longer capital-starve itself. Its value will have deteriorated only slightly and the SEO announcement is very good news. If quality happens to be revealed late (less good news), the firm has already suffered from capital starvation, and gains only a little from not having to wait until the very end.

wait as an ex-ante separating mechanism, [4] different from the mechanism of Titman and Trueman (1986) (willingness to hire a high-quality auditor), and the mechanism of Chemmanur (1990) and Brennan and Hughes (1991) (willingness to [indirectly] compensate security analysts). In contrast to the predictions of the model considered here, Brennan (1990, appendix) argues that high-quality firms may be ex-ante *less* willing to wait if faster operation increases the probability that the quality of their latent assets will be revealed. Lucas and MacDonald (1990) argue that because managers delay seasoned equity issues if they feel their

[4] For example, pharmaceutical companies could consent to prolonging their drug testing phase. Car sellers may consent to longer test-rides by potential buyers. Consumer companies may offer longer (not just more comprehensive) warranties

shares are undervalued, there is an immediate price runup before an SEO. A key difference of the model here is that firms' patience (or commitment thereto) can be a publicly recognized separating mechanism *working jointly with* a second signaling mechanism (cf. the Lucas and MacDonald discussion on p. 1037f).

The model in this paper is geared specifically toward producing empirically meaningful implications among three easily observable endogenous variables: IPO underpricing, the timing of the seasoned equity offering (SEO), and after-market returns. In contrast, many implications in Welch (1989), Allen and Faulhaber (1989), Chemmanur (1990), and Grinblatt and Hwang (1989) focus on variables that are observable in principle by IPO market participants and thus testable, but in practice present the researcher with overwhelming proxy identification problems. [5] Further, reasonable functional forms on the relative value decline due to inadequate funding and on the probability of revelation as a function of time result directly in an econometric specification for a calibration of the model, not only for the functional relationships between variables but even for the causes of prediction error! This is rare among asymmetric information models. [6]

In light of the model's predictions, the subsequent issuing activity of a set of about 600 underpricing reissuing IPO issuers from 1973 to 1989 is examined. Simple regressions reveal that firms that underprice more indeed wait longer before issuing seasoned equity, and firms that return to the market earlier (in the context of this model, firms that reissue because their quality has been revealed) experienced higher after-market returns.

In a full model estimation of the parameters (calibration), I find that the quality of a firm is revealed with about 30% probability in a year. Waiting and not issuing more securities, however, costs a waiting high-quality firm about 15% of its value. Deadweight imitation expenses (which low-quality imitating firms would have to incur to mimic high-quality firms) are estimated to represent about one-third of the capital raised by high-quality firms. Finally, the value of the typical high-quality firm is estimated to exceed the value of its low-quality equivalent (from which it separates) by a factor of about 2 to 3.

The paper proceeds as follows. Section I presents the model setting, actions, and equilibrium definition. Section II lists the constraints that define the underpricing equilibrium, and computes market expectations at the time of the IPO assuming this equilibrium. Section III solves for the best IPO underpricing and timing, as well as the after-market return pattern. Section IV describes the data set. Section V produces simple regressions, testing some comparative statics. Section

[5] For generic, intuitive empirical examinations, see Jegadeesh et al. (1993) and Michaely and Shaw (1994). All of these explore intuitive notions of strategic issuing behavior but do not try to exploit equations or strong implications coming out of the model (but on a set of *all* IPOs, reissuing or not).

[6] Notable exceptions include the tests in Downes and Heinkel (1982) and Ritter (1984b), which test the functional forms derived from the Leland and Pyle (1977) signaling model.

Table 1
List of symbols

Name	Description
Given: Exogenous parameters determining equilibrium	
H_0	true value of a high-quality firm at the IPO
L_0	true value of a low-quality firm (constant over time)
v	abbreviation for H_0 / L_0
H_t	true value of a high-quality firm as a function of time
d	(exponential) decay parameter of high-quality firm value
M	amount of money to be raised at the IPO
C	imitation (deadweight) costs incurred by imitating low-quality issuer
ω	abbreviation for $(M - C)/M$
r_t	(marginal) probability of revelation up to period t
R_t	(cumulative) probability of revelation up to period t
r	(exponential) revelation probability parameter
Solution: (Pseudo-) Endogenous Variables	
α	percentage of the firm sold at the IPO
P	price of the firm (not of shares) at the IPO
UP*	IPO return (underpricing)
t	time between SEO and IPO
$\tilde{t}^*$	actual observed time
$\bar{t}$	maximum time that an underpricing high-quality firm whose quality has not been revealed is prepared to wait (announced at IPO)
Solution: Exogenous state measures	
$\mathscr{H}_\tau$	after-market price/value of an underpricing but unrevealed IPO issuer at time τ
$\mathscr{H}_0$	immediate post-IPO after-market price/value
$\mathscr{H}_\tau(\bar{t})$	$\mathscr{H}_\tau$, assuming announced wait of $\bar{t}$
$\tilde{B}_{1,\tilde{t}^*}$	observed after-market price change (total)
$\tilde{A}_{t^*}$	observed after-market price increase just before the SEO announcement

A raised star on a variable denotes the optimal or observed choice. A lowered f on a variable denotes a firm-specific variable.

VI produces a full estimation of the model, using both maximum-likelihood and Bayesian estimators, and Section VII concludes.

1. The model

Table 1 provides a convenient summary of the symbols used in the paper.

1.1. Nature

It is important to emphasize that although the intuition of the model is robust and the model is more general than its predecessors, it must rely on many simplifying assumptions for the sake of tractability. The following simple scenario is assumed: There are two types of firms, high-quality and low-quality, whose identities are known only to firm owners. Every firm owner cares only about the sum of net issuing proceeds from an initial public offering (IPO) and a single seasoned equity offering (SEO). The value of a low-quality firm is L_0, which does not decay with time. [7] The value of a high-quality firm that issues its SEO at time t is H_t. [8] Because the value of a high-quality firm deteriorates if it is starved for capital, the value of a high-quality firm issuing its SEO at time t declines exponentially in t [9]

$$H_t = e^{-\mathbf{d}t} H_0, \tag{1}$$

where $L_0 < H_0$ and $\mathbf{d} > 0$. [10] The functional specification is correct if both the (additional) instantaneous cash flows of an unstarved firm and the continuous interest rate are constant, and cash flows accrue forever once the firm issues ($\int_{t_0}^{\infty} V_0 e^{-rt} dt = (V_0/r) e^{-rt}$) Note that it is not assumed that firms' market-value is too high (and therefore declining), because the market capitalizes the expected underlying value of future real opportunities correctly.

Further, nature occasionally perfectly reveals the firm type to investors, and firm owners know when such a revelation occurs. For example, a gold-exploration firm may find an ore, a bio-tech firm may announce its identification of a particular gene and file for a patent, a service company may announce an impending contract with the government, Merrill Lynch rates the industry or the firm a "definite buy", or an indicated earnings stream may begin to verifiably materialize in audited earnings. [11] The time of the revelation is modeled as an

[7] This can be relaxed. In the signaling equilibrium, a decay in value for low-quality firms would allow high-quality firms to underprice and wait *less*, because low-quality firms would be less eager to imitate them.

[8] The model can be viewed as examining the IPO underpricing choice on the margin; that is, other signals are assumed to have influenced the best market estimate of value for L_0 and H_0.

[9] High-quality firms could also raise more capital at the IPO to reduce this loss. This ability of firms is only partially captured by this model (by the exogenous parameter M); a more complete model could extend the value of a high-quality firm to be $H(t, \alpha P)$, where α is the fraction of the firm for sale at the IPO and P is the firm price. However, such a model would require specifying a functional form for αP and the interaction between αP and t in determining firm value. In the interest of model parsimony in bringing out the intuition on the roles of IPO underpricing and SEO timing decisions, this aspect of real life had to be sacrificed. Future research may address this rather complex issue.

[10] Low-quality firms could be subjected to a similar decline without changing the model significantly. Thus, this decline could legitimately be interpreted as a time discount factor.

[11] In real life, revelation could also be gradual and imperfect. The main insight of the paper – that IPO underpricing can be used together with patience to signal value – would remain. The "perfect (sudden) revelation" assumption can be defended on the basis that there are many situations where sudden revelation (success/failure) is realistic, that it is analytically tractable (barely), and that it has been used in other papers (Welch, 1989; Allen and Faulhaber, 1989). Furthermore, most corporate information models ultimately rely on implicit perfect revelation by assuming sudden payout when the game ends.

exponentially distributed random variable (appropriate when information arrives with constant probability) with rate r:

$$r_t = \mathbf{r}e^{-\mathbf{r}t},$$

so the probability of revelation before time t is

$$R_t = 1 - e^{-\mathbf{r}t}. \quad (2)$$

Naturally, the longer a firm waits before returning to the market, the higher the probability that its quality has been revealed. [12]

Further, because high-quality firms undertake certain operations, an imitating low-quality firm must incur additional costs C solely for the purpose of appearing to be a high-quality firm. For example, a firm without talents for oil exploration would want to farm its land. However, to imitate an oil-drilling company, the imitating firm would have to forego farming and instead spend money on the oil drilling equipment. Issuers pay for these imitation expenses up front. [13] Like low-quality firms, nonoperating high-quality firms are worth L_0. IPO issuers are so wealth-constrained (having issued as much debt as possible) that they must raise M dollars at the IPO.

The market is passive. Investors are risk-neutral and perfectly competitive. If investors were perfectly informed, they would pay up to L_0 for a low-quality firm and up to H_t for a high-quality firm – and would do so in a separating equilibrium.

Finally, note that although there are only two types of firms in this model, it applies to one firm at a time. That is, each firm separates itself from the market's low-quality perceptions. Therefore, the model can apply to an IPO market consisting of many firm types.

1.2. Sequence of actions and events

The players in this game are the two types of firms and the market. Investors act passively, purchasing the entire offering if and only if, given their current

[12] Most of the results in this paper are fairly robust to alternative value decline and revelation functions. However, the chosen specific forms not only produce closed-form solutions and precise econometric specifications, but also illustrate the point of this paper in a minimum amount of space.

[13] This differs slightly from Welch (1989), where issuers can load imitation expenses into the company, to be borne partially by shareholders if there is no revelation. For example, assume that the value of a low-quality (high-quality) firm is \$5 (\$10), the cost of imitation is \$2, and a low-quality imitator faces a probability of revelation of 50%, but could sell a third of the shares at the IPO at a firm-value of \$6 (the IPO price of high-quality firms). In the current model, the strategy of imitation provides low-quality issuers with

$$-\$2 + 1/3 * 6 + 2/3 * (50\% * \$10 + 50\% * \$5),$$

or \$5. In Welch (1989), the firm absorbs the imitation costs; an imitating low-quality issuer would expect

$$1/3 * \$6 + 2/3 * [50\% * \$10 + 50\% * (\$5 - \$2)],$$

or \$6.33. This change is inconsequential to the economic intuition of the theory.

information, its expected value is at least as high as the price. Firm owners actively maximize the expected sum of proceeds from two offerings, an IPO and a single SEO. (The value of the firm itself is assumed to decline over time with the interest rate, in effect incorporating a discount factor.)

The game begins when the firm concurrently issues its IPO, starts operations, offers a proportion α of the firm at price P (generating issue proceeds of αP), and announces that it plans to reissue its SEO (selling the remaining fraction $1 - \alpha$) as soon as a pre-specified time $\bar{t}$ (endogenously chosen by the issuer) has passed or its type has been revealed, whichever comes first. In other words, the market decides whether to purchase the offering, observing the **endogenous** triplet $(\alpha, P, \bar{t})$. [14] Firm owners use their IPO proceeds to fund operations.

After the IPO, issuers can return to the market at any time. After-market investors observe the information triplet, the time that has elapsed since the IPO, and the firm type if it has been revealed. Firms accept the highest price investors are willing to pay for the SEO. Market beliefs about firm quality are in turn determined by known past events.

1.3. Out-of-equilibrium behavior

There is a "timing" inconsistency in most signaling models. Signaling works when high-quality types can engage in actions that are cheaper for high-quality than for low-quality types. If such an action is otherwise wasteful, all parties could be made better off if it were avoided. That is, the instant when investors recognize that issuers are willing to carry through their promise to signal, they would like to step in and prevent this deadweight loss. Unfortunately, this intervention would alter the behavior of low-quality firms, which would then try to pretend to burn money, hoping that investors would step in. For example, in the Leland and Pyle (1977) model, issuers signal by retaining a large fraction of the firm and thus a high exposure to the firms' cash flows. Of course, if their quality were then perfectly revealed, they would prefer to simply sell more shares immediately thereafter, increasing their welfare. In effect, the lockup period can be considered a less flexible "patience" commitment device.

In this model, this problem is more pronounced because there are two sequential signals: IPO underpricing and the delay of the SEO. Everyone could be made better off if investors were to ex-post accept IPO underpricing as the only signal and then urge the firm to reissue immediately. This behavior cannot be sustained in an equilibrium, however, because low-quality firms could imitate it without risking revelation. Thus, underpricing alone, without enough delay before the SEO, would not allow investors to recognize firms as high-quality at the SEO.

[14] The firm does not need to precommit to $\bar{t}$, because the benefit of the signal is not realized until the SEO. Yet a "revelation principle" assures that the firm will adhere to the announced $\bar{t}$.

1.4. Equilibrium definition

Equilibrium is assumed to be sequential in the Kreps and Wilson (1982) sense (but subjected to modest additional refinements): an equilibrium is a set of optimal strategies, so that (a) at any time both high-quality and low-quality owners' choice of strategy – given their own information, future (wealth-maximizing) strategies, and market beliefs – is wealth maximizing, and (b) at any time the market's posterior beliefs about firm quality are consistent with Bayes' rule and the firm's specified and observed strategies. Specifically, equilibrium is [1] an optimal strategy $(\alpha,P,\bar{t})^*$ of the firm at the IPO; [2] efficient (posterior) market beliefs at each instant of time about firm quality at the IPO, prob*[''firm is type H''$|(\alpha,P,\bar{t})$]; [3] efficient (posterior) market beliefs between the IPO and the SEO, given that the firm has not reissued; [4] optimal SEO timing $(\bar{t}^*)$ of the firm; and [5] efficient (posterior) market beliefs about firm quality given IPO information, SEO information, and the state of revelation, prob*[''firm is type H''$|(\alpha,P,\bar{t},\tilde{t},R)$ RIGHT .], where $R \in$ {no-revelation, firm-is-low-type, firm-is-high-type}).

1.5. Equilibrium selection

Although there is a multitude of equilibria (discussed in Welch (1989)), this paper concentrates on the *pure separating equilibria* in which high-quality firms are best off. Because high-quality firms prefer this signaling (underpricing) equilibrium to potentially feasible pooling equilibria if the proportion of low-quality firms in the market is high (a free parameter h in Welch, 1989), it is effectively assumed the market believes the pool of potential issuers consists overwhelmingly of low-quality types ($h \to 1$). The Cho and Kreps (1987) equilibrium refinements could eliminate *all* pooling equilibria when separating equilibria are feasible. [15] Moreover, because IPO underpricing is observable, the subsequent empirical tests can condition on whether firms are in an underpricing equilibrium rather than a pooling or cost-free separation equilibrium. [16]

2. Feasible underpricing equilibria

To construct the equilibrium, one can specify the constraints on pricing and announced timing, $\bar{t}$, that ensure that high-quality and low-quality firms prefer separation (self-selection, incentive compatibility) and that investors are receiving

[15] Grossman and Perry's equilibrium refinements (Grossman and Perry, 1986a) can eliminate separating equilibria Pareto-dominated by pooling equilibria.

[16] I exclude mixed equilibria for two reasons: [1] The purpose of this model is to produce testable implications with as little modeling overhead as necessary; [2] the model applies to one issuer at a time. There are good arguments both for and against the inclusion of randomizing strategies.

at least fair compensation. Then high-quality firms' optimal announced timing and IPO price given these constraints is derived.

2.1. Equilibrium construction

Assume for a moment a separating equilibrium in which high-quality issuers announce that they will wait for $\bar{t}$ time to pass before they issue seasoned equity – unless their quality is revealed early, which allows firms to issue immediately – and sell proportion α of their IPO at price P. Feasible underpricing equilibria are defined by the triplet of $(\alpha, P, \bar{t})$ that satisfies the following constraints:

Funding High-quality firms must raise M to begin operating. This constraint is binding in the underpricing equilibrium in which high-quality firms are best off (henceforth simply "the best underpricing equilibrium"), because high-quality firms would prefer to postpone funding to the SEO, when the market accepts their quality. [17]

$$\alpha P \geq M. \tag{3}$$

No Overpricing The price P that investors are willing to pay at the IPO cannot exceed the inferred price of a high-quality firm – remember that in this *separating* equilibrium, investors can infer that the firm is high-quality at the IPO (the self-selection constraint ensures that low-quality firms do not imitate the pricing). [18]

$$P \leq \mathscr{H}_0, \tag{4}$$

where $\mathscr{H}_0$ is the expected first-day after-market value of a (separated) high-quality firm immediately after the IPO in this equilibrium, to be derived shortly. Of course, without IPO underpricing, equilibria are of only limited interest. [19]

Self-Selection If a low-quality firm reveals itself, it receives L_0. If it were to pretend to be of high quality, it would pay C up front, raise αP at the IPO, and wait for $\bar{t}$ time before issuing an SEO to receive $H_{\bar{t}}$ if quality had not been revealed, L_0 if quality has been revealed. In a separating equilibrium, the former payoffs have to exceed the latter:

$$-C + \alpha P + (1 - \alpha)\left[(1 - R_{\bar{t}}) H_{\bar{t}} + R_{\bar{t}} L_0\right] \leq L_0 \tag{5}$$

[17] See Footnote 9 for the important assumption that firms cannot escape the after-market value decline by raising more money at their IPO.

[18] This also implies that low-quality firms should not pay C, claim high-quality, and then reveal themselves immediately after the IPO. This out-of-equilibrium strategy is dominated by the strategy considered in Eq. 5, however.

[19] In any figures displaying IPO underpricing, the region where the no-overpricing constraint is binding is immediately apparent. In this region, a second "announcement" equilibrium exists in which issuers simply announce their quality and wait (e.g., until they are revealed or worth L_0). The exact boundary can be computed from (17) by setting UP* to zero. Naturally, because the derivation provides the best equilibrium in which the firm chooses a price, the discussed equilibrium with underpricing dominates alternative equilibria in which firms simply wait but do not underprice (at least for certain parameter values).

This is the binding (and interesting) constraint defining the underpricing equilibrium. It dominates another self-selection constraint in which low-quality firms underprice at the IPO but break the commitment to wait.

Incentive Compatibility If a high-quality firm adheres to the equilibrium, it expects to receive $\alpha P + (1-\alpha)\mathscr{H}_0$, where $\mathscr{H}_0$ is the after-market IPO value to be derived shortly. It could also operate but not underprice, in which case it could charge L_0 for its IPO shares to raise M, start operating, and wait and hope to be revealed. If revelation were to occur, such a firm would receive H_t, otherwise it would receive L_0. In contrast to what happens in the signaling/underpricing equilibrium, such a deviating high-quality firm would not be considered high-quality by the market after time $\bar{t}$ had elapsed. [20] In a separating equilibrium, high-quality firms have to prefer signaling, and thus: [21]

$$\begin{aligned} &\alpha P + (1-\alpha)\mathscr{H}_0 \\ &\quad \geq \alpha_2 L_0 + (1-\alpha_2)\left[R_{t_2} H_{t_2} + \left(1 - R_{t_2}\right) L_0\right] \forall(\alpha_2, t_2) \text{ with } \alpha_2 L_0 \geq M \end{aligned} \tag{6}$$

2.2. *The IPO after-market value of high-quality firms*

The immediate after-market value $\mathscr{H}_0$ in the separating equilibrium is now derived. Assume that a high-quality firm has announced it will wait for $\bar{t}$ time to pass before it reissues – unless it is revealed early.

At the time of the IPO, this expected value is

$$\mathscr{H}_0(\bar{t}) = \int_0^{\bar{t}} H_t r_t dt + H_{\bar{t}} \int_{\bar{t}}^{\infty} r_t dt = \frac{\mathbf{d}\, e^{-(\mathbf{r}+\mathbf{d})\bar{t}} + \mathbf{r}}{\mathbf{d}+\mathbf{r}} H_0. \tag{7}$$

Similarly, if at any time $\tau > 0$ quality is still hidden, two changes will have occurred: [1] the value of the high-quality firm will have declined to $e^{-\mathbf{d}\tau} H_0$; and [2] $\bar{t}$ will have moved closer by τ days. Thus, the value at of an unrevealed high-quality firm at time τ is

$$\begin{aligned} \mathscr{H}_\tau(\bar{t}) &= \int_0^{\bar{t}-\tau} \left(e^{-\mathbf{d}\tau} H_t\right) r_t dt + \left(e^{-\mathbf{d}\tau} H_{\bar{t}-\tau}\right) \int_{\bar{t}-\tau}^{\infty} r_t dt \\ &= \frac{\mathbf{d}\, e^{-(\mathbf{d}+\mathbf{r})\bar{t}} + \mathbf{r}\, e^{-(\mathbf{d}+\mathbf{r})\tau}}{\mathbf{d}+\mathbf{r}} e^{\mathbf{r}\tau} H_0. \end{aligned} \tag{8}$$

[20] As it turns out, this restriction is not important.

[21] If $M > L_0$, then no high-quality firm can raise enough money to operate without claiming high quality, and this constraint is satisfied.

2.3. Illustration

Before deriving the underpricing equilibrium, the following graph of reasonable relative values and prices *in equilibrium* may help the intuition. (The actual values are derived in the next section.)

0	L_0	P	$L_0 + C/\alpha$	$\mathscr{H}$	H_0	
	$(\alpha = 1)$	$(\alpha < 1)$				$\to \$$

The efficient after-market value is strictly less than H_0, the true value of a high-quality firm at time 0, because high-quality firms decline in value over time. The difference between the inferred value $\mathscr{H}$ and the IPO offer price P (the price high-quality firms receive if they are willing both to underprice and to wait to sell a significant fraction $(1-\alpha)$ of the firm at the SEO) is the commonly observed IPO underpricing. In turn, this price P exceeds L_0, so that high-quality issuers prefer P to accepting L_0, but low-quality issuers prefer L_0 to P if they have to incur the additional imitation cost C.

3. A best underpricing equilibrium

A firm cannot choose equilibria but must adhere to whatever equilibrium obtains. But, to find the "best" equilibrium, one can proceed as if high-quality firms chose $(\alpha, P, \bar{t})$ to maximize proceeds.

3.1. The optimal timing

The optimal timing, $\bar{t}$, is now derived. In equilibrium, the self-selection constraint is binding. (If it were not binding, high-quality firms could improve their welfare by increasing the offer price P.) Substituting this constraint (5) for αP into the expected proceeds of high-quality issuers $(\pi_H(t,\alpha,P) \equiv \alpha P + [1-\alpha]\mathscr{H}_0)$, we find that high-quality issuers receive

$$\pi_H(\bar{t},\alpha) = \{L_0 + C - (1-\alpha)[(1-R_{\bar{t}})H_{\bar{t}} + R_{\bar{t}}L_0]\} + (1-\alpha)\mathscr{H}_0(\bar{t}).$$

Let the value $\bar{t}$ that maximizes this expression be $\bar{t}^*$. Because $(1-\alpha)$ is a simple factor that scales proceeds, the issuer's choice of α does not affect the optimal timing, $\bar{t}^*$. [22] Substituting for $R_{\bar{t}}$ from (2), for $H_{\bar{t}}$ from (1), and for $\mathscr{H}_0$

[22] This linearity is the consequence of [1] risk-neutral issuer utility over the sum of IPO and SEO proceeds; [2] the constant value of the low-quality firm.

from (7), tedious algebra reveals that this expression simplifies to

$$\pi_H(\bar{t},\alpha) = (1-\alpha)\left[\frac{\mathbf{d}H_0}{(\mathbf{d}+\mathbf{r})e^{(\mathbf{d}+\mathbf{r})\bar{t}}} + \frac{\mathbf{r}H_0}{\mathbf{d}+\mathbf{r}}\right] + c + \alpha L_0 - \frac{(1-\alpha)\left(H_0 + e^{\mathbf{d}\bar{t}}L_0\right)}{e^{(\mathbf{d}+\mathbf{r})\bar{t}}}.$$

Differentiating with respect to $\bar{t}$ yields the F.O.C.

$$\frac{(1-\alpha)\mathbf{r}\left[e^{(\mathbf{d}+\mathbf{r})\bar{t}}L_0 - e^{\mathbf{r}\bar{t}}H_0\right]}{e^{(\mathbf{d}+2\mathbf{r})\bar{t}}} = 0. \tag{9}$$

The optimal $\bar{t}^*$ is thus

$$\bar{t}^* = \frac{\log(v)}{\mathbf{d}}, \tag{10}$$

where $v = H_0/L_0$. Note that the optimal $\bar{t}^*$ depends only on this value ratio and the decay parameter d. Also, $\bar{t}^*$ is the time at which the true value of a high-quality firm, H_t, has declined to L_0. High-quality issuers are in fact willing not to reissue as long as their value exceeds that of an otherwise equivalent low-quality firm. If issuers have to wait for $\bar{t}^*$, firms that reissue will be recognized as high-quality-albeit a moot advantage.[23, 24] The probability of revelation before $\bar{t}^*$ is $1 - v^{-\mathbf{r}/\mathbf{d}}$.

Unfortunately, the maximum time to reissue, $\bar{t}^*$, is not observable; only the realized time of the SEO is observable. The expected time of the issue is:

$$\mu_{\bar{t}^*} = \int_0^{\log(v)/\mathbf{d}} t\mathbf{r}e^{-\mathbf{r}t}dt + v^{-\mathbf{r}/\mathbf{d}}\log(v)/\mathbf{d}$$
$$= \frac{1}{\mathbf{r}} + \frac{v^{-\mathbf{r}/\mathbf{d}}\log(v)}{\mathbf{d}} - \frac{\mathbf{d}+\mathbf{r}\log(v)}{\mathbf{d}\mathbf{r}v^{\mathbf{r}/\mathbf{d}}} = \frac{1-v^{-\mathbf{r}/\mathbf{d}}}{\mathbf{r}} \tag{11}$$

and the variance is

$$\sigma_{\bar{t}^*}^2 = \int_0^{\log(v)/\mathbf{d}} (t-\mu_{\bar{t}^*})^2\mathbf{r}e^{-\mathbf{r}t}dt + v^{-\mathbf{r}/\mathbf{d}}\left[\log(v)/\mathbf{d} - \mu_{\bar{t}^*}\right]^2$$
$$= \frac{-\mathbf{d} + \mathbf{d}v^{2\mathbf{r}/\mathbf{d}} - 2\mathbf{r}v^{\mathbf{r}/\mathbf{d}}\log(v)}{\mathbf{d}\mathbf{r}^2v^{2\mathbf{r}/\mathbf{d}}}. \tag{12}$$

---

[23] It is important to understand that this is not the *ex-post* optimal decision (when $\bar{t}^*$ arrives), but the *ex-ante* optimal decision. (Under different distributional assumptions, high-quality firms might have found it in their interest to commit ex-ante to waiting a longer or shorter time.) Because the result is that the *ex-post* and *ex-ante* decisions not to return coincide, there is no time inconsistency in firms' decision (and no need for commitment devices).

[24] This solution, together with the incentive compatibility constraint, implies that $L_0 < P < H_0$ (see the appendix for a proof). This condition in turn implies that $P < L_0 + C$.

These two equations will be used to extrapolate parameters in the empirical estimation procedure.

3.2. The optimal underpricing

The optimal pricing and fraction for sale are determined by the binding self-selection and funding constraints. (If the funding constraint were not binding, high-quality firms could raise fewer funds in the IPO, expecting to enjoy a higher price $[\mathscr{H}_0]$ at the SEO.) Solving these two constraints gives

$$\alpha^* = \frac{ce^{(\mathbf{d}+\mathbf{r})\bar{t}^*} - e^{(\mathbf{d}+\mathbf{r})\bar{t}^*}M - H_0 + e^{\mathbf{d}\bar{t}^*}L_0}{-H_0 + e^{\mathbf{d}\bar{t}^*}L_0 - e^{(\mathbf{d}+\mathbf{r})\bar{t}^*}L_0}, \tag{13}$$

$$P^* = \frac{M\left(-H_0 + e^{\mathbf{d}\bar{t}^*}L_0 - e^{(\mathbf{d}+\mathbf{r})\bar{t}^*}L_0\right)}{ce^{(\mathbf{d}+\mathbf{r})\bar{t}^*} - e^{(\mathbf{d}+\mathbf{r})\bar{t}^*}M - H_0 + e^{\mathbf{d}\bar{t}^*}L_0} \tag{14}$$

These two equations can be simplified by substituting in the value of the optimal wait, $\bar{t}^*$:

$$\alpha^* = \frac{M-C}{L_0}, \tag{15}$$

$$P^* = \frac{M}{M-C}L_0. \tag{16}$$

The observed IPO underpricing is $P^*/\mathscr{H}_0(\bar{t}^*) - 1$. Substituting (7) and (16), underpricing simplifies to

$$UP^* = -1 + \omega\left(\frac{\mathbf{d}v^{-\mathbf{r}/\mathbf{d}} + \mathbf{r}v}{\mathbf{d}+\mathbf{r}}\right), \tag{17}$$

where ω is $(M-C)/M$. In a valid underpricing equilibrium, underpricing has to be positive. Unfortunately, v cannot be determined from other parameters and IPO underpricing algebraically because

$$(UP^* + 1)(\mathbf{d}+\mathbf{r})\,\omega^{-1} = \mathbf{d}v^{-\mathbf{r}/\mathbf{d}} + \mathbf{r}v. \tag{18}$$

Furthermore, this equation imposes parameter restrictions on feasible underpricing equilibria. Because $v > 1 (H_0 > L_0)$, the right-hand side can never fall below $(\mathbf{d}+\mathbf{r})$.

To summarize this "best" underpricing equilibrium, a high-quality firm that needs to separate itself chooses a strategy of UP* and $\bar{t}^*$ (along with α^*) that satisfies three important constraints: [1] high-quality issuers raise only as much as is necessary to fund the start up operations; [2] high-quality issuers wait the optimal amount of time before they reissue-unless their quality is revealed earlier; [3] low-quality issuers are indifferent between imitating and not imitating. Investors in turn use all available information in determining the after-market value of an issue ($\mathscr{H}_0$ for high-quality issues).

3.3. After-market price pattern

The model offers further predictions on after-market price patterns. When an IPO issuer announces a seasoned issue unusually early, it is because the firm's quality has been revealed, and further capital starvation is no longer necessary. Intuitively, this should result in a downward post-IPO price drift ("early revelation has not yet occurred") until revelation occurs. If early revelation occurs, the firm value jumps, not because quality is revealed (in the signaling equilibrium, for rational companies, it can be inferred after the IPO), but because further capital starvation is no longer necessary to "complete" a credible signal/quality separation.

The total after-market appreciation, $\tilde{B}^*_{1,\tilde{t}}$, measured from the first after-market price (given the announcement that the firm will wait up to $\bar{t}^*$) to the *post-revelation* SEO price is $H^*_{\tilde{t}}/\mathscr{H}_0(\bar{t}^*)-1$, where $\tilde{t}^*$ is the realized [early] revelation and issue. Substituting H_t from (1), this return is

$$\tilde{B}_{1,\tilde{t}^*} = -1 + \frac{(\mathbf{d}+\mathbf{r})e^{-(\mathbf{d}\tilde{t}^*)+(\mathbf{d}+\mathbf{r})\tilde{t}^*}}{\mathbf{d}+\mathbf{r}\,e^{(\mathbf{d}+\mathbf{r})\tilde{t}^*}} = -1 + \frac{(\mathbf{d}+\mathbf{r})e^{-\mathbf{d}\tilde{t}^*}}{\mathbf{d}v^{-(\mathbf{d}+\mathbf{r})/\mathbf{d}}+\mathbf{r}}. \tag{19}$$

The immediate price runup before the offering is the difference between the expected value immediately before revelation ($\mathscr{H}^*_{\tilde{t}}(\bar{t}^*)$) and the actual value at revelation ($H^*_{\tilde{t}}$). The after-market value, assuming optimal maximum timing ($\bar{t}^*$), before revelation (time $\tilde{t}^*$) can be shown to simplify to

$$\mathscr{H}_{\tilde{t}^*}(\bar{t}^*) = \frac{v^{-(\mathbf{d}+\mathbf{r})/\mathbf{d}}\left[\mathbf{d}e^{\mathbf{r}\tilde{t}^*}+\mathbf{r}v^{(\mathbf{d}+\mathbf{r})/\mathbf{d}}e^{-\mathbf{d}\tilde{t}^*}\right]}{\mathbf{d}+\mathbf{r}}H_0. \tag{20}$$

Thus, the observed "announcement" return, $\tilde{A}^*_{\tilde{t}}$, simplifies to

$$\tilde{A}_{\tilde{t}^*} = -1 + \frac{(\mathbf{d}+\mathbf{r})e^{(\mathbf{d}+\mathbf{r})\tilde{t}^*}}{\mathbf{d}\,e^{(\mathbf{d}+\mathbf{r})\tilde{t}^*}+\mathbf{r}e^{(\mathbf{d}+\mathbf{r})\tilde{t}^*}} = -1 + \frac{(\mathbf{d}+\mathbf{r})}{\mathbf{r}+\mathbf{d}\,e^{(\mathbf{d}+\mathbf{r})\tilde{t}^*}v^{-(\mathbf{d}+\mathbf{r})/\mathbf{d}}}. \tag{21}$$

3.4. Model summary and uncertainty in after-market returns

In sum, the theoretical model can predict four observable variables: $\tilde{t}^*$ (the [random] time between the SEO and the IPO), UP* (IPO underpricing), $\tilde{B}^*_{1,\tilde{t}}$ (after-market price appreciation between the IPO and the observed SEO), and $\tilde{A}^*_{\tilde{t}}$ (the price runup immediately before the SEO announcement). [25] This set

$$\left\{\tilde{t}^*, UP^*, \tilde{B}_{1,\tilde{t}^*}, \tilde{A}_{\tilde{t}^*}\right\}$$

[25] Remember that the lower case stands for a continuously compounded return.

is generated from the following equations

$$prob\big(\tilde{t}^* \,[= \text{observed issue at time t}] \,\big|\, H_0, L_0, i, M, C\big)$$

$$= \begin{cases} \mathbf{r}\, e^{-\mathbf{r}\tilde{t}^*} & \text{if } \tilde{t}^* < \dfrac{\log(v)}{\mathbf{d}} \\ v^{-\mathbf{r}/\mathbf{d}} & \text{if } \tilde{t}^* = \dfrac{\log(v)}{\mathbf{d}} \\ 0 & \text{if } \tilde{t}^* > \dfrac{\log(v)}{\mathbf{d}} \end{cases}$$

$$1 + \tilde{B}_{1,\tilde{t}^*} = \frac{(\mathbf{d}+\mathbf{r})e^{-\mathbf{d}\tilde{t}^*}}{\mathbf{d}v^{-(\mathbf{d}+\mathbf{r})/\mathbf{d}} + \mathbf{r}}$$

$$1 + \tilde{A}_{\tilde{t}^*} = \frac{(\mathbf{d}+\mathbf{r})}{\mathbf{r} + \mathbf{d}e^{(\mathbf{d}+\mathbf{r})\tilde{t}^*}v^{-(\mathbf{d}+\mathbf{r})/\mathbf{d})}}$$

where

$$UP^* + 1 = \omega\left(\frac{\mathbf{d}v^{-\mathbf{r}/\mathbf{d}} + \mathbf{r}v}{\mathbf{d}+\mathbf{r}}\right).$$

The timing or revelation uncertainty is endogenous to the model ($\tilde{t}^*$ has been algebraically eliminated). An additional source of error is in the after-market returns; not only do company values change after the IPO in a noisy manner, but uncertainty about the time lag between random revelation and observed issue announcement induces measurement error. Therefore, in the following empirical estimation, two additional sources of error are introduced,

$$B_f^{1,\tilde{t}^*} - \hat{B}_f^{1,\tilde{t}^*}(\omega, \mathbf{d}, \mathbf{r}) \sim N(\mu_b, \sigma_b),$$

$$A_f^{\tilde{t}^*} - \hat{A}_f^{\tilde{t}^*}(\omega, \mathbf{d}, \mathbf{r}) \sim N(\mu_a, \sigma_a),$$

where the caret denotes the expectations given parameters (see above equations), the unhatted variables denote the observed values, and the forecast errors are normal with means μ, standard deviation σ, and correlation ρ. (A nonzero mean is probably appropriate, because Ritter (1991) documents that IPO firms on average experience significant drifts.)

3.5. Equilibrium illustration

Fig. 2 and Table 2 give the reader the flavor of this underpricing equilibrium. Table 2 describes the after-market value and returns of a high-quality (underpricing) firm whose quality has not yet been revealed (assuming no noise in the

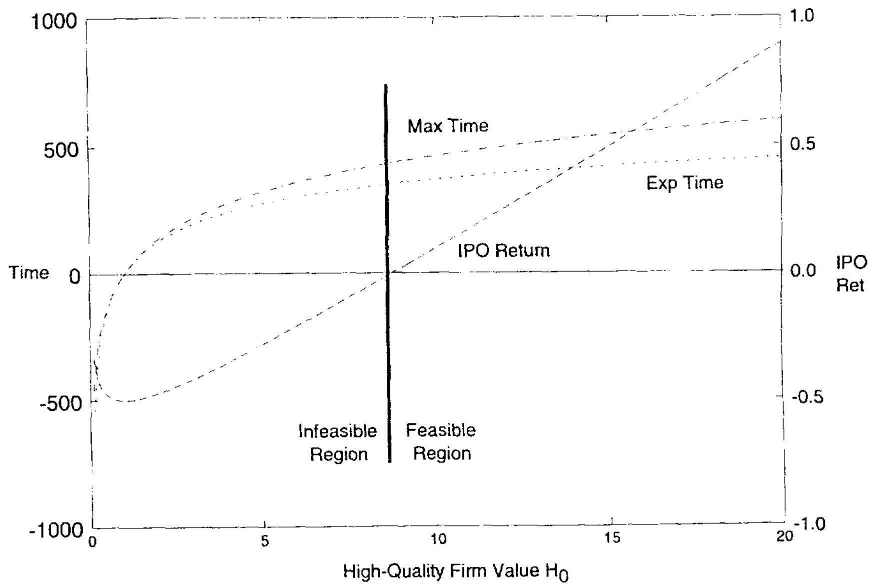

Fig. 2. **Comparative equilibrium statics for varying high-quality firm value (v).** This figure illustrates the comparative statics for high-quality firm values. In other words, how does a higher high-quality firm value ("inside information") affect observable variables (IPO return, expected SEO timing, maximum SEO timing) in equilibrium? The graph shows that higher quality causes more IPO underpricing and later SEO timing. The following parameters are fixed for this figure: $L_0 = 1$ (thus $H_0 = v$), M = 1, C = 0.5, r = 0.1%, d = 0.5%. In all equilibria, high-quality firms choose ($\alpha = 0.5$, $P = 20$). Note that when this equilibrium is infeasible (investors do not purchase overpriced offerings), a costless separating equilibrium exists.

after-market returns). Column 3 shows that the after-market value ($\mathscr{H}_t(\bar{t}^*)$) is monotonically declining, reflecting the market disappointment with the lack of revelation. If revelation were to occur, the value of the firm would jump to H_t (column 4). Columns 5 and 6 show the effect of (random) revelation at time t. If the firm type were publicly revealed immediately after the IPO, after-market investors would reap a windfall of 92.3%. If, however, revelation were to occur later, e.g., after time 10, investors who had held the security since the first day of after-market trading would have lost a total of 21.8% (0.407/0.520 − 1). Still, revelation at time 10 is better than no revelation, as would be reflected in a 61% (0.407/0.252 − 1) revelation announcement return.

Fig. 2 illustrates some comparative statics. If the value of the high-quality firm exceeds that of its low-quality counterpart by only a "small" amount, then little or no IPO underpricing is necessary for separation (waiting is sufficient). If the market considers the value of the low-quality firms to be much lower, however, a higher-value high-quality firm has to send a stronger signal by underpricing more

Table 2
After-market revelation and returns

Time t	Revel. prob. R_t	Values		Returns if revealed	
		Market $E\mathscr{H}^t$	True H_t	Overall $\tilde{B}_{1,\tilde{t}}$.	Immediate $\tilde{A}_{\tilde{t}}$.
ϵ	0	0.520	1.000	92.3%	92.3%
1	0.095	0.475	0.905	74.0%	90.7%
2	0.181	0.434	0.819	57.5%	88.7%
3	0.259	0.397	0.741	42.5%	86.4%
4	0.330	0.365	0.670	28.9%	83.7%
5	0.393	0.336	0.607	16.6%	80.4%
6	0.451	0.311	0.549	5.5%	76.6%
7	0.503	0.289	0.497	−4.5%	72.1%
8	0.551	0.269	0.449	−13.6%	66.9%
9	0.593	0.252	0.407	−21.8%	61.0%
10	0.632	0.238	0.368	−29.3%	54.4%
11	0.667	0.227	0.333	−36.0%	47.0%
12	0.699	0.217	0.301	−42.1%	38.8%
13	0.727	0.210	0.273	−47.6%	30.0%
14	0.753	0.204	0.247	−52.6%	20.6%
15	0.777	0.201	0.223	−57.1%	10.9%
16	0.798	0.200	0.202	−61.2%	0.9%
16.1	0.8	0.200	0.200		0.0%

Fixed values: $\mathbf{d}=0.1$, $\mathbf{r}=0.1$, $v=5$ ($H_0=1$, $L_0=0.2$). The true value exceeds the market value, because the market rationally anticipates further capital starvation. The firm value jumps from the market value to the true value if random revelation occurs.

and expect to wait longer to return to the SEO market. Note that this figure can also give some insight into the relationship between observable variables. Higher values of v (the relative value of high-quality firms) increase both IPO underpricing and the expected time to the SEO. Thus, if firm types are heterogeneous, the expected time to the SEO is positively correlated with IPO underpricing.

4. Data description

4.1. Documented empirical evidence on IPO after-market performance

Before proceeding with the calibration of the model on empirical data, it is important to review the evidence in Ritter (1991) and Loughran and Ritter (1993). They document that IPOs from 1975 to 1984 substantially underperformed in the three years following the IPO, arguing that the evidence suggests that IPO issuers were able to "time" the market. An obvious question is why a reader would be interested in an efficient-market model, which cannot explain the empirically observed after-market patterns of IPOs. There are two "excuses": [1] It is possible to interpret the Ritter evidence to a few odd industry realizations; and [2] The Ritter evidence presents more of a challenge to equilibrium return models (APT, ICAPM, etc.) than to the IPO signaling model considered here. The intuition of the model would go through even if IPO firms experienced systematic post-IPO negative returns,

Concerning point [1], most IPO firms are in similar industries at specific times. Consequently, there are really only a few realizations of the long-run underperformance phenomenon – and, although statistically significant, it is possible that after-market underperformance could be due to a few cases of "bad luck." For example, the "hot issue" market of 1980, documented in Ritter (1984a), consisted mostly of natural resource firms – most of these firms failed when oil prices plummeted a few years later. Indeed, the oil and gas industry is by far the poorest after-market performer in Ritter's sample. Similar but less spectacular incidences of adverse post-IPO developments might have occurred in 3–4 other industries. (The question is whether these IPO issuers were indeed smarter at forecasting their future industry than industry analysts and the stock market overall.)

In contrast, financial services sector IPO issuers significantly outperformed their peer group. Larger, older, firm-commitment issuers, and some other industries did not underperform their peer group, either. Indeed, the firms driving Ritter's results were small, traded rarely, and concentrated in some specific industries. Thus, despite contrary evidence, "a firm believer in market efficiency" might hesitate before believing in a systematic ability to make money by shorting IPO firms in the after-market.

Concerning point [2], if poor long-run performance were indeed a general phenomenon, to be expected ex-ante, modellers would be presented with some real challenges. Indeed, the very point of Ritter's article is that he believes that no model of rational investor behavior can explain his empirical evidence. Why would any rational person be willing to purchase relatively illiquid, small IPOs in the after-market, knowing that her wealth is expected to decline, relative to simple available benchmarks? Ritter's evidence may be inconsistent with the assumption of an efficient market in this paper, but it presents more of a challenge to factor-pricing models. [26]

The intuition of the current model, however, would go through even if after-market values were expected to decline. If issuers are aware of post-IPO drift but investors are not, both high-quality and (imitating) low-quality firms would have an additional incentive to sell quickly, and high-quality firms could conse-

[26] Models of irrational behavior, on the other hand, still leave many questions unanswered: Why are the best "exploiters" of market irrationality small firm owners? Why do analysts not adjust?

quently still use patience as a signaling device. (However, the math appears to be untractable, and some nice results [like time consistency] might disappear.) [27]

A final related unresolved question is whether market participants are aware not only of the average pattern of underperformance, but also of the industry-specific patterns of underperformance. Assuming that they are, the tests can concentrate on firms that are not subject to extreme after-market underperformance: larger, firm-commitment IPOs, excluding the unusual natural resource sector. (Subsequent unreported investigation reveals that the exclusion of oil and gas firms does not change the estimated parameters.)

4.2. Data

The following empirical investigation concentrates on the sales of a single seasoned equity offering, although the model could be interpreted to fit any other after-market activity of the firm in which the issuer is better off if the firm has separated itself at the IPO. For example, insiders may effectively sell their stakes by divesting their shares not only through seasoned equity offerings, but also in direct insider sales (after the lockup period), by paying high dividends.

Securities Data Corporation (SDC) lists 5,113 firm-commitment initial public offerings (IPOs) from January 1970 to August 1989. Of these, 4,500 are listed on the CRSP data base, a necessary condition for inclusion in order to track firms that change names over time (a common occurrence in this data set). Within 10 years of the IPO, 1,118 of these firms issue seasoned equity offerings (SEOs). Of the 1118 firms, 926 have the data to compute IPO underpricing (a price within 30 days of the IPO; most of the missing firms precede the CRSP Nasdaq tape). In this sample, a regression of IPO underpricing on pre-IPO sales, a dummy for whether on offering is a unit-offering (warrants plus common), and a comprehensive set of IPO year and SIC dummies is run to obtain a "purer" measure of IPO underpricing. Another 91 firms are eliminated because they lack the uninterrupted price series (typically the price at the SEO) necessary to reliably compute after-market returns.

The underpricing equilibrium can explain how IPO underpricing affects after-market returns and the timing of a single SEO in a separating equilibrium across firms. The complete model with all equilibrium (pooling and first-best announcement equilibria) can also explain firms that do not underprice at the IPO and decide to return (a "wait-and-hope" equilibrium in which high-quality firms only wait but do not underprice), and firms that neither underprice nor return (low-qual-

[27] If issuers, like investors, are unaware of post-IPO drift, they would use the same IPO underpricing and plan on the same timing, but then be surprised by low post-IPO returns. This might lead them to issue earlier (if their actual value has declined) or later (if they believe the true value is in excess of the market value.)

ity firms). Because this paper focuses on the underpricing equilibrium, 279 reissuing IPO firms are excluded that did not underprice their IPO and would not be expected to follow the hypothesized cross-sectional functional relationships. [28] Because the focus is on predicting (conditional) after-market patterns, this selection criterion based on IPO characteristics, does not bias the results.

Thus the final sample consists of 574 reissuing, underpricing IPO firms. An important question is how to compute after-market returns. Lacking a good equilibrium return model (and/or proper APT factors), the equal-weighted NYSEAMEX market return (with dividends) is subtracted from each daily return, and this difference is compounded over time. [29] The theory predicts that when quality is revealed, firm value increases instantaneously and capital starvation is no longer necessary. While it would be very desirable to measure the date of revelation, the heterogeneity in the sources for individual firms' quality revelation renders such an exercise impossible. Instead, it is assumed that capital-starved firms approach the SEO market within a period from 15 days before to one day after the filing date to measure the SEO announcement price reaction. (The problem is equivalent to precisely identifying an event-study date – itself an error-prone procedure typically solved by widening the event-window.) Thus, the remainder of the paper works only with 15 day intervals. (In real life, owners could accrue benefits through alternative mechanisms, such as dividend issuances, insider selling, etc.) Table 3 describes the relevant variables.

The typical firm in the sample (of ex-post underpriced, subsequently returning issuers) issues its IPO in about 1983 at a discount of 16.2% (11.1% risk-adjusted), and reissues in 1986. These firms wait on average about three years before returning, although the mode time between IPO and SEO is one year. These firms also experience a small price decline in the few days before the SEO, and about a +30% IPO after-market return (net of the market return) before returning for an SEO. This return is different from that reported in Ritter (1991), because the focus here is only on reissuing IPOs. Note that the overall after-market return mean pattern is inconsistent with the model. This could however be significantly influenced by the truncation method. If non-reissuing firms were considered to have more patience, i.e., to return after 10-years, the after-market mean return

[28] This model cannot satisfactorily explain, however, why some firms underprice but never return to the market. Of course, there are other models not based on signaling that can explain such IPO underpricing, e.g., Rock (1986), Tinic (1988), and Welch (1992). Yet there are at least two explanations in the context of this model: [1] IPO returns could contain a random element from the issuer's perspective. Signaling considerations could still come into play if actual values are replaced by expected values. However, these underpricing issuers did not mean to signal, and thus will not return. [2] The data ends in 1991. Underpricing issuers may still be waiting to return. Further, none of these models can explain the observed bunching of IPO issuing activity without time-varying parameters.

[29] The finance literature offers no reliable equilibrium model of after-market returns, especially for these small, young firms.

Table 3
Univariate statistics

Panel A: Distribution of equity offerings over time

Yr	IPOs	SEOs	Yr	IPOs	SEOs
1973	7	0	1983	119	71
1974	3	1	1984	58	33
1975	2	3	1985	61	71
1976	8	2	1986	67	94
1977	4	3	1987	46	56
1978	10	7	1988	10	25
1979	19	3	1989	23	38
1980	27	19	1990	0	28
1981	86	21	1991	0	67
1982	24	32	1992	0	0
		574 Firms			

Panel B: Descriptive statistics

Variable	Note	N	Mean	Stddev	Min	Max	%Pos	%Neg
$\tilde{B}_{1,\tilde{t}^*}$	Total Returns	574	29.6%	78.0%	−97.0%	555.3%	63	37
$\tilde{A}_{\tilde{t}^*}$	15 days	574	−0.8%	10.8%	−29.3%	63.5%	41	59
$\tilde{A}_{\tilde{t}^*}$	60 days	573	5.7%	19.8%	−48.1%	99.8%	59	42
$(\tilde{t}^*)$	(Unadjusted)	574	872	662	100	3,412	100	0
$\tilde{t}^*$	15-day bins	574	9.2	7.355	1	37	100	0
UP^*	observed > 0	574	16.2%	25.0%	0.3%	368.8%	100	0
UP^*	residual > 0	648	11.1%	5.6%	0.1%	31.2%	100	0

Panel C: Distribution of Timing

Years after IPO $(\tilde{t}^*)$	0	1	2	3	4	5	6	7	8	9
Number of SEOs	28	195	151	82	51	28	14	10	10	5

The sample comprises all firm-commitment IPOs on the Securities Data Corp (SDC) and CRSP data bases from 1973 to 1989 in which the issuer both underprices the IPO and issues a seasoned equity offering. $\tilde{B}_{1,\tilde{t}^*}$ is the total after-market return from the IPO to the SEO. $\tilde{A}_{\tilde{t}^*}$ is the 15-day SEO announcement price reaction. Both of these returns are market-adjusted. $\tilde{t}^*$ is the time between the IPO and the SEO, measured in trading days. UP^* is the IPO underpricing, either unadjusted or adjusted for sales, industry, and year of IPO.

patterns could correspond closer to that predicted by the model. The cutoff problem is of lesser concern in an examination of a subset of firms in cross-section, and therefore the paper concentrates only on the cross-sectional investigation.

5. Simple regressions

Although the focus of this paper is on the calibration of the model (in the next section), it is straightforward to provide some descriptive evidence with a set of regressions, following from comparative statics of the model. [30] Although only bivariate OLS results are reported, subsequent unreported regressions indicate that the omission of related variables (e.g., sales, the fraction of shares for sale) and White's heteroskedasticity corrections (White, 1980) do not affect the results. Section VI offers a better econometric test, which takes the inherently non-linear nature of the observed relationships into account. Further, I advise the reader [1] to keep in mind that these regressions apply only to the set of subsequently reissuing IPO firms and that the purpose of this paper is to explain SEO timing conditional on SEO issuing activity, not IPO underpricing; and [2] to consider only the entire set of regressions, because there are good alternative explanations for each separate regression.

$$\frac{\partial \tilde{t}^*}{\partial \mathbf{UP}^*} > 0:$$

The model predicts that higher-quality firms have to both underprice more and wait longer before they can return (see also the discussion on page 18), so, we should observe a positive relationship between IPO underpricing and the time before the firm returns to the market (measured in trading days).

$$\tilde{t}^* = \underset{(23.37)}{56.33} + \underset{(0.84)}{969}\,\mathrm{UP}^* + \underset{R^2=0.12\%}{\epsilon}$$

Although the sign on UP* is correct, the null hypothesis that IPO underpricing and timing are unrelated cannot be rejected. When estimated with residual IPO underpricing – that is measured as residual underpricing after industry, year, firm-sales, and unit are taken out in a first stage regression – however, this positive relationship becomes highly significant. [31]

$$\tilde{t}^* = \underset{(8.93)}{42.40} + \underset{(3.21)}{129.56}\,\mathrm{UP}^* + \underset{R^2=2.15\%}{\epsilon}$$

Jegadeesh et al. (1993) argued that firms might underprice (signal) when they plan to return quickly for an SEO. The evidence here is inconsistent with this alternative hypothesis. Firms that underprice by an extra (residual) 10% tend to wait about half a year longer.

Additional simple regressions have to rely on after-market returns, which in turn relied on a (mediocre) model for equilibrium expected rate of returns and an arbitrary 15-day assumption for the exact date of revelation to the market. Note also that IPO underpricing is not expected to predict average after-market returns

[30] These comparative statics can be formally derived. Because they are easy to explain, the messy algebraic details are omitted.

[31] Jegadeesh et al. (1993) find the opposite sign (albeit barely significant). I am using a larger data set (extended by over 100 observations after 1989) and, most importantly, permit reissues after more than 3 years. The coefficient in this data set is negative, too, if the three year truncation is imposed.

(although ex-post, unreported evidence shows that it does); otherwise, a trading rule would allow investors to earn abnormal returns.

$$\frac{\partial \log\left(\tilde{B}_{1,\tilde{t}^*} + 1\right)}{\partial \tilde{t}^*} < 0:$$

Although after-market returns are zero on average, high-quality firms that are revealed early can reissue early, and avoid any unnecessary value decay. In fact, all issuers should experience a continuous downward drift until they reissue. A longer wait is thus associated with more negative after-market stock-price performance.

$$1{,}000 \log\left(1 + \tilde{B}_{1,\tilde{t}^*}\right) = \underset{(12.30)}{494.8} - \underset{(-12.86)}{7.092\tilde{t}^*} + \underset{R^2=22.42\%}{\epsilon}$$

The relationship has the proper sign, and is highly significant. As (19) shows, the coefficient is the negative of the decay coefficient. It indicates an estimate of **d** of about 17% per year in the loss of real underlying opportunities (not market-value!) when cash-starved, a reasonable estimate.

$$\frac{\partial \log\left(1 + \tilde{A}_{\tilde{t}^*}\right)}{\partial \tilde{t}^*} < 0:$$

Similarly, we would expect firms whose quality is revealed early to experience an unusually large positive announcement response, whereas we would expect firms that have to wait until very late to experience virtually no residual stock-price reaction at the announcement. Thus, a longer wait should be associated with a less positive announcement return.

$$1{,}000 \log\left(1 + \tilde{A}_{\tilde{t}^*}\right) = \underset{(-0.97)}{-6.923} - \underset{(-1.17)}{0.114\tilde{t}^*} + \underset{R^2=0.24\%}{\epsilon}$$

The estimated relationship has the proper sign, but is insignificant.

$$\frac{\partial \tilde{A}_{\tilde{t}^*}}{\partial\left(\tilde{B}_{1,\tilde{t}^*} - \tilde{A}_{\tilde{t}^*}\right)} > 0:$$

High-quality firms that issue early experience a small overall price drop before the announcement, but a large positive announcement price reaction. High-quality firms that issue late have dropped significantly in value, and experience only a small positive announcement price appreciation. To avoid a mechanistic correlation, $\tilde{A}_{\bar{t}^*}$ is excluded from $\tilde{B}_{1,\bar{t}^*}$.[32]

$$\tilde{A}_{\bar{t}^*} = \underset{(-1.16)}{-0.006} - \underset{(-1.36)}{0.008}\left(\tilde{B}_{1,\bar{t}^*} - \tilde{A}_{\bar{t}^*}\right) + \underset{R^2=0.32\%}{\epsilon}$$

This relationship has an incorrect sign but is insignificant. The weakest finding is the negative but insignificant correlation between after-market returns. Clearly, these returns reflect the behavior of outside markets, and are rather noisy, especially because neither the exact timing of revelation – crucial to measure noisy returns – and a good equilibrium return model are available.

In sum, the preceding empirical evidence provides some support for this theory. The strongest finding is the somewhat surprising positive relationship between residual IPO underpricing and the time before the first SEO – a reversal of the evidence in Jegadeesh et al. (1993), which relied on a shorter 3-year time-horizon.

6. Model estimation

6.1. Parameters to estimate

The focus of this paper was to calibrate the model summarized in Section III.D, specifically exploiting its non-linear relationship between variables, and using all information in a single estimation. First, note that there are eleven parameters of interest: six model parameters (M, C, L_0, H_0, **r**, **d**), plus five parameters measuring aftermarket return uncertainty. Yet the number of free parameters to estimate is not eleven, but nine. M and C appear together only in the equation determining IPO underpricing (UP^*), and thus a parameter $\omega(=(M-C)/C)$ is estimated instead. H_0 and L_0 appear exclusively as a ratio, **v**. Because firm heterogeneity is caused by cross-sectional differences in firm value (v), UP_f^* can be used to infer the relative value of each (high-quality) firm. The parameters **r**, **d**, and ω, and the after-market uncertainty are estimated from the observed SEO timing and after-market return patterns (given v inferred from UP_f^*).

In sum, the five plus four parameters to estimate are: μ_R, μ_S, σ_R, σ_S, and ρ (the after-market return mean, standard deviations, and correlations); **d** (the per-time value decay of high-quality firms that have not reissued); **r** (the per-time probability of revelation); and ω (the percentage difference between M and C).[33] The posterior distribution across all observations is summarized in Table 4.

[32] This is casually denoted by $(\tilde{B}_{1,\bar{t}^*} - \tilde{A}_{\bar{t}^*})$, although it is computed as $(1+\tilde{B}_{1,\bar{t}^*})/(1+\tilde{A}_{\bar{t}^*})-1$.

[33] Note that α could be used to fix M. However, the uncertainty about C would continue to enter the estimation in the same fashion. Thus, we ignore α and its information about M.

Table 4
Posterior distribution of the model

$$\mathscr{P}(\omega,\mathrm{d},\mathrm{r},\mu_R,\mu_S,\sigma_R,\sigma_S,\rho\,\Big|\,\{\bar{t}^*,\mathrm{UP}^*,\bar{B}_{1,\bar{t}^*},\bar{A}_{\bar{t}^*}\}_f)\propto \quad (23)$$

$$\mathscr{P}(\{\bar{t}^*,\mathrm{UP}^*,\bar{B}_{1,\bar{t}^*},\bar{A}_{\bar{t}^*}\}_f|\,\omega,\mathrm{d},\mathrm{r},\mu_R,\mu_S,\sigma_R,\sigma_S,\rho)\times f(\omega,\mathrm{d},\mathrm{r},\mu_R,\mu_S,\sigma_R,\sigma_S,\rho)$$

$$=\prod_f^F \Phi\Big(B_f^{1,\bar{t}^*}-\hat{B}_f^{1,\bar{t}^*}(\omega,\mathrm{d},\mathrm{r}),A_f^{\bar{t}^*}-\hat{A}_f^{\bar{t}^*}(\omega,\mathrm{d},\mathrm{r});\mu_R,\mu_S,\sigma_R,\sigma_S,\rho\Big)\times\mathrm{prob}(\bar{t}_f^*\,|\,\omega,\mathrm{d},\mathrm{r})$$

$$\times f(\omega,\mathrm{d},\mathrm{r},\mu_R,\mu_S,\sigma_R,\sigma_S,\rho)$$

subject to

$$1+\hat{B}_f^{1,\bar{t}^*}(\omega,\mathrm{d},\mathrm{r})=\frac{(\mathrm{d}+\mathrm{r})e^{-\mathrm{d}\bar{t}_f^*}}{\mathrm{d}v_f^{-(\mathrm{d}+\mathrm{r})/\mathrm{d}}+\mathrm{r}}$$

$$1+\hat{A}_f^{\bar{t}^*}(\omega,\mathrm{d},\mathrm{r})=\frac{(\mathrm{d}+\mathrm{r})}{\mathrm{r}+\mathrm{d}e^{(\mathrm{d}+\mathrm{r})\bar{t}_f^*}v_f^{-(\mathrm{d}+\mathrm{r})/\mathrm{d}}}$$

$$prob[\bar{t}_f^*\,|v_f(\omega,\mathrm{d},\mathrm{r},UP_f^*)]=\begin{cases}\mathrm{r}e^{-\mathrm{r}\bar{t}_f^*} & \text{if } int(\bar{t}_f^*)>int\left(\frac{\log(v_f)}{\mathrm{d}}\right)\\ v_f^{\mathrm{r}}/\mathrm{d} & \text{if } int(\bar{t}_f^*)=int\left(\frac{\log(v_f)}{\mathrm{d}}\right)\\ 0 & \text{if } int(\bar{t}_f^*)>int\left(\frac{\log(v_f)}{\mathrm{d}}\right)\end{cases}$$

or, alternatively,

$$prob[\bar{t}_f^*\,|v_f(\omega,\mathrm{d},\mathrm{r},UP_f^*)]=\phi\left(t,\mu=\frac{1-v^{-\mathrm{r}/\mathrm{d}}}{\mathrm{r}},\sigma=\frac{-\mathrm{d}+\mathrm{d}v^{2\mathrm{r}/\mathrm{d}}-2\mathrm{r}v^{\mathrm{r}/\mathrm{d}}\log(v)}{\mathrm{d}\mathrm{r}^2v^{2\mathrm{r}/\mathrm{d}}}\right)$$

$$v_f \text{ solves } UP_f^*=-1+\omega\left(\frac{\mathrm{d}v_f^{-\mathrm{r}/\mathrm{d}}+\mathrm{r}v_f}{\mathrm{d}+\mathrm{r}}\right)$$

where *int* is the integer function (necessary to discretize the model), and $\Phi(\cdot)$ is the bivariate normal density.

6.2. Feasible parameter values

The model imposes additional restrictions on feasible ω through $\bar{t}^*$. In fact, the optimal estimate of ω may be determined by the corner solution that no single firm may issue after $\bar{t}$.

$$\omega\le\frac{(UP_f^*+1)(\mathbf{d}+\mathbf{r})}{\mathbf{d}v_f^{-\mathbf{r}/\mathbf{d}}+\mathbf{r}v_f}\ s.t.\ \bar{t}_f=\frac{\log(v_f)}{\mathbf{d}}\forall f.$$

Obviously, if the chosen unit of time is a day, this boundary is likely to be set by one, or perhaps a very small number of, firms. There are two solutions to this problem. First, the number of days per time-unit could be increased. Second, the model's specific exponential-truncated uncertainty could be abandoned in favor of a smoother distribution on $\bar{t}^*$ with equal conditional mean and variance, as derived in (12) and (11). The reported maximum likelihood estimates are similar with the two methods.

The model has other estimation problems, however. In addition to non-linear constraints on feasible values of the likelihood function imposed by the nonnegativity constraint in the variance, and computational problems in handling large exponentials, there is a model-inherent close substitutability of the parameters **d** and ω. [34] These problems do not significantly affect the parameter point estimates reported below, but they do wreak havoc on the estimates of their standard errors (see below).

6.3. Results with unadjusted IPO underpricing

Panel A of Table 5 reports the results of the maximum likelihood estimation. The interesting point estimates are $\mathbf{r} = 0.01478$, $\mathbf{d} = 0.00736$, and $\omega = 0.627$. (The **d** coefficient is similar to the one obtained from the univariate regression on page 24.) Because a time period in this estimation is 15 days, the estimation implies that the probability of revelation in the first year is about 30% per year, and the value decay due to inadequate funding is about 15% per year. ω implies that firms need to raise about 2.7 times the deadweight cost of imitation.

The estimated parameter standard errors on **r** and **d** indicate complete insignificance, but deserve further attention. These standard errors can be large because [1] the point estimates are meaningless; [2] the parameters are highly collinear (specifically, because ω absorbs the significance of the other parameters); [35] or [3] the (numerically computed) Hessian matrix indicates a slower descent from the maximum than implied by the imputed standard deviation.

If the cause of the insignificance is multicollinearity, then holding other parameters at their estimated values and looking only at the own second derivative at the mode of the three parameters **r**, **d**, and ω (i.e., computing the own standard deviation) would substantially reduce the standard error. Therefore, the multivariate parameter distribution is cut into slices at the maximum-likelihood estimates, and the conditional univariate statistical estimates for each parameter is computed. (This also has an asymptotic justification – with infinite observations, other parameter estimates are perfect.) Indeed, the "de-collinearized" standard errors for **r**, **d**, and ω are 0.034, 0.056, and 0.012. I conclude that collinearity (uncertainty) among the parameter estimates increases the standard deviation by factors of roughly 2, 6, and 5 respectively.

[34] Computing symbolic derivative, although feasible in principle, is out of the question: The derivatives contain literally dozens of terms.

[35] Collinearity can arise either when the model fails to identify variables (e.g., $Z = aX + bX + \epsilon$), or when there is insufficient variation in observed variables to disentangle effects (e.g., $Z = aX + bY + \epsilon$, and all observed Y's are close to cX). Further examination reveals that the data seem to support the latter explanation. An alternative estimation would estimate one parameter combining **r** and **d**.

Table 5
Full-period parameter estimates with unadjusted IPO underpricing

Panel A: Multivariate maximum likelihood estimation

Parameter	Mode	Stddev	T-stat
$\mu(\tilde{B}_{1,\tilde{i}^*})$	29.65%	3.25%	9.11
$\sigma(\tilde{B}_{1,\tilde{i}^*})$	77.93%	2.95%	26.40
$\mu(\tilde{A}_{\tilde{i}^*})$	−0.80%	0.45%	−1.78
$\sigma(\tilde{A}_{\tilde{i}^*})$	10.79%	2.95%	3.65
$\rho(\tilde{A}_{\tilde{i}^*},\tilde{B}_{1,\tilde{i}^*})$	12.44%	6.71%	1.85
r	0.01478	0.06†	0.24†
d	0.00736	0.35†	0.02†
ω	0.62759	0.07	8.56

Panel B: Conditional univariate Bayesian estimates ignoring multicollinearity

Parameter	Mean	Stdev	T-stat
$\mu(\tilde{B}_{1,\tilde{i}^*})$	29.65%	3.22%	9.21
$\sigma(\tilde{B}_{1,\tilde{i}^*})$	78.10%	2.30%	34.00
$\mu(\tilde{A}_{\tilde{i}^*})$	−0.80%	0.45%	−1.80
$\sigma(\tilde{A}_{\tilde{i}^*})$	10.82%	0.32%	34.19
$\rho(\tilde{A}_{\tilde{i}^*},\tilde{B}_{1,\tilde{i}^*})$	12.32%	4.04%	3.05
r	0.014785	0.00045†	32.83†
d	0.007356	0.00036†	20.34†
ω	0.625464	0.0195	31.98

Panel C: Multivariate parameter Bayesian estimates

Parameter	Mean	Stddev	T-stat
$\mu(\tilde{B}_{1,\tilde{i}^*})$	28.69%	0.57%	50.206
$\sigma(\tilde{B}_{1,\tilde{i}^*})$	−1.06%	0.07%	−15.842
$\mu(\tilde{A}_{\tilde{i}^*})$	78.97%	0.48%	165.710
$\sigma(\tilde{A}_{\tilde{i}^*} x)$	10.88%	0.17%	63.428
$\rho(\tilde{A}_{\tilde{i}^*},\tilde{B}_{1,\tilde{i}^*})$	11.38%	1.51%	7.558
r	0.014043	0.000848	16.568
d	0.009681	0.001245	7.775
ω	0.589639	0.014529	40.585

Panel D: Distribution of values

Variable	Median	Mean	Minimum	Maximum	Stddev
v_f	2.5081	2.70144	2.30270	11.18880	0.61152
$\tilde{t}_f$	125	132.84	113.43	328.22	23.02

r = 0.014776. d = 0.007360, ρ = 0.627402

Now, note that because computation of the MLE variance-covariance estimates through the Hessian matrix assumes multivariate normality, each of these univariate slices should also be univariate normal. Thus, the univariate standard errors computed from the own second derivatives (0.034, 0.056, and 0.012) should equal the equivalent results from a univariate integration, conditional on the estimates of other parameters. (A univariate integration is typically numerically reliable and accurate.) These standard errors are reported in Panel B of Table 5. The conditional standard deviation estimates of **r** and **d** are two orders of magnitude lower than the standard deviations obtained by computing only the second derivative at the model. The conclusion is that the sampling distribution is significantly flatter at the top than the normal distribution, leading to large upward biases in the estimated standard errors.

If the reader is willing to believe that the multivariate distribution suffers from flatness at the mode similar to that found in its univariate slices, I would advise adjusting the reported standard errors of **r** and **d** (0.06 and 0.35) upward by two orders of magnitude, properly adjusting for collinearity, which results in strong statistical significance for **r** ($T \sim 15–20$) and decent statistical significance for **d** ($T \sim 2–3$)

An alternative is a full multidimensional Monte-Carlo integration (quadratic loss function). When two variables are highly collinear, the multidimensional integration could be highly inaccurate. Even with 200,000 draws, the grid is not even five draws per dimension. The results are in Panel C of Table 5. The Bayesian point estimates are about the same for **r**, but higher for **d** and lower for ω. (As already mentioned, ω and **r** act as substitutes. Their estimated Bayesian correlation is about 60%.) The standard errors of **d** and **r** are notably closer to the flatness-adjusted standard errors than they are to the inverse Hessian estimates reported in Panel A.

Finally, the estimated model allows us to infer firm type and the commitment to wait. Panel D shows that the typical high-quality firm is about 2.5 times the value of its nonseparated low-quality counterpart, using parameters obtained from the unadjusted IPO underpricing maximum-likelihood estimation.

Notes to Table 5:
†: Unreliable Estimates
The sample comprises all firm-commitment IPOs on the SDC and CRSP data bases from 1973 to 1989 in which the issuer both underprices the IPO and issues a seasoned equity offering. Estimates in Panels A–C are of the model summarized in Table 4. $\mu(\tilde{B}_{1,\bar{i}^{*}})$, $\sigma(\tilde{B}_{1,\bar{i}^{*}})$. $\mu(\tilde{A}_{\bar{i}^{*}})$. $\sigma(\tilde{A}_{\bar{i}^{*}})$, and $\rho(\tilde{A}_{\bar{i}^{*}}, \tilde{B}_{1,\bar{i}^{*}})$ parameters control for noise in after-market returns. r, d, and ω are model parameters measuring the 15-day probability of revelation (r), the 15-day decay in firm value when a high-quality firm cannot issue (d), and the amount of capital that has to be raised in relation to low-quality firms' deadweight costs of imitation (ω). The relative value of high-quality firms, v_f, is inferred for each firm from its own IPO underpricing (see Panel D).

Table 6
Full and sub period parameter estimates with residual IPO underpricing

Parameter	Multivariate MLE			Conditional Univariate Estimates		
	Mode	Stddev	T-stat	Mean	Stdev	T-stat
r	0.01428	0.05607	0.25	0.014288	0.000399	35.8
d	0.00356	0.15000	0.02	0.003559	0.000035	102.38
ω	0.83123	0.01173	70.85	0.829591	0.012267	67.62
First Third						
r	0.01202	0.10169	0.12	0.012043	0.000603	19.97
d	0.00676	0.25353	0.03	0.006759	0.000194	34.85
ω	0.70967	0.03851	18.43	0.705802	0.024833	28.42
Second Third						
r	0.01455	0.09587	0.15	0.014572	0.000688	21.17
d	0.00313	0.29003	0.01	0.003128	0.000033	94.61
ω	0.83008	0.02234	37.16	0.823661	0.024742	33.29
Third Third						
r	0.01615	0.08797	0.18	0.016168	0.000762	21.21
d	0.00238	0.23047	0.01	0.002379	0.000039	61.66
ω	0.90193	0.00886	101.85	0.897306	0.016583	54.11

Standard Errors and T-statistics for r and d are unreliable (see text).
The sample comprises all firm-commitment IPOs on the SDC and CRSP data bases from 1973 to 1989 in which the issuer both underprices the IPO and issues a seasoned equity offering. These estimates are equivalent to the estimates in Panels A and B of Table 5, except that residual IPO underpricing is used instead of unadjusted IPO underpricing, and the after-market return noise parameters are excluded.

6.4. Results with adjusted IPO underpricing

Table 6 displays only the interesting model estimates (**r**, **d**, ω) with residual (size-, industry- and year-adjusted) IPO underpricing, perhaps a better measure of IPO underpricing. Compared with the unadjusted underpricing estimates, the point estimate of **d** is a lower 0.4% (10% per year), whereas the point estimate of ω is a higher 0.83. (As previously observed, ω and **d** are close substitutes.) Perhaps more interesting, earlier IPOs (whose seasoned equity offerings can come later, giving them more dispersion in $\tilde{t}^*$) provide higher estimates of **d**.

7. Conclusion

This paper contributed theoretically by showing how issuers can use both IPO underpricing (the signaling device introduced in Allen and Faulhaber (1989) and Welch (1989)) with patience (the signaling device introduced in Lucas and MacDonald (1990)). By generalizing these models to multiple signaling dimensions, the paper has provided the theoretical firm with a more realistic set of choices: issuers can select both IPO underpricing and the timing of their seasoned equity offerings. High-quality firms cannot only underprice but also wait longer to reissue to increase the probability that nature will reveal their quality. In equilibrium, the highest-quality firms send the strongest signal: the most pronounced IPO underpricing and the longest patience/period before a seasoned equity offering (unless their quality is randomly revealed early). Indeed, once the extra dimension of choice is considered, it becomes difficult to imagine a world in which IPO issuers signal with underpricing but fail to consider after-market patience. In this sense, the model methodology and evidence in this paper reflects on a wider class of IPO signaling models than just the model considered here.

Yet, the paper's main contribution was the development of a model with empirically more meaningful implications on variables more directly observable to the IPO researcher: IPO underpricing, the timing of the seasoned equity offering, and after-market returns. In contrast, earlier models offered poorer proxy identification and consequently poorer testability. The model's predictions allowed the first empirical calibration of an IPO signaling model (a rarity even in the wider class of information models), using a set of about 600 underpricing, reissuing IPO issuers from 1973 to 1989.

In a full model estimation of the parameters (calibration), I find that the quality of a firm is revealed with about 30% probability per year. Waiting and not issuing more securities, however, costs a waiting high-quality firm about 15% of its value. Deadweight imitation expenses (which low-quality imitating firms would have to incur to mimic high-quality firms) are estimated to represent about one-third of the capital raised by high-quality firms. Finally, the value of the typical high-quality firm is estimated to exceed the value of its low-quality equivalent (from which it separates) by a factor of about 2 to 3.

In conclusion, I find evidence in favor of the model (e.g., in simple regressions, firms that underprice more are indeed found to wait longer before reissuing seasoned equity, and firms that return earlier [firms not experiencing random revelation] experience higher after-market returns). Still, although the evidence in this paper suggests that IPO underpricing and SEO timing are linked, they are probably not fully explained by the model. In addition to signaling considered here, there seem to be additional factors influencing both. Because the model applies in principle to issuer benefits from signaling quality other than a higher price at an SEO, the next step will be to apply the model to such after-market activities as dividends, and insider sales of registered shares after the lockup period expires.

8. Other sources

Grossman and Perry (1986b), Rock (1982) and Corporate Finance Sourcebook (1982).

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Appendix A

A.1. Expected equilibrium proceeds

This appendix verifies that the incentive compatibility condition is satisfied. Given the best underpricing equilibrium $(P^*, \alpha^*, \bar{t}^*)$, high-quality issuers expect to receive [36]

$$\alpha^* P^* + (1-\alpha^*)\mathscr{H}_0 \tag{22}$$

To satisfy the incentive compatibility constraint, we simply need to check whether the price high-quality firms charge in equilibrium exceeds the price a low-quality firm could charge, because the optimal strategy for both a deviating and a nondeviating company is to wait for $\bar{t}^*$ time to elapse unless quality is revealed. This is satisfied as long as C is positive but smaller than M.

As a side note, when α^*, P^* (eqns. 16 and 15 on page 14) and $\mathscr{H}_0$ (eq. 7, page 11) are substituted into the above equation, we find that a high-quality issuer expects to receive

$$M + (C - M + L_0)\left(\frac{\mathbf{r}}{\mathbf{d}+\mathbf{r}}\upsilon + \frac{\mathbf{d}}{\mathbf{d}+\mathbf{r}}\upsilon^{-\mathbf{r}/\mathbf{d}}\right)$$

in this equilibrium.

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[36] Another equilibrium in which high-quality firms simply wait and hope for revelation (until their value (H_t) drops to L_0) exists, too. In this equilibrium, high-quality firms benefit from not having to satisfy the self-selection constraint, but are hurt by being grouped with low-quality firms, which lowers the IPO price. If there are many low-quality firms in the pool $(P = L_0, \alpha P = M)$, the underpricing equilibrium strictly dominates the ''wait-and-see'' equilibrium. If there are few low-quality firms, the wait-and-see equilibrium dominates the underpricing equilibrium.

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