Demand Uncertainty, Bayesian Update, and IPO Pricing

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ABSTRACT

When the market undergoes a learning process about the IPO, it takes time for the demand to reach the equilibrium consistent with the new issue's intrinsic value. Hence, the temporary short-term demand can deviate substantially from the stabilized long-term demand. This difference requires the underwriter to respond differently to different pre-market conditions that are dictated by the short-term demand: While she must accommodate the overly pessimistic views of investors in a cold IPO (because the shares cannot be sold at a *perceived* premium), she has the option to respond only partially to investors' overly optimistic views in a hot IPO. We model this asymmetric response of the underwriter and derive IPO regularities relating underpricing, partial price revision, and long-run underperformance. We provide evidence that supports the model's predictions.

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When the intrinsic value of an initial public offering (IPO) is initially unknown, the market inevitably undergoes a learning process in early aftermarket trading. As a result of market learning, the short-term demand that applies to both the pre-market and the early aftermarket can deviate greatly from the stabilized long-term demand. In this paper, we model IPO pricing in such a setting, where the demand for the new issue is initially biased (i.e., it is initially too high or too low) and it approaches the long-term or sustainable demand gradually as aftermarket trading progresses.

The difference between the short-term demand and the expected long-term demand requires the underwriter to respond differently to different pre-market conditions: While she must accommodate the overly pessimistic views of investors in a cold IPO (because the shares cannot be sold at a *perceived* premium), she has the option to respond only partially to investors' overly optimistic views in a hot IPO (for the shares can be placed at a *perceived* discount). We model this asymmetric response of the underwriter in IPO pricing. We make two key assumptions: (i) The demand for the new shares is initially biased in the sense that it is too high or too low relative to the long-term demand, and (ii) the underwriter's learning on market demand follows the Bayes' rule. With these two assumptions, we characterize the decision of the underwriter, who face rational yet uninformed investors in the new issue, and derive IPO regularities relating underpricing, partial price revision, and long-run underperformance.

Our results are asymmetric between hot and cold IPOs. We define an IPO as hot (cold) if the short-term demand for the new issue is stronger (weaker) than the expected long-term demand. The IPO starts with a preliminary offer price proposed by the underwriter based on her initial belief. Through book building, the underwriter learns about the current-market demand and then updates her belief as a Bayesian learner. For a hot IPO, the underwriter revises the pre-market demand upwards and accordingly adjusts the offer price from the preliminary price to the expected intrinsic value. Under the Bayes' rule, the price adjustment must be insufficient to absorb the abnormally-strong temporary demand, thus leaving the first-day price to go up beyond the offer price. Therefore, hot IPOs in our model are associated with a positive price update, a positive first-day return, and a positive relation between the two. On the other hand, in a cold IPO, the sales constraint forces the underwriter to fully adjust the price downwards to meet the abnormally-low temporary demand. As a result, cold IPOs are associated with a negative price update, zero initial return, and non-meaningful link between the two.

Although many of these results are also derived, one way or the other, by previous IPO-pricing models, our model is different in significant manners. First, the information setting and thus the initial-return mechanism are different. In our model, because the new issue's intrinsic value is initially inherently unknown and it takes time to show up, all IPO participants in our model are initially equally uninformed. Hence, the various asymmetric-information-based mechanisms such as adverse selection (Rock, 1986), signaling (e.g., Allen and Faulhaber, 1988), information revelation (e.g., Benveniste and Splidt, 1989), and strategic pricing (Aggarwal, Krigman, and Womack, 2002) do not apply with our model. Indeed, the first-day return in our model is not a discount on the stock's fundamental value, but a hot-market effect due to a lack of market learning. Unlike the investor-sentiment argument that attributes this effect to investors' irrational behavior (Derrien, 2005), we justify it by the nature of market learning: it takes time for the market to converge to the new issue's intrinsic value and thus the sustainable demand.

Second, we model the underwriter as a Bayesian learner, who, in a decision under uncertainty, finalizes the offer price by using the book-building information in a standard

Bayesian-updating process. Previous models do not describe this price-revision mechanism. On the one hand, underwriter learning is trivial in previous book-building models, where the uninformed underwriter becomes fully informed immediately after the book-building process. On the other hand, underwriter learning does not occur in various models without book building. Our assumption of the uncertainty in short-term market demand requires the underwriter to be a Bayesian learner.

Third and more important, our model has further predictions for decomposed IPO initial returns that clearly distinguish our model from previous models. We decompose an initial return into a "demand-uncertainty component" and a "fundamental-discount component." The former is the first-trading day closing price over the expected intrinsic value, which measures the deviation of the initial aftermarket price from the fair value. The latter is the expected intrinsic value over the offer price, which presents "true" underpricing (and which is apparently different from the total initial return). This latter component is the main concern of previous models.[1] We derive explicit and testable predictions for these two components and their relations with the price update, distinguishing between hot and cold IPOs. While these predictions cannot be obtained from any models without book building, they are mostly inconsistent with prior book-building models.

In the second part of this paper, we perform empirical tests for the initial-return components using a sample of US IPOs. To decompose an initial return, we follow Purnanandam and Swaminathan (2004) and estimate the new issue's intrinsic value using price multiples of industry peers. With IPO valuations based on three price multiples (which are price-to-EBITDA, price-to-sale ratio, and price-to-earnings), we obtain empirical results that are highly

[1] The investor-sentiment models of IPO pricing such as Derrien (2005) and Ljungqvist, Nanda, and Singh (2006) involve both components.

consistent with our model's predictions. Our major findings include the following: First, for hot IPOs, initial returns come exclusively from the demand-uncertainty component and this component is positively associated with the price update. In other words, there is no underpricing in a hot IPO and the positive initial return and its positive relation with price revision are purely a demand-uncertainty phenomenon. Second, for cold IPOs, the two components are perfectly offsetting and, consequently, there is zero initial return. More specifically, in a cold IPO, the demand-uncertainty component is negative but is positively associated with the price update, while the fundamental-discount component is positive but is negatively associated with the price update. Underpricing as a discount on the fundamental value occurs in our model only with cold IPOs, which is a forced result due to the excessively low short-term demand.

As an alternative approach, we also decompose IPO initial return using a secondary-market price as the proxy for the new issue's fair value. When the secondary-market price is sufficiently stabilized (which, in our sample, occurs about one year after the IPO), the results from this alternative approach are also consistent with our model's predictions.

The paper proceeds as follows. Section I briefly discusses the literature of IPO underpricing. Section II describes our theoretical model. Section III presents our test of the model's predictions. Section IV concludes the paper.

I. Literature

Among the various theories in finance that model IPO underpricing, most prominent are those based on asymmetric information. Rock (1986) presents an adverse-selection model of IPO pricing in which information is asymmetric between investors. In Rock, underpricing is a mechanism that helps the uninformed rational investors breakeven who would otherwise not participate in the IPO. Allen and Faulhaber (1988), Grinblatt and Hwang (1989), and Welch (1989) address asymmetric information between issuers and investors. They argue that when issuers are better informed than investors about the firm's future prospects, high-quality issuers have an incentive to signal by underpricing the new issue. Benveniste and Splidt (1989) and Shermand and Titman (2002) model the IPO as a book-building process in which the underwriter collects private information from informed investors. The new issue is on average sold at a discount to compensate the investors for disclosing costly private information.[2] By focusing on investor sentiment, Derrien (2005) and Ljungqvist, Nanda, and Singh (2006) emphasize the role of investor sentiment in IPO pricing and argue that underpricing is used as compensation to regular investors either for providing information or for bearing sentiment induced risk. … While asymmetric-information models are theoretically appealing, they have difficult in explaining the great variation of IPO initial returns.[3]

Assuming away asymmetric information, other theories are also proposed to explain IPO underpricing. Tinic (1988) and Hughes and Thakor (1992) contend that new issues are underpriced because the issuers and investment banks want to avoid the legal risk. Rydqvist (1997) highlights the tax advantage of IPO underpricing to issuers as well as underwriters. Chemmanur (1993) and Aggarwal, Krigman, and Womack (2002) argue that the issuer

[2] In support of this theory, Hanley (1993) provides evidence showing that underwriters do not fully adjust the offer price upwards when the demand is strong. Because underwriters only partially incorporate the positive information obtained during the book-building process in the finalized offer price, such investors are compensated by receiving more underpriced shares. However, Ince (2008) shows that this phenomenon is better explained by the bargaining hypothesis of IPO offer price adjustment as hypothesized by Loughran and Ritter (2002).

[3] Lowry, Officer, and Schwert (2010) report that IPO initial returns display extremely high volatility. For IPOs conducted between 1965 and 2005, while underpricing averages 22%, only five percent of the initial returns are between 20% and 25% and nearly one-third of them are zero or negative. This finding poses a challenge to IPO underpricing theories. In particular, the large fraction of overpriced IPOs and severely underpriced IPOs are difficult to explain with arguments of asymmetric information.

strategically underprices the issue in order to generate information momentum by attracting more analyst research activities and media coverage, which helps push up the demand and benefits the owners to sell the shares after the lockup period expires. Hao (2007) models the effect of laddering on IPO pricing. She shows that with laddering, in which the underwriter requires the ladderer to buy additional shares of the issuer in the aftermarket as a condition for receiving shares at the offer price, the expected underpricing is greater.

II. Theory

A. Information setting

We consider the underwriter and the investors in an IPO. The underwriter represents the issuer and takes the firm public. The investors are assumed to be either short-term or long-term oriented. Short-term investors are concerned with the initial return and wish to sell the shares in the immediate aftermarket. On the other hand, long-term investors have an incentive to hold the shares for the long run so they look forward to the expected long-term return. The investors are heterogeneous and, based on their individual beliefs, decide whether or not to purchase the shares in the IPO. The new stock's intrinsic value is unknown to the investors and the underwriter, but is gradually revealed in aftermarket trading. Therefore, with no market-equilibrium history, the market takes time to approaches the "fundamental" demand for the new stock that is consistent with the stock's intrinsic value. In other words, in the early aftermarket, the demand is subject to a new-stock volatility, in addition to that associated with the stock's fundamental risk, that diminishes over time.

We consider the new issue pricing as a two-stage process: preliminary pricing and price finalization. In the first stage, the underwriter determines a preliminary offer price, P_{-1}, from which investors are invited to submit their intended bids. These bids are informative of the market demand for the new stock and thus the stock's intrinsic value, *V*. We refer to this stage as the pre-market period in which book building takes place, which, in the U.S., is known as the registration period. In the second stage, the issuer determines the final offer price, P_0, and allocates the shares to investors based on the distribution of shares demanded at this price. This stage refers to the short period after the book-building process is completed and before aftermarket trading starts. After the stock begins to trade, the first-day closing price, P_1, and the initial return in dollar terms, $R = P_1 - P_0$, are realized.

In this study, our main concern is the effect of the demand uncertainty in the pre-market and early aftermarket on the pricing of the IPO. We do not model the potential role of the preliminary offer price. In this study, the determination of the preliminary price is trivial: it is chosen based on the underwriter's prior belief and it does not affect, in any way, the efficiency of information acquisition. After the book-building process, the underwriter updates her belief on the market demand and then adjusts the offer price. The final offer price simultaneously determines the price revision and, given the immediate aftermarket demand, the initial return.

B. IPO Pricing under Demand Uncertainty

The demand curve is a decreasing function of the share price, P,[4]

$$Q(P) = \tilde{a} - bP, \qquad (1)$$

where the first term, $\tilde{a}$, is random, which equals H or L, where $H > L$. Unlike the conventional secondary market volatility associated with the stock's fundamental risk, the uncertainty in $\tilde{a}$ is new-stock specific, which occurs because the market experiences a learning

[4] See Hao (2007) and Aggarwal, Krigman, and Womack (2002) for downward sloping demand curves.

process before converging to the sustainable level of demand for the new stock. Therefore, as aftermarket trading progresses, the uncertainty diminishes and $\tilde{a}$ gradually approaches to the fundamental level, H or L, that is determined by the stock's intrinsic value. For simplicity, the slope, b, is assumed to be constant and known to the underwriter.[5]

At the time when the IPO is filed with SEC, the underwriter has a prior probability of one half for the high or low level of the demand, and hence the expected value of $\tilde{a}$ is $(H+L)/2$. Because the decision on P_{-1} will have no effect on the information obtained from the book-building process, the underwriter's decision at this stage is to choose a preliminary price P_{-1} based on her prior belief alone, regardless of what might happen to the final offer price. Suppose the total number of shares is N_{-1}, so the total capital to be raised from the IPO is $P_{-1}N_{-1}$. By abstracting from issues about liquidity and control, we ignore the difference between the shares being retained and those being placed. Then the underwriter's problem is:

$$\underset{P_{-1},N_{-1}}{Max}\ N_{-1}P_{-1} \qquad \text{s.t.} \quad P_{-1} \le \frac{(H+L)/2 - N_{-1}}{b}. \tag{2}$$

The valuation constraint rules out intended overpricing. The solution for the preliminary price is:

$$P_{-1} = \frac{H+L}{4b}. \tag{3}$$

Because P_{-1} will have no effect on the efficiency of the book-building process and hence on the determination of the final offer price, this solution gives an uninformative preliminary price that fulfills the regulatory filing requirement.

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[5] b can also to be random. However, this variation will have no added value but make the solution more complex.

After book building, the underwriter observes the pre-market demand, a_{PM} , which equals H or L . Because the short-term demand will remain uncertain in the early aftermarket, this observed demand is still to converge to the stabilized level in the longer run, a^* , which is also H or L . After having gathered information from the book-building process, the underwriter becomes better informed of the market demand. Therefore, in the second stage, the underwriter updates her belief and finalizes the offer price. To model the underwriter's learning, we assume that the pre-market demand is a random realization of the new issue's intrinsic value as the following:

$$a_{PM} = \begin{cases} H & \text{with probability } q, \\ L & \text{with probability } 1-q. \end{cases} \tag{4}$$

where the probability q is a function of the unobserved sustainable demand a^* . It equals δ^H if $a^* = H$, and δ^L if $a^* = L$, where $\delta^H > \delta^L$. The underwriter learns about δ^H and δ^L from the book-building information. With (4), we have implicitly assumed that the pre-market demand is either too high (because when $a_{PM} = H$, there is a chance for $a^* = L$) or too low (because when $a_{PM} = L$, there is a chance for $a^* = H$). Although we can easily add one scenario for unbiased pre-market demand, it will add no value to our model except that the solution will become more complex and less convenient to interpret.

After observing a_{PM} , the underwriter updates her belief following the Bayes' rule and obtain the following posterior probabilities:

$$\delta\left(a^* = H \mid a_{PM} = H\right) = \frac{\delta^H}{\delta^H + \delta^L}, \qquad \delta\left(a^* = H \mid a_{PM} = L\right) = \frac{1-\delta^H}{2-\delta^H-\delta^L}. \tag{5}$$

Apparently, $\delta\left(H \middle| a_{PM} = H\right) > \frac{1}{2}$ and $\delta\left(H \middle| a_{PM} = L\right) < \frac{1}{2}$, which means that the book-building process is informative. The Bayesian updating of the underwriter's belief is an important feature of our model. Before the book-building process, the underwriter is equally uninformed as investors. After the updating, she becomes partially informed although uncertainty in the demand still remains.

The underwriter's problem in the second stage is to choose P_0 and N_0 to maximize total capital, $N_0 P_0$. There are now two constraints that the underwriter needs to consider. The first constraint requires the number of total shares to be sold be subject to the pre-market demand. This is a sales constraint imposed by the pre-market condition. The number of shares that can be placed is confined to the demand at the time when the shares are priced and allocated, and this demand deviates from that of both short-term and long-term investors. The sales constraint requires $N_0 \leq Q(P_0)$. That is,

$$N_0 \leq a_{PM} - bP_0 . \tag{6}$$

The second constraint is to rule out intentional overpricing. This valuation constraint requires $P_0 \leq E(P^*)$. That is,

$$P_0 \leq \frac{H\delta(H|a_{PM}) + L[1-\delta(H|a_{PM})] - N_0}{b} . \tag{7}$$

Because this constraint derives from the posterior probabilities instead of from the priors, the investors in the pre-market are willing to pay a price that is either higher or lower than one satisfying (7). We view (7) as the long-term demand constraint that is dictated by the participation of long-term investors. With this constraint, we assume away the possibility that the underwriter purposely overprices the new issue thus allowing informed investors to make short-term profits at a cost to uninformed ones (see, e.g., Derrien, 2005).[6]

The underwriter maximizes the total capital raised from the offering subject to the sales and valuation constraints, (6) and (7). The sales constraint assures the participation of short-term investors and the valuation constraint assures the participation of long-term investors. When early-market liquidity and underwriter reputation are important, it is necessary for the new issue to be attractive to both short-term and long-term investors.

We obtain the solution for the final offer price as a function of the pre-market demand as follows (see Appendix A for the proof):

$$P_0(a_{PM}) = \begin{cases} \dfrac{H\delta^H + L\delta^L}{2b(\delta^H + \delta^L)} & \text{If } a_{PM} = H, \\ \dfrac{a^L}{2b} & \text{If } a_{PM} = L. \end{cases} \quad (8)$$

We note three points about this solution. First and as expected, $P_0(a_{PM} = H) > P_0(a_{PM} = L)$. That is, the price of a "hot" IPO (in which the investors are overly optimistic) is higher than that of a "cold" IPO (in which the investors are overly pessimistic). Second, with the hot-IPO solution, $P_0(a_{PM} = H)$, the valuation constraint is binding while the sales constraint is unbinding. This result comes directly from the assumption that the underwriter avoids new issue overpricing. So when investors in the IPO are overly optimistic, the underwriter disregards the high market sentiment and prices the IPO at its expected intrinsic value. Third, on the other hand, with the cold-IPO solution, $P_0(a_{PM} = L)$, the sales constraint is binding while the valuation constraint is unbinding.

[6] An alternative approach to the specification of the valuation constraint is to use a weight average demand that takes into account both the uncertain current demand and the expected long-term demand, where the weight reflects the trade-off in the underwriter's pricing strategy between the current-deal success and her long-term reputation.

In the solution, short-term investors earn an abnormal return in a hot IPO and zero return in a cold IPO, while long-term investors earn a market return in a hot IPO and an abnormal return in a cold IPO. On average, IPO investors, who purchase the shares in the pre-market, earn an abnormal return. The cost, however, is born by a different party; secondary-market investors, who purchase the shares in the aftermarket, bear the cost in a hot IPO while the issuer bears the cost in a cold IPO. Such wealth transfer occurs as a consequence of market learning.

To obtain the first-day return, we need to determine the immediate aftermarket price, P_1. Because in aftermarket trading, the price is pushed up to the demand curve, the price adjusts so that the condition $N_0 = a_{PM} - bP_1$ is satisfied. We therefore have:

$$P_1(a_{PM}, N_0) = \frac{a_{PM} - N_0}{b}. \tag{9}$$

Combing Eqs. (3), (8) and (9), we obtain the price update and initial return as a function of the pre-market demand as follows:

Proposition 1: *The IPO's price update, initial return, and their relationship are as follows:*

(i) Price update:
$$P_0 - P_{-1} = \begin{cases} \dfrac{(H-L)}{4b}\left(\dfrac{\delta^H - \delta^L}{\delta^H + \delta^L}\right) & \text{If } a_{PM} = H, \\ -\dfrac{(H-L)}{4b} & \text{If } a_{PM} = L. \end{cases} \tag{10}$$

(ii) Initial return:
$$P_1 - P_0 = \begin{cases} \dfrac{(H-L)\delta^L}{b(\delta^H + \delta^L)} & \text{If } a_{PM} = H, \\ 0 & \text{If } a_{PM} = L. \end{cases} \tag{11}$$

(iii) Initial return and price update:
$$P_1 - P_0 = \begin{cases} \dfrac{4\delta^L}{(\delta^H - \delta^L)}(P_0 - P_{-1}) & \text{If } a_{PM} = H, \\ 0 & \text{If } a_{PM} = L. \end{cases} \tag{12}$$

All three results are asymmetric between hot IPOs and cold IPOs. For hot IPOs, the demand in the pre-market and immediate aftermarket is higher than the expected long-term demand, but the price is only adjusted up to the expected intrinsic value that is consistent with the long-term demand. Therefore, the offer price is updated upwards but only partially,[7] and the initial return, which comes from the excessively high short-term demand, is positive and changes with the price update. On the other hand, for cold IPOs, because the price is forced down to meet the excessively low demand, the price is adjusted downwards and fully and, as a result of full adjustment, there is zero initial return.

A restatement of these results gives the following testable predictions:

Prediction 1. *The offer price is updated upwards and partially for hot IPOs, and is updated downwards and fully for cold IPOs.*

Prediction 2. *Hot IPOs earn positive initial returns, while cold IPOs earn zero initial return.*

Prediction 3. *For hot IPOs, there is a positive association between the initial return and the price update. This association does not occur with cold IPOs.*

These predictions cannot be derived from models without book building, because without the book-building mechanism such models have no implication for price revision and do not distinguish between hot and cold IPOs. Most of these predictions, however, are not new to book-building models of IPO pricing. Table 1 summarizes these predictions in comparison with those from Benveniste and Spindt (1989), the most prominent book-building model, and from Derrien (2005), the closely comparable model.

[7] An upward adjustment of $\frac{(H-L)}{4b}\left(\frac{\delta^H-\delta^L}{\delta^H+\delta^L}\right)$ is smaller than a full-adjustment of $\frac{(H-L)}{4b}$.

The model of Benveniste and Spindt (1989) implies a positive association between initial returns and price updates for hot IPOs, and this implication finds strong empirical support. On the other hand, their model is less clear for cold IPOs about this association. In fact, if underpricing is also used to compensate informed investors for providing unfavorable information, the offer price needs to be adjusted downwards and excessively in order to leave money on the table. An excessive negative adjustment would thus cause a negative association between a positive initial return and a negative price adjustment.

Our model's predictions in this table are the same as those from Derrien's investor-sentiment model of IPO pricing. This is not surprising because the notion of investor sentiment is necessarily associated with abnormally high or low short-term demand. However, the economic rationale in Derrien is conceptually different, which requires irrational behavior of the uninformed investors who would otherwise face an adverse-selection problem. Further differences arise between the two models regarding the long-term effect. For hot IPOs, while both models predict a short-term positive abnormal return, in the long run this return disappears in our model but turns negative in Derrien. And for cold IPOs, which earn zero initial return in both models, Derrien predicts fair pricing while our model predicts a discount on the fundamental value. Therefore, the two models have quite different implications for IPO returns in the short run (which is associated with the early aftermarket uncertainty) and in the long run (which is associated with the fundamental value). In the next subsection, we discuss such differences by decomposing IPO initial return to separate the short-term effect and the long-term effect.

C. Decomposition of IPO Initial Return

We now decompose the initial return into two components: the demand-uncertainty component and the fundamental-discount component which we define below. We denote the new issue's intrinsic value per share as P^*, which is initially unknown and is gradually realized as aftermarket trading progresses. The initial return (*IR*) can be decomposed as:

$$IR = P_1 - P_0 = \left(P_1 - P^*\right) + \left(P^* - P_0\right) = IR_{DU} + IR_{FD}, \qquad (13)$$

where subscript *DU* denotes demand uncertainty and subscript *FD* denotes fundamental discount. The first component represents the premium in the first-day price over the shares' fundamental value. This component reflects the uncertainty effect of the volatile short-term demand, which we refer to as the demand-uncertainty component of IPO initial return. The second component represents the discount of the shares' fundamental value at the offer price, which we refer to as the fundamental-discount component of IPO initial return. We also call it the underpricing component.

All book-building-based models of IPO pricing have explicit or implicit implications for these two components and their relations with the price update. To derive such implications of our model, we obtain the intrinsic value that is consistent with the underwriter's posterior probabilities:

$$P^*\left(a_{PM}, N_0\right) = \begin{cases} \dfrac{H - N_0}{b} & \text{with probability } \delta\left(H \middle| a_{PM}\right), \\ \dfrac{L - N_0}{b} & \text{with probability } 1 - \delta\left(H \middle| a_{PM}\right). \end{cases} \qquad (14)$$

Therefore, $E\left(P^*\right) = \frac{1}{b}\left[L + (H - L)\delta\left(H \middle| a_{PM}\right)\right] - P_0$. Noting that $P_0 = \dfrac{N_0}{b}$ and

$P_1 = \dfrac{a_{PM} - N_0}{b} = \dfrac{a_{PM}}{b} - P_0$ and using Proposition 1, we obtain the following further results for the two initial-return components and their relations with the price update:

Proposition 2: *The expected initial-return components are a function of the pre-market demand and are determined as follows:*

$$E(IR_{DU}) = P_1 - E(P^*) = \begin{cases} \dfrac{(H-L)\delta^L}{b(\delta^H + \delta^L)} & \text{If } a_{PM} = H, \\ -\dfrac{(H-L)(1-\delta^H)}{b(2-\delta^H-\delta^L)} & \text{If } a_{PM} = L, \end{cases} \tag{15}$$

$$E(IR_{FD}) = E(P^*) - P_0 = \begin{cases} 0 & \text{If } a_{PM} = H, \\ \dfrac{(H-L)(1-\delta^H)}{b(2-\delta^H-\delta^L)} & \text{If } a_{PM} = L, \end{cases} \tag{16}$$

which can be further expressed as their relations with the price update:

$$E(IR_{DU}) = \begin{cases} \dfrac{\delta^L}{(\delta^H + \delta^L)}(P_0 - P_{-1}) & \text{If } a_{PM} = H, \\ \dfrac{4(1-a^H)}{(2-\delta^H-\delta^L)}(P_0 - P_{-1}) & \text{If } a_{PM} = L, \end{cases} \tag{17}$$

$$E(IR_{FD}) = \begin{cases} 0 & \text{If } a_{PM} = H, \\ -\dfrac{4(1-\delta^H)}{(2-\delta^H-\delta^L)}(P_0 - P_{-1}) & \text{If } a_{PM} = L. \end{cases} \tag{18}$$

This is a key result of our model that contains rich testable implications and distinguishes our model from various previous models. One immediate observation is the meaning of underpricing …

A restatement of Proposition 2 gives the following testable predictions for the decomposed IPO initial returns:

Prediction 4. *(i) For hot IPOs, the initial return exclusively comes from the demand-uncertainty component: this component is positive and positively associated with price update, while the fundamental-discount component is zero, unassociated with price update. (ii) For cold IPOs, the two components are perfectly offsetting (so there is zero initial return): the* *demand-uncertainty component is negative and positively associated with price update, while the fundamental-discount component is positive and negatively associated with price update.*

This is a unique prediction that differentiates our model from all previous models. Table 2 summarizes the predicted signs for decomposed IPO initial returns and their relations with price updates in contrast to the predictions from Benveniste and Spindt (1989) and Derrien (2005).

Benveniste and Spindt (1989) do not consider aftermarket mispricing so their predictions of underpricing apply to the fundamental-discount component. For hot IPOs, Benveniste and Spindt predict a positive initial return and a positive link between the initial return and price update; in our model, this component is zero while the other component determines a positive initial return and a positive link between the initial return and price update. For cold IPOs, the predictions from Benveniste and Spindt are less clear, while our model predicts the two components to be perfectly offsetting and to have opposite relations with price updates (which we further discuss below).

The comparison between Derrien (2005) and our model is particularly interesting because both models have direct implications for the initial return components. The investor-sentiment component in Derrien corresponds to the demand-uncertainty component in our model. As shown in Table 2, the two models have sharply contrasted predictions for the decomposed initial returns for both hot and cold IPOs. For hot IPOs, although the two models have the same predictions for the demand-uncertainty component, their predictions for the fundamental-discount component are different: while Derrien predicts the fundamental-discount component to be negative (due to overpricing relative to the fair value) and to be increasing in the price update, our model predicts this component to be zero and thus unassociated with the price update. In particular, the two models have sharply contrasted predictions for cold IPOs. With cold IPOs being fairly priced, Derrien predicts both initial return components to be zero and thus unrelated to price revision. On the other hand, cold IPOs are underpriced in our model, which dictates a positive fundamental-discount component and a corresponding offsetting demand-uncertainty component, and accordingly the two components change in opposite directions with the price update.

The predictions for the decomposed IPO initial returns are the key results that distinguish our model from and previous ones. Our empirical test shall focus on these predictions.

III. Data

We collect data on IPOs for the period of 1991-2006 from the Securities Data Company (SDC) New Issues Database. Following previous studies, we eliminate ADRs, closed-end funds, REITs, spin-offs, and unit issues by only choosing common stocks with the IPO flag equal to one. To ensure that our results are not disproportionally affected by very small issuers, we exclude from the sample any IPOs with an offer price less than $5 per share (see, e.g., Lowry and Schwert, 2004; Bradley and Jordan, 2002). For each IPO, we collect information on the offer date, preliminary filing offer price range, proceeds, SIC code, and VC backing. We also collect the financial statement information such as total sales, EBITDA (earnings before interest, tax, depreciation and amortization) and earnings from Compustat. Since the accounting information of IPO firms for the fiscal year prior to IPO is very limited with Compustat and we further require IPO firms to have positive EBITDA, our final sample size is reduced to 3411.

To describe underwriter reputation, we follow Carter and Manaster (1990) and Carter, Dark and Singh (1998) to identify the lead underwriter from SDC and assign a rank in a 10-point scale based on the Loughran and Ritter (2002) classification. For IPOs with more than one leading manager, the average rank of all leading underwriters is used.

Table 3 presents descriptive statistics of the sample. On average, IPOs are sold at $13.65 per share and raise capital of $47 million. After book building, the average offer price is updated upwards by about 1.1%. The mean and median initial returns are 18.81% and 7.58%, respectively, with the distribution displaying significant positive skewness as in Loughran and Ritter (2004). Of all issuing firms, 36% receive funding from venture capitalists, 31.9% of our sample is technology and internet stocks as defined by SIC codes in Loughran and Ritter (2004), and about two thirds of all IPOs are listed on NASDAQ.

IV. Empirical Analysis

(The writing of this section is very preliminary, but the results are carefully reported in Tables 3-9) The first and key step in our test is to estimate the intrinsic or fair value of an IPO and use it to decompose the initial return. We perform initial-return decomposition in two alternative approaches. In the first approach, we use comparable industry peers' price multiplies to estimate the intrinsic value; and in the second approach, we use the secondary-market price of the IPO over time (on which the effect of investor sentiment diminishes over time) as a proxy for the intrinsic value. As we will show, the two approaches give highly consistent results that support our model's predictions.

Our first approach is similar to Bhojraj and Lee (2002) and Purnanandam and Swaminathan (2004). We first choose matching firms from the same industry based on the 48-industry classification of Fama and French (1997). Firms within the same industry are likely to have similar operating and business nature and face similar market-wide and firm-specific risks.

More specifically, to select an appropriate matching firm, we first look at all firms in the Compustat active and research files for the fiscal year prior to the IPO year. For each IPO, we identify all potential matching firms that are in the same industry as the IPO firm and were listed at least three years earlier. We then classify the matching firms into three groups base on past sales, and further divide each sales group into two groups based on the EBITDA profit margin (which is defined as EBITDA/Sales).[8] With IPO firms' pre-IPO sales and profit margin information, we match each IPO firm to its appropriate matching portfolio: from all matching firms in the portfolio, we choose the one with the closest sales to the IPO firm. In this way, the matching by sales assures that the matching firms have similar size to the IPO firms while the operating profitability being reasonably controlled. In untabulated results, we compare the characteristics of IPO firms and their matching counterparts by performing non-parametric mean and median tests on the difference between them in terms of total asset, sales, EBITDA and net incomes. We find no difference in firm fundaments between the IPO firms and their matching firms at the conventional level.

To further ensure robustness of our results, we use three price multiplies, which are the price-to-earning ratio (P/E), the price-to-EBITDA ratio (P/EBITDA), and the price-to-sales ratio (P/S), and obtain the following alternative intrinsic value estimates:

$$P^* = \frac{Earnings(IPO) * \Pr ice(Match) * Shares(Match)}{Shares(IPO) * Earnings(Match)}$$

$$P^* = \frac{EBITDA(IPO) * \Pr ice(Match) * Shares(Match)}{Shares(IPO) * EBITDA(Match)}$$

$$P^* = \frac{Sales(IPO) * \Pr ice(Match) * Shares(Match)}{Shares(IPO) * Sales(Match)}$$

[8] When there are not enough firms for an industry, we change to 2×2 classifications.

We obtain the price and number of shares outstanding data of matching firms on the day when the matched IPO firm went public. All the accounting information of IPO and matching firms are from the fiscal year prior to the IPO. We calculate the demand-uncertainty component of IPO initial return as the percentage difference between the first-trading day closing price and the estimated intrinsic value of the IPO, and calculate the fundamental-discount component as the percentage difference between the estimated intrinsic value and the final offer price.

Table 4 reports the summary statistics of IPO initial returns and the two components. Because the information content in small price updates is often more difficult to interpret and for the purpose of obtaining contrasted results for hot and cold IPOs, we remove IPOs with price update between -5% and 5%. Therefore, we consider an IPO as hot if the price update is above 5% and an IPO as cold if the price update is below -5%.[9] This classification leaves us 1240 hot IPOs and 1232 cold IPOs from the P/EBIDTA multiple valuation, and 1261 hot IPOs and 1285 cold IPOs from the P/Sales multiple valuation. Since many IPOs have negative earnings before the IPO, the number of observation from the P/Earning multiple valuation is further reduced to 1025 hot IPOs and 1016 cold IPOs.

Consistent with the predictions reported in Table 2 (Panel A), for hot IPOs, the initial return mostly comes from the demand-uncertainty component. The mean and median of this component is positive in all three panels, ranging from 15.43% to 72.14%. This observation implies that due to excess short-term demand relative to the firm's fundamentals, investors are willing to pay much higher prices than the expected intrinsic value. On the other hand, the fundamental-discount component of hot IPOs is mixed, depending on the price multiple chosen. This component has a positive mean and median with the P/Earnings multiple

[9] Our main results are qualitatively similar if we use other thresholds for hot and cold IPOs classification.

valuation, but a positive mean together with a negative median with the P/EBIDTA and P/Sales valuation.

For cold IPOs, our model predicts the fundamental-discount component to be positive and the demand-uncertainty component to be negative, with the two perfectly offsetting. This prediction finds very strong support in Table 4. The fundamental-discount component is positive in all three panels, with the three mean numbers averaged at 41.13% and the three median numbers averaged at 10.42%. On the other hand and as expected, the numbers for the demand-uncertainty component are all negative, each with a magnitude very close to its fundamental-discount counterpart. There numbers suggest strongly that, in a cold IPO, after leaning the unexpected low demand from book building, the underwriters have to place a significant discount relative to the intrinsic value to sell the IPO in the pre-market.

Before conducting our major tests for decomposed initial returns, we run regressions of (total) IPO initial return on the price update. Such regressions present the test for our model's predictions for the initial return-price update relationship (Table 1), which also replicate previous studies regarding this relationship. The first regression in Table 5 presents the regression result for the whole sample. Consistent with Hanley (1993) and others (e.g. Loughran and Ritter, 2004; Liungqvist and Wilhelm, 2002), the estimated coefficient on price update is 0.713 and is significant at the 1% level. When the regression is run for hot IPOs and cold IPOs separately, the coefficient changes dramatically. For hot IPOs, the coefficient is 0.687 and remains statistically highly significant; for cold IPOs, however, the coefficient reduces to as low as -0.011 and becomes statistically insignificant.

While this asymmetric initial return-price update relation between hot and cold IPOs is well documented in previous studies, our interpretation is completely different. ...

The coefficients on the control variables are largely in line with the existing literature. Consistent with Loughran and Ritter (2004) and Chemmanur and Krishnan (2007), the coefficient on top-underwriter dummy is significantly positive for the whole sample. In the subsample regressions, separating hot and cold IPOs, however, this coefficient becomes statistically insignificant. In addition to reduced sample size, one possible reason for this insignificant coefficient is that the way we classify hot and cold IPOs is related to the underwriter ranking dummy. For example, when more reputed underwriters have better sales forces and networks than others, such writers, who are associated with higher underwriting rankings, are more likely to attract higher than expected demand. The coefficients on VC dummy are positive and significant for the regressions for hot IPOs, which is consistent with more recent studies such as Hamao, Packer and Ritter (2000), Brav and Gompers (2002), and Bradley and Jordan (2002), who find that underpricing is in fact more severe among VC-backed firms during the 1990s.

Table 6 presents our major results, the test for decomposed initial returns (Prediction 4). We run regressions of the two initial-return components on the price update, controlling for issuer, underwriter, and market characteristics as in Table 5. The three panels report the regressions for the return components decomposed based on new-issue-valuation using the P/Earnings, P/EBITDA, and P/Sales ratio, respectively, separating hot IPOs and cold IPOs. The parameter for the price update is our main concern. The coefficient estimate for this parameter is consistent with our model's predictions in all regressions. For hot IPOs, in all three panels, the coefficient on the price update is positive and statistically significant in the regression of the demand-uncertainty component while it is statistically not different from zero in the regression of the fundamental-discount component. Consistent with the model's predictions, these estimates show that the well-documented positive association of IPO initial return with price revision in a hot IPO is purely a demand-uncertainty effect. This effect is also significant economically. With the estimated coefficient ranging from 0.445 to 0.598, the estimates indicate a half-percentage point increase of the initial return for every one percentage point increase in the price update. On the other hand, the finding that the fundamental-discount component does not respond to the price adjustment in a hot IPO does not support the notion that the underwriter takes an advantage of market sentiment to overprice the IPO or uses underpricing as a compensation scheme for informed investors.

The results for cold IPOs are particularly interesting. The usual perception is that cold IPOs earn negligible initial returns and such returns are not meaningfully associated with price adjustments, so cold IPOs are uninformative and uninteresting. In contrast to this perception, the estimates in Table 6 suggest a significantly negative effect of price update on the fundamental-discount component. This effect is particularly strong in Panels A and B, which indicates a roughly one-for-one change, in percentage-point terms, in the fundamental-discount component for a price update. This result highlights our model’s prediction that in a cold IPO, the abnormally low demand pushes the offer price below the fair value, and as a result of the binding demand, every dollar of change in the price is translated into an opposite change in the fundamental discount or underpricing. Such forced underpricing is caused directly by the abnormally low demand that, on the other hand, determines the demand-uncertainty component in the opposite direction. Consistent with this mechanism, in the three regressions for the demand-uncertainty component, the coefficient on the price update is positive and has a magnitude closely comparable with the counterpart in the regressions for the fundamental-discount component.

Many of our estimated coefficients for the control variables are also very interesting. For instance, the coefficients on the VC dummy variable are positive in the regressions for the demand-uncertainty component, while they are negative in the regressions for the fundamental-discount component. This result seems to imply that venture capital backing helps generate high short-term demand and reduce underpricing. For IPOs conducted during the bubble period, the demand-uncertainty component returns are higher while the fundamental-discount component return is lower. This finding is reasonable as in bubble period, investor sentiment pushes the short-term demand above the expected long-term demand, and the pressure for the underwriter to underprice the new issue is low. The coefficients for the dummy variables for high tech and NASDAQ are also associated with the similar pattern: They are mostly positive with the demand-uncertainty component and mostly negatively with the fundamental-discount component.

As an alternative test for our model's main predictions (Prediction 4), we use the new stock's aftermarket prices over time as a proxy for the fair value and use them to decompose initial returns. It should be noted that the secondary prices can be a very noise measure of the intrinsic value, of which the problem is perhaps most serious with early aftermarket prices. However, our major interest in this test is in the over time pattern of the estimation as we will choose many aftermarket prices of different post-IPO time periods. For this test, we exclude dividend-paying IPOs from the sample, as dividends reduce the share price that consequently would underestimate the fair value at the IPO. This exclusion leaves us with 975 hot IPOs and 1099 cold IPOs.

Tables 7 presents the mean values of decomposed initial returns, separately, for hot and cold IPOs. We use a series of IPO aftermarket prices as the proxy for the fair value, and use each of these proxies to decompose the initial return. When the first-trading day closing price, P_1, is used as the proxy (which is when we consider the immediate aftermarket price to be the fair price), we assume away short-term demand uncertainty so that, by construction, the demand-uncertainty component is zero and the fundamental-discount component equals total initial return. The predicted signs for the fundamental-discount component in this case are the same as those for total initial return (as summarized in Table 1). The first row of Table 7 summarizes the predicted signs for the two components when P_1 is used as the fair value. On the other hand, in the ideal case when the long-term share price, P^{∞}, approaches the intrinsic value (which is when the demand uncertainty is gradually resolved in aftermarket trading so the market demand approaches the long-term demand), the decomposed initial returns based on P^{∞} approach the theoretically defined components. Therefore, the predicted signs for the initial-return components in this case approach our model's predictions (Table 2), which we summarize in the last row of Table 7. In summary, as the post-IPO time period of the aftermarket price increases over time, we expect the decomposed initial-return components to be initially consistent with the predicted signs given in the first row in Table 7, and then change over time and toward the predicted signs given in the last row.

As shown in Table 7, the summarized means of the decomposed initial returns and their trends over time are consistent with our model's predications. For hot IPOs, the initial return starts as a fundamental-discount component and is as high as 36.12%. As the excessively high demand for hot IPOs diminishes over time, this component declines and the demand-uncertainty component emerges. In about one year of aftermarket trading, the initial fundamental-discount component essentially disappears and the fundamental-discount component increases to as high as 37.75%. The statistics for cold IPOs are not as strong as that for hot IPOs, but the trends are also consistent with our predictions. Cold IPOs show an initially modest fundamental-discount component, which increases over time as the uncertainty in aftermarket demand diminishes. At the same time, the demand-uncertainty component is initially zero and becomes negative in about 30 days of aftermarket trading.

Two important points are worth noting about these statistics. First, because many factors other than demand uncertainty may play a role in IPO pricing, as numerous existing studies indicate, the statistics for the fundamental-discount component in this table may either understate or overstate the degree of underpricing. Therefore, it is the trend shown in the statistics that is more relevant to our model's predictions. Second, to avoid introducing noise or any systematic bias, we do not discount aftermarket prices to obtain the IPO fair value. This strategy tends to weaken the demand-uncertainty component and strengthen the fundamental-discount component in longer terms.

In Table 8, we report the regressions for the two return components using the aftermarket prices as the proxy for IPO fair value, controlling for the issuer, underwriter, and market variables as in Tables 5 and 6. To save space, for each regression, we only report the estimated coefficient on the price update and its White's (1980) heteroskedasticity consistent *t*-statistics. The trends of the coefficients are highly consistent with our predictions (which, as in Table 7, are also shown in the first and last rows in the table). For hot IPOs, there is initially a strong positive association between the fundamental-discount component and the price update, and this association declines over time and becomes insignificant after about 100 trading days. On the other hand, for the demand-uncertainty component, there is initially no relation between this component and the price update, but a positive relation emerges after about 30 trading days and the relation continues to increase over time. Consistent with our findings reported in Table

6, this result shows that the widely observed positive relation between initial returns and price updates for hot IPOs are essentially a demand-uncertainty effect. This effect emerges as an underpricing effect in the short-run, but it does not persist in the long run.

For cold IPOs, within the first 200 trading days, the coefficients show no relationship between either component of the initial return and the price update. After about 300 trading days, the fundamental-discount component becomes negatively associated with the price update while the demand-uncertainty component becomes positively associated with the price update. As the two coefficients (for the two components, respectively) show, the two effects are significant both statistically and economically. And the two effects are substantially offsetting to each other: While the two coefficients are with different signs, their magnitudes are closely comparable.

Our model also has a strong implication for the long-run performance of IPOs. It is well-known that IPO stocks underperform their matching firms. Ritter (1991) finds issuing firms during 1975-1984 substantially underperformed their matching firms over the three-year periods after their IPOs. On the other hand, Brav and Gompers (1997) and Brav, Geczy and Gompers (2000) show that if one takes into consideration that IPO firms are typically small and high-growth companies, IPO firms appear to perform no worse than similar firms. Our model contributes to this debate by distinguishing between hot and cold IPOs. Because of demand uncertainty, in the early aftermarket, the price of a hot IPO is expected to be higher than the intrinsic value while the price of a cold IPO is expected to be lower than the intrinsic value. Therefore, our model predicts post-IPO underperformance of hot IPOs and post-IPO overperformance of cold IPOs.

To test for this prediction, we further examine the performance of IPO stocks within the first 12 months. We focus on the one-year window because the results in Tables 7 and 8 suggest that demand uncertainty is likely to be resolved in one year. To evaluate IPO long-run performance, we obtain IPO cumulative average adjusted return (CAR) calculated with monthly rebalancing. The adjusted return is computed using two different benchmarks alternatively: the CRSP value-weighted index return and the return of a matching firm. Daily stock return information is collected from the CRSP daily stock files, from which we exclude IPO first-trading-day returns. For each IPO firm, we choose the matching firm which has the same 2-digit SIC code, went public at least three years earlier, and has the closest size and book-to-market ratio. Table 9 presents the result for this examination, where we report the CAR for 3, 6, 9 and 12 months periods, respectively, for hot and cold IPOs. Over the three-months period, hot IPOs under-perform their benchmark by 4.33% (1.46%) using style-adjusted (index-adjusted) cumulative average return, while cold IPOs over-perform their benchmark by 4.55% (3.76%) using style-adjusted (index-adjusted) cumulative average return. The underperformance of hot IPOs persists and over the 12 months period, hot IPOs under-perform their benchmark by 9.96% (10.70%) using style-adjusted (index-adjusted) cumulative average return. However, the overperformance of cold IPOs diminishes over time, and becomes insignificant after six months.

The sharp difference in post-IPO performance between hot and cold IPOs is consistent with our model's prediction, although the performance of cold IPOs beyond six months is mixed. As suggested by previous studies, the long-run performance of newly listed firms is likely to be affected by various factors and hence displays complex regularities. It is hence not surprising that demand uncertainty alone cannot ideally account for the complex long-run performance regularities.

V. Conclusion

The role of market learning in the demand for new issues has largely been ignored in the literature of IPO pricing. Previous models unanimously ignore this role and hence, in those models, the intrinsic value is always immediately realized in aftermarket trading (unless the market is driven by irrational investors). Departing from this literature, in this paper we examine IPO pricing by allowing the early-market demand to deviate from its stabilized long-term demand. We propose a simple model to formalize the effect of abnormal early-market demand on IPO pricing.

We show that in the presence of the new-issue uncertainty, the decision of the underwriter, a Bayesian learner who faces uninformed rational investors, displays properties that are consistent with a variety of IPO regularities. Some of these regularities are well documented in the empirical literature, which involve IPO initial return, partial price update, and asymmetric effects between hot and cold IPOs. By decomposing the initial return into the demand-uncertainty component and the fundamental-discount component, our model predicts further properties of IPOs that show deeper pricing mechanisms unexplored in previous studies. We empirically test these properties and provide evidence that is highly consistent with the model's predictions.

However, it is important to note that our results by no means undermine the roles of other important factors in IPO pricing such as asymmetric information, strategic pricing and allocation, and market timing. Although we have highlighted the role of abnormal short-term demand associated with market learning, this role should be limited. For instance, without the presence of other factors, market learning alone would predict long-run over-performance of IPOs, because excessive uncertainty arising from market learning pushes the price down. This prediction is apparently inconsistent with the abundant evidence on the long-run performance of IPOs.

Appendix A. Proof of Proposition 1

For the underwriter's problem,

$$\underset{P_0, N_0}{Max} \; N_0 P_0 \qquad \text{s.t.} \quad N_0 \le a_{PM} - bP_0 \, ; \quad P_0 \le \frac{H\delta(H|a_{PM}) + L[1-\delta(H|a_{PM})] - N_0}{b} \, ,$$

the Lagrangian function is:

$$L = N_0 P_0 + \lambda_1 (a_{PM} - bP_0 - N_0) + \lambda_2 \left[H\,\delta(H|a_{PM}) + L(1-\delta(H|a_{PM})) - N_0 - bP_0 \right],$$

where λ_1 and λ_2 are the multipliers for the two constraints, respectively. We have the following first-order derivatives:

$$\frac{\partial L}{\partial P_0} = N_0 - \lambda_1 b - \lambda_2 b \, , \tag{A1}$$

$$\frac{\partial L}{\partial N_0} = P_0 - \lambda_1 - \lambda_2 \, , \tag{A2}$$

$$\frac{\partial L}{\partial \lambda_1} = a_{PM} - bP_0 - N_0 \, , \tag{A3}$$

$$\frac{\partial L}{\partial \lambda_2} = H\,\delta(H|a_{PM}) + L(1-\delta(H|a_{PM})) - N_0 - bP_0 \, . \tag{A4}$$

At the optimum, there must be $\frac{\partial L}{\partial P_0} = 0$ and $\frac{\partial L}{\partial N} = 0$, which requires

$$N = bP_0 \, . \tag{A5}$$

Further, the sales and valuation constraints cannot simultaneously be binding, because otherwise $a_{PM} = H\,\delta(H|a_{PM}) + L(1-\delta(H|a_{PM}))$ which never holds. On the other hand, the two constraints cannot simultaneously be unbinding, because otherwise $\frac{\partial L}{\partial P_0} > 0$ and $\frac{\partial L}{\partial N} > 0$ which violate the necessary conditions. Therefore, in the solution, one constraint must be binding and the other must be unbinding.

We now discuss the solution for $a_{PM} = H$ and $a_{PM} = L$ separately. For $a_{PM} = a^H$, the posterior probability is $\delta(H|a_{PM} = H) = \frac{\delta^H}{\delta^H + \delta^L}$. We start with the binding valuation constraint and obtain:

$$P_0 = \frac{H\delta^H + L\delta^L}{2b(\delta^H + \delta^L)}. \tag{A6}$$

With this solution, we can verify that the sales constraint

$$\frac{\partial L}{\partial \lambda_1} = \frac{(H - L)\delta^L}{\delta^H + \delta^L}$$

is positive and thus unbinding. Therefore, Eq. (A6) gives the solution for $a_{PM} = H$.

For $a_{PM} = L$, the posterior probability becomes $\delta(H|a_{PM} = L) = \frac{1-\delta^H}{2-\delta^H-\delta^L}$. We start with the binding sales constraint and obtain:

$$P_0 = \frac{L}{2b}. \tag{A7}$$

With this solution, we can verify that the valuation constraint

$$\frac{\partial L}{\partial \lambda_2} = \frac{(H - L)(1-\delta^H)}{2-\delta^H-\delta^L}$$

is positive and thus unbinding. Therefore, (A7) must be the solution for $a_{PM} = L$. ■

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Table 1. Theoretical Predictions for Initial Return and its Relation with Price Update

This table summarizes testable predictions of our model for IPO initial return and its relation with IPO price update in comparison with two representative book-building models of IPO pricing (Benveniste and Spindt (1989); Derrien (2005)). In these predictions, we define an IPO as "hot" if the price update is positive and an IPO as "cold" if the price update is negative.

Theory	Models	Price update		Initial return		Relation between initial return and price update	
		Hot IPOs	Cold IPOs	Hot IPOs	Cold IPOs	Hot IPOs	Cold IPOs
Information revelation	Benveniste and Spindt (1989)	Partial adjustment	Excessive adjustment	+	?	+	?
Investor sentiment	Derrien (2005)	Partial adjustment	Full adjustment	+	0	+	0
Demand uncertainty	This paper	Partial adjustment	Full adjustment	+	0	+	0

Table 2. Theoretical Predictions for Decomposed Initial Return and their Relations with Price Update

This table summarizes testable predictions of our model for decomposed IPO initial returns and their relations with IPO price update in comparison with two representative book-building models of IPO pricing (Benveniste and Spindt (1989); Derrien (2005)). We decompose an IPO's initial return as follows:

$$\text{InitialReturn}(IR) = P_1 - P_0 = \left(P_1 - P^*\right) + \left(P^* - P_0\right) = IR_{DU} + IR_{FD},$$

where $P*$ is the IPO's intrinsic value that is consistent with the stabilized long-term market demand for the stock. We call the first component, IR_{DU}, the demand-uncertainty component and the second component, IR_{FD}, the fundamental-discount component. In these predictions, we define an IPO as "hot" if the price update is positive and an IPO as "cold" if the price update is negative.

Theory	Model	Demand-uncertainty component (IR_{DU})		Fundamental-discount component (IR_{FD})	
		Hot IPOs	Cold IPOs	Hot IPOs	Cold IPOs
A. Initial-return components					
Information revelation	Benveniste and Spindt (1989)	NA	NA	+	?
Investor sentiment	Derrien (2005)	+	0	−	0
Demand uncertainty	This paper	+	−	0	+
B. Relations between initial-return components and price update					
Information revelation	Benveniste and Spindt (1989)	NA	NA	+	?
Investor sentiment	Derrien (2005)	+	0	−	0
Demand uncertainty	This paper	+	+	0	−

Table 3: Summary Statistics

Our IPO sample is obtained from the SDC database. We include all IPOs conducted during the period of 1991-2006 with the final offer price above $5. IPO initial return is the percentage difference between the first-trading day closing price and the final offer price. IPO price update is the percentage change from the midpoint of the filing low and high initial offer prices to the final offer price. VC dummy (which is equal to one if the IPO is backed by venture capitalists, and equal to zero otherwise), top-underwriter dummy (which, is equal to one if the managing underwriter has a ranking of eight or above out of ten, and equal to zero otherwise), tech dummy (which is equal to one if the firm is a high-technology company, and zero otherwise), bubble dummy (which is equal to one if the IPO is in 1999 or 2000, and zero otherwise), and the NASDAQ dummy for stocks listed on NASDAQ.

	Mean	Median	Minimum	Maximum	Standard deviation	Observation
Offer Price	13.653	13.000	5	97	6.120	3411
Initial return (%)	18.812	7.576	-75.789	525.00	39.325	3411
Price update(%)	1.126	0	-98.419	400	23.809	3411
Log (Proceeds)	3.852	3.766	-1.609	9.286	1.206	3411
Top underwriter dummy	0.592	1	0	1	0.492	3411
VC dummy	0.361	0	0	1	0.480	3411
Tech dummy	0.319	0	0	1	0.466	3411
Bubble dummy	0.127	0	0	1	0.334	3411
NASDAQ dummy	0.676	1	0	1	0.468	3411

Table 4: Statistics for Decomposed IPO Initial Returns

This table reports the summary statistics for decomposed of IPO initial return. We decompose an IPO's initial return as follows:

$$\text{Initial Return}\,(IR) = P_1 - P_0 = \left(P_1 - P^*\right) + \left(P^* - P_0\right) = IR_{DU} + IR_{FD},$$

where P^* is the estimated fair value using a price multiple of non-IPO industry peers. We call the first component, IR_{DU}, the demand-uncertainty component and the second component, IR_{FD}, the fundamental-discount component. We calculate the demand-uncertainty component as the percentage difference between the first-trading day closing price and the estimated intrinsic value of the new stock, and calculate the fundamental-discount component as the percentage difference between the new stock's estimated fair value and the final offer price. We compute IPO fair value using three price multiples of matching non-IPO industry peers, alternatively, which are the price-to-EBITDA ratio, the price-to-sales ratio, and the price-to-earnings ratio. Industry groupings are based on the 48 industries defined in Fama and French (1997). We define an IPO as "hot" if the price update is positive and greater than 5%, and an IPO as "cold" if the price update is negative and lower than -5%. We report the summary statistics for each of the price-multiple based matching methods.

	Initial return (IR)			Demand-uncertainty component of initial return (IR_{DU})			Fundamental-discount component of initial return (IR_{FD})		
	All IPOs	Hot IPOs	Cold IPOs	All IPOs	Hot IPOs	Cold IPOs	All IPOs	Hot IPOs	Cold IPOs
				A. Matched by P/Earnings					
Mean	19.322	39.169	4.789	-25.192	15.432	-54.011	44.514	23.736	58.800
Median	7.895	22.024	1.562	-26.393	54.168	-8.475	15.169	32.242	4.292
Minimum	-33.077	-30.100	-33.077	-563.067	-552.453	-563.067	-93.472	-93.472	-93.472
Maximum	525.000	525.000	107.143	602.166	602.166	168.472	549.000	549.000	549.000
Standard deviation	39.563	55.668	12.858	172.353	163.076	173.839	164.201	148.416	173.127
Observation	2713	1025	1016	2713	1025	1016	2713	1025	1016
				B. Matched by P/EBIDTA					
Mean	19.390	39.134	5.065	-3.392	34.111	-31.353	22.782	5.023	36.418
Median	7.895	22.448	1.653	34.731	63.110	-14.393	-22.416	-38.880	10.555
Minimum	-53.030	-30.100	-33.077	-458.035	-440.783	-453.393	-127.330	-127.330	-127.330
Maximum	525.000	525.000	107.143	634.830	634.830	178.025	435.536	435.535	435.536
Standard deviation	39.946	56.231	13.249	148.353	145.711	147.506	139.724	131.281	146.353
Observation	3279	1240	1232	3279	1240	1232	5379	1240	1232
				C. Matched by P/Sales					
Mean	18.813	38.675	4.949	-0.189	42.269	-23.213	19.001	-3.594	28.161
Median	7.576	22.115	1.559	40.753	72.137	-21.389	-29.946	-48.797	16.427
Minimum	-75.789	-30.100	-33.077	-400.256	-386.037	-400.256	-92.855	-92.856	-92.856
Maximum	525.000	525.000	107.143	609.011	509.011	171.275	381.198	381.198	381.198
Standard deviation	39.325	55.882	13.079	138.091	135.539	129.228	127.706	117.016	127.395
Observation	3411	1261	1286	3411	1261	1286	3411	1261	1286

Table 5. Regressions for IPO Initial Returns

This table reports the regression results for IPO initial return on the price update. The price update is the percentage change from the midpoint of the filing low and high initial offer prices to the final offer price. We include the following control variables: The logarithm of IPO proceeds, VC dummy (which is equal to one if the IPO is backed by venture capitalists, and equal to zero otherwise), top-underwriter dummy (which, is equal to one if the managing underwriter has a ranking of eight or above out of ten, and equal to zero otherwise), tech dummy (which is equal to one if the firm is a high-technology company, and zero otherwise), bubble dummy (which is equal to one if the IPO is in 1999 or 2000, and zero otherwise), and the NASDAQ dummy for stocks listed on NASDAQ. White's (1980) heteroskedasticity consistent *t*-statistic is reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

	Initial return		
	All IPOs	Hot IPOs	Cold IPOs
Price update	0.713***	0.687***	-0.011
	(6.85)	(3.22)	(-0.30)
log (Proceeds)	-1.327**	1.516	-1.165***
	(-2.23)	(1.00)	(-2.61)
Top-underwriter dummy	2.046*	3.849	-0.564
	(1.81)	(1.40)	(-0.68)
VC dummy	6.764***	11.110***	-0.282
	(5.47)	(4.02)	(-0.33)
Tech dummy	6.018***	7.296**	2.650***
	(3.99)	(2.31)	(2.59)
Bubble dummy	34.084***	51.477***	5.982***
	(10.93)	(9.72)	(2.79)
NASDAQ dummy	3.240***	9.274***	0.405
	(2.65)	(2.75)	(0.51)
Intercept	11.032***	-10.038	7.504***
	(3.68)	(-1.22)	(3.51)
Observation	3411	1261	1286
Adjusted R^2	0.373	0.367	0.041

Table 6. Regressions for Decomposed IPO Initial Returns on Price Update

We decompose an IPO's initial return as follows:

$$\text{Initial Return}\,(IR) = P_1 - P_0 = \left(P_1 - P^*\right) + \left(P^* - P_0\right) = IR_{DU} + IR_{FD},$$

where P^* is the estimated fair value using a price multiple of non-IPO industry peers. IR_{DU} is the demand-uncertainty component and IR_{FD} is the fundamental-discount component. This table presents the regression results from the IPO initial-return components on IPO price update. The price update is the percentage change from the midpoint of the filing low and high initial offer prices to the final offer price. Control variables used in the regressions include the following: The logarithm of IPO proceeds, VC dummy (which is equal to one if the IPO is backed by venture capitalists, and equal to zero otherwise), top-underwriter dummy (which, is equal to one if the managing underwriter has a ranking of eight or above out of ten, and equal to zero otherwise), tech dummy (which is equal to one if the firm is a high-technology company, and zero otherwise), bubble dummy (which is equal to one if the IPO is in 1999 or 2000, and zero otherwise), and the NASDAQ dummy for stocks listed on NASDAQ. The regressions are run separately for hot IPOs (of which the price update is positive and more than 5%) and for cold IPOs (of which the price update is negative and lower than -5%). Panel A, B and C report the regressions for the decomposed initial-return components based on the estimated fair value from the P/E ratio, the P/EBITDA ratio, and the P/sales ratio, respectively. White's (1980) heteroskedasticity consistent *t*-statistic is reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

	Demand-uncertainty component (IR_{DU})		Fundamental-discount component (IR_{FD})	
	Hot IPOs	Cold IPOs	Hot IPOs	Cold IPOs
	A. Match by P/Earnings			
Price update	0.598**	1.044**	-0.004	-1.089**
	(2.25)	(2.16)	(-0.02)	(-2.26)
log (Proceeds)	-4.901	-10.843*	6.809	9.875
	(-0.80)	(-1.81)	(1.15)	(1.66)
Top-underwriter dummy	16.122	28.285**	-11.531	-28.435**
	(1.46)	(2.30)	(-1.09)	(-2.33)
VC dummy	33.356***	18.364	-23.778**	-18.623
	(3.25)	(1.48)	(-2.42)	(-1.51)
Tech dummy	20.385*	-22.169	-14.016	23.815*
	(1.80)	(-1.61)	(-1.34)	(1.73)
Bubble dummy	66.884***	55.861***	-14.330	-51.447***
	(5.13)	(3.53)	(-1.22)	(-3.30)
NASDAQ dummy	36.225***	25.643*	-25.828**	-24.498*
	(2.63)	(1.94)	(-2.00)	(-1.86)
Intercept	-53.240*	-35.603	42.935	41.250
	(-1.68)	(-1.26)	(1.43)	(1.47)
Observation	1025	1016	1025	1016
Adjusted R^2	0.109	0.023	0.031	0.021
	B. Match by P/EBITDA			
Price update	0.445***	1.230***	0.245	-1.243***
	(2.79)	(2.78)	(1.04)	(-2.83)
log (Proceeds)	-3.216	-14.176***	4.732	12.943***
	(-0.62)	(-3.06)	(0.95)	(2.80)
Top-underwriter dummy	-1.397	3.004	5.368	-3.612
	(-0.16)	(0.34)	(0.63)	(-0.41)
VC dummy	26.793***	25.124***	-15.803**	-25.525***
	(3.22)	(2.83)	(-2.01)	(-2.89)
Tech dummy	32.631***	9.603	-25.373***	-6.990
	(3.54)	(0.98)	(-3.03)	(-0.72)

Bubble dummy	62.109***	48.359***	-10.696	-42.725***
	(5.38)	(4.06)	(-1.02)	(-3.66)
NASDAQ dummy	27.465***	27.540***	-17.979*	-27.196***
	(2.54)	(2.72)	(-1.80)	(-2.69)
Intercept	-21.152	2.517	10.911	5.328
	(-0.85)	(0.12)	(0.47)	(0.25)
Observation	1240	1232	1240	1232
Adjusted R^2	0.107	0.046	0.029	0.041
		C. Match by P/Sales		
Price update	0.515***	0.584*	0.172	-0.594*
	(3.63)	(1.79)	(1.09)	(-1.85)
log (Proceeds)	-5.062	-13.384***	6.577*	12.218***
	(-1.16)	(-3.24)	(1.63)	(2.99)
Top-underwriter dummy	-2.946	5.346	6.796	-5.910
	(-0.38)	(0.68)	(0.92)	(-0.76)
VC dummy	36.705***	6.096	-25.594***	-6.378
	(4.67)	(0.77)	(-3.51)	(-0.82)
Tech dummy	36.299***	24.223***	-29.004***	-21.573***
	(4.52)	(3.04)	(-4.09)	(-2.75)
Bubble dummy	72.852***	54.337***	-21.375***	-48.355***
	(7.68)	(5.40)	(-2.66)	(-4.98)
NASDAQ dummy	28.578***	18.714**	-19.304**	-18.309**
	(2.84)	(2.13)	(-2.08)	(-2.10)
Intercept	-13.741	5.027	3.703	2.477
	(-0.64)	(0.26)	(0.19)	(0.13)
Observation	1261	1286	1261	1286
Adjusted R^2	0.178	0.051	0.071	0.043

Table 7. IPO Initial Returns Decomposed Using Aftermarket Prices

This table reports the mean components of IPO initial return decomposed using an aftermarket price, P_t, as the proxy for the new-issue fair value. Our decomposition approach is the following:

$$IR = P_1 - P_0 = (P_1 - P_t) + (P_t - P_0) = IR_{DU}(t) + IR_{FD}(t),$$

where IR_{DU} is the demand-uncertainty component and IR_{FD} is the fundamental-discount component, both as a function of the aftermarket price at time *t*. In the immediate aftermarket, $P_t = P_1$ and, hence, the demand-uncertainty component is zero and the fundamental-discount component equals total initial return (as predicted in Table 1). The first row presents the predictions for the two components in the immediate aftermarket. In the long term, the aftermarket price approaches the shares' intrinsic value (i.e. $P_t \rightarrow P^*$), so the decomposed initial returns approach the model's predictions. The last row presents the predictions for the two components in the long run (which are from the third row of Panels A, Table 2).

This table reports the mean components of IPO initial returns. The demand-uncertainty component is the percentage difference between the IPO first-trading-day price and the aftermarket price at trading day *t*. The fundamental-discount component is the percentage difference between the aftermarket price at trading day *t* and the IPO final offer price. The hot IPOs are IPOs with price update is more than 5%, and the cold IPOs are IPOs with price update less than -5%. Stocks paying dividends are excluded from the sample.

Day since IPO	Demand-uncertainty component (IR_{DU})		Fundamental-discount component (IR_{FD})	
	Hot IPOs (N=975)	Cold IPOs (N=1099)	Hot IPOs (N=975)	Cold IPOs (N=1099)
Predicted signs based on the immediate aftermarket price: $P_1 = P^*$	0	0	+	0
Day 1	0	0	36.119	4.368
Day 2	0.712	0.011	38.360	4.378
Day 5	0.920	0.047	38.152	4.343
Day 10	-0.148	-0.007	39.221	4.396
Day 30	-2.980	-3.064	42.053	7.454
Day 60	0.681	-6.836	38.391	11.225
Day 100	4.663	-11.006	34.409	15.396
Day 150	16.157	-8.774	22.915	13.164
Day 200	19.197	-5.312	19.875	9.702
Day 300	32.831	-6.114	4.785	10.784
Day 400	37.754	-2.445	-0.137	7.114
Predicted signs based on the long-term price: $P^{\infty} = P^*$	+	−	0	+

Table 8. IPO Initial-Return Components (Decomposed Using Aftermarket Prices) and Price Update

This table reports the coefficients on price update in the regressions for IPO initial return components. IPO initial return is decomposed, as the following, using an aftermarket price, P_t, as the proxy for the new-issue fair value:

$$IR = P_1 - P_0 = (P_1 - P_t) + (P_t - P_0) = IR_{DU}(t) + IR_{FD}(t),$$

where IR_{DU} is the demand-uncertainty component and IR_{FD} is the fundamental-discount component, both as a function of the aftermarket price at time *t*. In the immediate aftermarket, $P_t = P_1$ and, hence, the demand-uncertainty component is zero and the fundamental-discount component equals total initial return. The relations between initial-return components and price update are presented in the last two columns in Table 1. In the long term, the aftermarket price approaches the shares' intrinsic value (i.e. $P_t \to P^*$), so the decomposed initial returns approach the model's predictions. The last row presents the predictions for this relation for the two components, respectively, in the long run (which are from the third row of Panels B, Table 2).

Regressions are run for hot IPOs and cold IPOs, separately, for the two intial-return components. Hot IPOs are IPOs with the price update above 5%, and cold IPOs are IPOs with the price update below -5%. The same control variables as in Tables 5 and 6 are included in these regressions, for which the coefficients are not reported. White's (1980) heteroskedasticity consistent *t*-statistic is reported in parentheses. The signs ***, **, and * indicate statistical significance levels at the 1%, 5%, and 10% level, respectively.

Day since IPO	Demand-uncertainty component (IR_{DU})		Fundamental-discount component (IR_{FD})	
	Hot IPOs	Cold IPOs	Hot IPOs	Cold IPOs
Predicted signs based on the immediate aftermarket price: $P_1 = P^*$	0	0	+	0
Day 1	0.000 (0.00)	0.000 (0.00)	0.871*** (3.65)	0.003 (0.07)
Day 2	0.017 (1.28)	0.003 (0.23)	0.843*** (3.52)	0.000 (0.01)
Day 5	-0.084 (-0.79)	-0.001 (-0.02)	0.943*** (3.82)	0.003 (0.07)
Day 10	-0.022 (-0.30)	0.037 (0.93)	0.882*** (3.49)	-0.034 (-0.59)
Day 30	0.160* (1.91)	0.025 (0.36)	0.699*** (3.36)	-0.022 (-0.30)
Day 60	0.436** (2.50)	0.090 (0.83)	0.423*** (3.16)	-0.087 (-0.72)
Day 100	0.559*** (2.69)	0.108 (0.53)	0.300** (2.05)	-0.106 (-0.49)
Day 150	0.728** (2.57)	0.030 (0.15)	0.132 (1.06)	-0.027 (-0.13)
Day 200	0.751*** (2.60)	0.182 (1.06)	0.108 (0.82)	-0.178 (-1.04)
Day 300	1.009*** (3.10)	0.575*** (2.08)	-0.096 (-0.96)	-0.596** (-2.20)
Day 400	1.014*** (2.81)	0.867*** (2.91)	-0.101 (-0.78)	-0.888*** (-3.06)
Predicted signs based on the long-term price: $P^\infty = P^*$	+	+	0	–

Table 9. IPO long-run performance

This table reports the long-run performance of hot and cold IPOs. Hot IPOs have a price update above 5% and cold IPOs have a price update below -5%. Daily stock returns are obtained from the CRSP daily stock file. CAR is an IPO's cumulative adjusted return. The cumulative return is computed for four trading periods from the first trading day to 3, 6, 9 and 12 months, respectively. The style-matching-adjusted CAR is calculated as the cumulative monthly average excess return of an IPO over that of its matching stock. Style-matching requires the matching stock to be a seasoned stock (that had been listed for at least three years) to have the closest market capitalization and book-to-market ratio. The market capitalization and book-to-market ratio are based on the data at the time of IPO. The index-adjusted CAR is the cumulative monthly average excess return of an IPO over the CRSP value-weighted index return. Following Ritter (1991), we define the corresponding *t*-statistic as $CAR*n^2/csd$, where n is the number of issuing firms trading in each month, and $csd=[t*var+2*(t-1)*cov]^2$, where t is the event month, var is the average cross-sectional variance, and cov is the first-order autocovariance of the abnormal return series.

Time period since IPO	Hot IPOs		Cold IPOs	
	Style-matching-adjusted CAR (%)	Index-adjusted CAR (%)	Style-matching-adjusted CAR (%)	Index-adjusted CAR (%)
3 month	-4.326***	-1.465	4.547***	3.764***
	(-3.45)	(-1.53)	(3.67)	(4.13)
6 month	-6.531***	-4.018***	1.798	2.418*
	(-3.64)	(-2.93)	(1.02)	(1.86)
9 month	-6.223***	-5.225***	-1.358	0.166
	(-2.77)	(-3.04)	(-0.62)	(0.10)
12 month	-9.956***	-10.699***	-3.855	-1.696
	(-3.75)	(-5.28)	(-1.49)	(-0.89)