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Valuation of IPOs using a Stochastic Frontier Approach: A Revisit*

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Abstract

We estimate the magnitude and determinants of market value and underpricing in Initial Public Offerings (IPOs) for 1,221 firms using a stochastic frontier model applied to the previously unexamined 1999-2010 period. We find that the book value of a firm's assets, the percentage of shares retained by the original owners of the firm immediately after the IPO, the commission rate paid to the underwriters and the reputational rankings of the underwriters are the most important determinants of firm value and underpricing. We estimate that the mean ex-ante underpricing is 39.7% which, while high compared with previous studies, is consistent with unusually large first day returns in our sample period and our focus on emerging growth IPOs. However, contrary to an earlier study, we do not find a positive relation between our model-based measure of ex-ante underpricing and first day aftermarket returns at the firm level.

Keywords: IPO; Market Value; Stochastic Frontier Model.

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1. Introduction

There is a voluminous literature studying the initial underpricing and subsequent performance of initial public offerings (IPOs). Issues related to this phenomenon that have received particular attention include the valuation of IPOs and how various factors affect the price performance of IPOs. The reasons IPOs have received extensive examination are straightforward. First, firms thatwant to finance through the stock market need guidance in setting a reasonable price for their IPOs. Second, investors (including both individual and institutional investors) must make purchase decisions based on the available information with respect to the issuing firms and/or the whole market. Finally, analysts need academical support to write recommendation reports.

Numerous empirical regularities have been documented relative to IPOs. Virtually all comprehensive studies, beginning with Ibbotson (1975), have shown that IPOs appear underpriced in the sense that they experience large run-ups in price, on average, on the first day or first month of trading. Lowry, Officer and Schwert (2010) and others have shown that the variance of the first-month price run-up in the cross section of IPOs is extremely large. Both the volume and the underpricing of IPOs have been shown to vary over time (see, for example, Ibbotson and Jaffe, 1975; Ibbotson, Sindelar and Ritter, 1988), and the magnitude of the first public trading day price run-up is positively related to pre-issue price increases as measured by the difference between the final offering price and the midpoint of the anticipated issue price range in the preliminary prospectus filed with the Securities and Exchange Commission (Hanley, 1993; Loughran and Ritter, 2002; Lowry and Schwert, 2004). Finally, numerous studies show that the long-run performance of IPOs is unappealing in general and is inversely related to the short run price run-up or to various measures of fair value, particularly during “hot market” periods (Ritter, 1991; Ritter and Welch, 2002; Purnanandam and Swaminathan, 2004).

Many different explanations of the observed IPO empirical regularities have been proposed in the literature. As Hunt-McCool, Koh and Francis (1996) discuss, the key question as it pertains to our study is whether the observed short-run price run-up is due to deliberate underpricing of IPOs. One possible reason for deliberate underpricing is that it indirectly compensates the underwriter for the large risks associated with a fixed-price offering when the issuing firm is inherently difficult to value (Rock, 1986; Benveniste and Spindt, 1989; Lowry et al., 2010). Other explanations focusing on deliberate underpricing include lack of concern about underpricing by issuing firms due to prospect theory (Loughran and Ritter, 2002), due to selling only a small part of the firm at the IPO (Habib and

Ljungqvist, 2001) or due to deficiencies in corporate governance and/or managerial compensation structure in the issuing firm (Chahine and Goergen, 2013, 2014). However, alternate explanations of the first-day price run-up that focus on behavioral issues and do not involve deliberate underpricing have received increasing attention in the literature. Aggarwal and Rivoli (1990) and Shiller (1990) argue that the first day price run-up may be caused by fads or speculative bubbles in the IPO market. Ritter (1991), who documents that IPOs consistently underperform the market in the long run, notes that it may be that the first aftermarket price is too high rather than the issuing price being too low. More recent studies that provide evidence consistent with this conjecture include: Cornelli, Goldreich and Ljungqvist (2006) who note that in the European data high grey market prices (which proxy for over optimism by small and retail investors) can explain both the initial price run-up and the long-term underperformance, and Da, Engelberg and Gao (2011), who show that a high Google Search Volume Index specific to an issuing firm (a proxy for small investor attention) strongly contributes to short-term price run-ups and long-term underperformance in the firm's IPO.

As noted above, the short-term aftermarket performance of an IPO is not necessarily a correct measure of (deliberate) underpricing. In order to properly examine underpricing, one needs to compare the offering prices with the intrinsic values of the shares of the issuing firms. Kim and Ritter (1999) summarize that there are three valuation methods that could be used: the discounted cash flow approach, the asset-based approach, and the comparable firms approach. The discounted cash flow approach is the best way to determine the value of a firm since it fully considers the firm's earning potential and growth opportunities; however, it is hard to estimate the future cash flows, determine an appropriate discount rate and value growth options in practice. The asset-based approach proxies a firm's value by estimating the underlying value of the issuing firm's assets. However, this approach is not applicable in most IPOs unless there is a significant proportion of the assets which can be liquidated quickly at well-determined market prices. Consequently, the comparable firms approach, which is usually implemented by capitalizing the earnings per share of the issuing firm at the average price-to-earnings (P/E) ratio of publicly-traded comparable firms, is the most widely used since accounting information for these firms is generally available. However, Kim and Ritter (1999) show that the comparable firms approach can result in large valuation errors because P/E and other ratios relating to accounting numbers and market-determined prices often display great variation among firms in the same industry. Thus, we note that while each of these possible methods for determining the intrinsic values of IPOs has positive features, their

limitations are substantial. In addition, these methods share a point in common: all of them usually employ aftermarket information in some fashion to evaluate the IPOs. As demonstrated by our previous discussion regarding the use of stock return data for the issuing firm, it is difficult to determine if the underpricing of new issues is deliberate or if the underpricing is due to aftermarket characteristics such as fads or underwriter price support. Thus, in this study, we employ an alternative method, the stochastic frontier approach, to evaluate IPOs by using information only from the premarket period.[1]

Hunt-McCool et al. (1996) and Koop and Li (2001) also employ the stochastic frontier model to evaluate IPOs and examine the underpricing in IPOs. In particular, one of the most significant advantages of this model is that the estimation and measurement can be conducted with premarket information alone. Hunt-McCool et al. (1996) mix the pricing factors from firm specific characteristics and the factors resulting in underpricing to estimate firms' frontiers and compute the gap between real value and the frontier. They conclude that most abnormalities in aftermarket returns cannot be explained by the factors leading to premarket underpricing. The underpricing in IPOs is sensitive to issuing period (hot and non-hot periods). However, with the mixture of the firm-specific pricing factors and underpricing factors, it is hard to figure out the exact relationship between deliberate underpricing and underpricing factors. To avoid this shortcoming, Koop and Li (2001) categorize firm-specific pricing factors and underpricing factors in order to estimate the magnitude of underpricing in IPOs and determine how underpricing factors associate with underpricing simultaneously. But the data they employ contain both IPO and Seasoned Equity Offering (SEO) firms. The reason they mix IPO and SEO data is that they believe SEO firms are expected to be efficiently priced such that they can be used as a more relevant benchmark. However, they do not provide evidence to support that SEO firms are evaluated without bias, and there is no theoretical justification for comparing IPO firms and SEO firms directly given that IPOs are much more difficult to value and therefore pose much greater risks for underwriters. Hence, we will only employ IPO firms in this study and extend the sample period to recent years. In addition to possible defects in their data, another weakness of the model employed by Koop and Li (2001) is the narrow focus on asymmetric information as the underlying reason for the underpricing of IPOs, while ignoring non-rational and agency conflict explanations which have played major roles in

[1] Following Hunt-McCool et al. (1996), we do examine the firm-level relations between underpricing measured using the frontier approach and subsequent first day aftermarket returns, but the underpricing estimates themselves are estimated solely using pre-market data.

more recent studies (Ritter and Welch, 2002; Loughran and Ritter, 2004; Filatotchev and Bishop, 2002; Lee and Wahal, 2004; Cornelli et al., 2006; Da et al., 2011; Chahine and Goergen, 2013, 2014).

Following Koop and Li (2001) we use the market value (MV) of a firm as the dependent variable and develop a stochastic market value frontier (similar to the stochastic production frontier) of a firm. This stochastic market value frontier defines the maximum market value attainable by a firm for a given set of observable firm characteristics. However, at the time of initial public offering (IPO) the actual market capitalization is below its market value frontier. This shortfall in the actual market value of a firm from its maximum possible attainable value is due to the underpricing of the IPO. In our market value frontier, the conditional mean of the inefficiency term could be viewed as the average loss in market value of a firm. Following Jondrow, Lovell, Materov and Schmidt (1982), we compute the conditional mean of the one-side error term of the stochastic frontier model as the point estimate of the firm-specific underpricing. Thus, the magnitude of underpricing can be explicitly computed using only firm-specific premarket characteristics instead of aftermarket information and/or comparable information. Next, the determinants of underpricing are also investigated here as is done in Koop and Li (2001), and we add an additional variable (venture capital involvement) that was not considered in their model. Finally, unlike Koop and Li (2001), we investigate the relations between firm level underpricing estimated by our model and the subsequent first day aftermarket returns.

This study estimates the magnitudes of the underpricing of IPOs of 1,221 firms during the period 1999-2010. To our knowledge, this sample period lies entirely outside those used in previous studies that have employed any variation of the stochastic frontier approach in the context of examining IPOs: the sample period in Hunt-McCool et al. (1996) was 1975-1984, and Koop and Li (2001) sample ran from 1985-1998. Moreover, as explained in greater detail below, the IPO database we use in this study contains only de-novo (i.e. brand new) firms going public for the first time; it excludes spinoffs from, and reorganizations of, established publicly-traded firms. In this respect, our sample may significantly differ from those used in previous studies.

The rest of the paper is organized as follows. The methodology is explained in detail in Section 2. Sections 3 and 4 are devoted to the specific model and the data. Our findings are presented in Section 5 and Section 6 concludes the study.

2. Methodology

Similar to a production frontier, the market value frontier describes the relationship between firm characteristics and the maximum attainable market value. The word "frontier" emphasizes the idea of maximality. Let Q be the market value of a firm, P the offer price of the IPO and NS the total number of outstanding shares after the offering; then $Q = P \times NS$. Since NS is fixed at the time of offering, MV depends on P. If the IPO is underpriced, Q will not attain its frontier and will fall short of its maximum. Let Q_i^* be the maximum attainable market value of the firm i at the time of IPO if all characteristics of the firm are accurately and/or efficiently accounted for in the offer price. The maximum market value, Q_i^* is defined as the predicted market value frontier and is expressed as

$$Q_i^* = f(X_i, \beta)exp(v_i), \quad (1)$$

where X_i is a vector of firm characteristics, β is a parameter vector and v_i is a random disturbance term independently distributed as $N(0, \sigma^2)$. It is stochastic in sense that it captures the random shocks in the market beyond the underwriter's control.

If an IPO is underpriced, Q_i^* will not be attained. Let Q_i be the actual market value at the time of IPO. Then the underpricing of an IPO is computed as 1 minus its IPO pricing efficiency. In particular, the IPO pricing efficiency is defined as the ratio of the actual and maximum market value and could be represented by the exponential factor, $exp(-u_i)$, i.e.

$$\frac{Q_i}{Q_i^*} = exp(-u_i). \quad (2)$$

Thus, the actual Q_i could be expressed as a function of frontier maximum value,

$$Q_i = Q_i^* \, exp(-u_i), \quad (3)$$

where u_i is assumed to be independently distributed as truncations above zero of $N(\mu, \sigma^2)$. Following Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), the frontier function to be estimated is expressed as

$$Q_i = f(X_i, \beta)exp(v_i - u_i) = f(X_i, \beta)exp(\varepsilon_i)$$

$$\text{or} \quad \ln Q_i = \ln f(X_i, \beta) + \varepsilon_i, \; i = 1, \ldots, n, \quad (4)$$

where ε_i, the disturbance term, is composed of two terms: v_i and u_i. In particular, $\varepsilon_i = v_i - u_i$, $u_i \geq 0$, and u_i and v_i are independent of each other, i.e., $cov(u_i, v_i) = 0$

with $v_i \sim N(0, \sigma^2)$ and $u_i \sim N^+(\mu_i, \sigma^2)$. Thus, $\sigma^2 = \sigma^2 + \sigma^2$.[2] Since $u_i \geq 0$, the value of each firm, ln Q_i, is bounded by the maximum benchmark value denoted by ln Q_i^*, i.e.,

$$\ln Q_i = \ln Q_i^* - u_i, \; u_i \geq 0. \tag{5}$$

Koop and Li (2001) also used u_i to capture the shortfall in a firm's actual value but they estimated the stochastic frontier by using the Bayesian method.[3]

In the stochastic production frontier literature, u_i measures the technical inefficiency, and Jondrow et al. (1982) suggest using the mean or mode of the conditional distribution of u_i given ε_i as a point estimate of u_i. Since the production function is generally defined as the logarithm of production, Battese and Coelli (1988) proposed that, for firm i, the technical efficiency should be estimated by $E[exp(-u_i|\varepsilon_i)]$. Following Battese and Coelli (1993, 1995), we assume that u_i is obtained by the truncation at zero of the normal distribution with mean δZ_i and variance σ^2. Z_i denotes a set of g variables considered to be the determinants of underpricing in IPOs and δ is a $(1 \times g)$ vector of coefficients to be estimated. Thus, the indicator of the underpricing is specified as

$$u_i = \delta Z_i + \omega_i, \tag{6}$$

where ω_i is a truncated normal random variable with zero mean and variance σ^2. The frontier model given in Equation (4) is jointly estimated with Equation (6). Thus, the u_i is distributed as $N^+(\delta Z_i, \sigma^2)$. Following Battese and Coelli (1993, 1995), the underpricing in IPOs is computed by

$$UdPr_i = 1 - \mathrm{E}[\exp(-u_i \mid \varepsilon_i)] = 1 - \left\{\frac{1-\Phi(\gamma_i+\sigma_*)}{1-\Phi(\gamma_i)}\right\} \exp\left(-\mu_{*i} + \frac{1}{2}\sigma_*^2\right) \tag{7}$$

where $\gamma_i = \frac{-\mu_{*i}}{\sigma_*}$, $\mu_{*i} = \frac{-\sigma_u^2 \varepsilon_i + \delta Z_i \sigma_v^2}{\sigma_u^2 + \sigma_v^2}$ and $\sigma_*^2 = \frac{\sigma_u^2 \sigma_v^2}{\sigma_u^2 + \sigma_v^2}$.

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[2] We define γ as the ratio of σ^2 to σ^2, i.e., $\gamma = \sigma^2 / \sigma^2$. Following Battese and Coelli (1993), this ratio will be used $u\varepsilon$ u ε to test the hypothesis on the existence of underpricing.

[3] It is beyond the scope of this paper to debate whether estimation of the frontier model is better using the classical method or the Bayesian method. A quick google search will reveal during the last twenty years how many researchers have used the classical method versus the Bayesian method.

3. The Model

To construct the benchmark of a firm's initial market value, i.e. the frontier, we employ a set of variables to specify the characteristics of a firm. Based on prior literature, the following model is specified as the firms' frontier:

$$\ln Q_i = \beta_0 + \beta_1 \ln(\ Total\ \ Assets_i) + \beta_3 \ln(Total\ \ Debt_i) + \beta_3 \ln(R\&D_i) + \beta_4 \ln(Commission\ Rate_i) + \beta_5 \ln(Age_i) + \beta_6(Retention\ \ Ratio_i) + \beta_7(Post\ \ IPO\ \ Insider\ \ Ownership_i) + \Sigma_{k=8}^{14}\beta_k(Industry\ Dummay_{ki}) + \beta_{15}(Boom\ Dummy) + \beta_{16}(Crash\ Dummy) + \beta_{17}(Financial\ Crisis\ Dummy) + v_i - u_i. \quad (8)$$

Following Koop and Li (2001), the market value of a firm, *Q*, is used as the dependent variable for the frontier model since the market value is more comparable across firms relative to stock prices.[4] The market value of a firm is computed as the log of the product of the offer price and the total number of outstanding shares after the offering.

Many previous studies have (unsurprisingly) shown that there is a relation between historical accounting information and a firm's market value. It is straightforward that the expected relationship between the book value of a firm's assets, as reflected on its latest balance sheet prior to the offering, and a firm's market value is positive. Similar to the assets, other things held constant, the relation between a firm's level of debt and its market value should be negative.[5] However, it is not neglectable that the firms, studied in this paper, are emerging growth or de-novo firms, whose debt level may also reflect their lenders' confidence regarding to their growth potential. Hence, we cannot predict the relation between debt and firm value at the stage of model construction.

[4] We are perplexed by the choice of Hunt-McCool et al. (1996) to use the log of the offer price per share as the dependent variable in their model, especially because the independent variables they use to capture firm value (book value and sales) do not appear to be on a per-share basis.

[5] Following earlier studies, we initially included other accounting variables, i.e. sales and net income, as direct indicators of firm value in our model. However, because our sample consists entirely of emerging growth (de-novo) firms, we found that these variables had odd distributions. When included in our models their coefficients often had the wrong sign, were invariably statistically insignificant, and did not meaningfully affect efficiency estimates. For these reasons, we chose to exclude them from the models for which we report results in this paper.

Clearly, innovation and new technology serve as a resource for the growth of firms, and the capital used in production is not limited to physical capital. Habib and Ljungqvist (2005) documented that there is a positive relationship between "soft spending" and firm value. In this study, "soft spending" is measured by the log of *R&D* (research and development expenses) in the fiscal year prior to the offering, and we expect "soft spending" to be positively related with firm value.

Valuation risk associated with an offering should, logically, negatively affect the offering price for an IPO and, by extension, the market value based on the offering price. Similar to Hunt-McCool et al. (1996), we hypothesize that one indicator of valuation risk is the commission rate paid by the issuing firm to the underwriter(s). Hughes (1986) argues that underwriter compensation is related to the costs of investigating firm characteristics, implying that the commission rate will be higher for firms about which there is less public information that are, in turn, more difficult to value. Thus we expect a negative relation between commission rate and firm value.

The retention ratio in our model represents the percentage of the total shares in the company that will collectively be retained by the previous owners of the firm, i.e., it is formally defined as 1 minus shares offered in IPO/total number of outstanding shares after the offering. Following Hunt-McCool et al. (1996), we hypothesize that the retention ratio proxies for insider information possessed by owners of the privately-held firm, and that previous owners with positive information will retain a larger percentage of the shares than those with negative information. Thus, we expect a positive relation between the retention ratio and firm value.

Hunt-McCool et al. (1996) used firm age in their model, and found that it has a weak positive relation with the offer price. Because this data is easy for us to obtain, we also include it in our model. However, we are not certain, a-priori, what the directional relation should be theoretically between firm age and total market value. On the one hand, an older firm that has survived for a long time might be less risky and easier to value, implying a positive relationship with firm value. Another interpretation, though, could be that a firm that has existed for a long time without going public is (ceteris paribus) less exciting and has a lower upside than a younger firm, which would imply a negative relation between age and value.

In light of the importance of corporate governance for post-IPO performance (Chahine and Goergen, 2013, 2014), another variable that we believe could affect firm value is post-IPO insider ownership of shares, where insiders for this purpose are defined as officers and directors of the firm after it has gone public. We hypothesize that greater post-IPO insider ownership as a percentage of total shares outstanding after the IPO, as revealed in the prospectus, is associated with closer future alignment between management and outside stockholders and thus higher firm value at the time of the offering.[6]

Following both Hunt-McCool et al. (1996) and Koop and Li (2001), we include industry controls in our model, whereby membership in certain industry groups may signal additional firm value. Consequently, we include the following industry dummy variables (which equal 1 if a firm is a member of the given industry based on primary SIC code and 0 otherwise): Chemicals, Oil and Gas (144 IPOs in our sample), Computer-related (412 IPOs), Electronics (112 IPOs), Health Care and Scientific (99 IPOs), Communications (72 IPOs) and Retail (59 IPOs). A total of 222 IPOs did not belong to any of these industry groups. In addition, we include three year dummies in our model to indicate Dot-com bubble period (Boom), Dot-com bubble crashing period (Crash), and the latest financial crisis period (Fincris) respectively, which equals 1 if the IPO filing date was in the corresponding period and 0 otherwise, so as to control for the possibility that investors valued stocks in general more highly or lowly during these periods.[7]

By using the shortfall from the frontier, i.e., the difference between the market value of a firm and its predicted optimal market value, the factors associated with the underpricing are determined. Our model for investigating determinants of IPO underpricing is:

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[6] We should note that while the retention ratio defined earlier appears to be very similar to post-IPO insider ownership, in actuality the former focuses on continued ownership by previous shareholders when the firm was private, while the latter focuses on future ownership by officers and directors after the firm goes public. These groups are not necessarily the same, as evidenced by the low correlation (less than 0.2) at the firm level between the two variables in our sample.

[7] Following Aggarwal, Bhagat and Rangan (2009), Dot-com bubble period is from January 1999 to March 2000, while Dot-com bubble crashing period is from April 2000 to December 2001. The latest financial crisis period is from July 2008 to December 2010.

$$u_i = d_0 + d_1(Underwriter\ Rank_i) + d_2(NBERUp_i) + d_3(HOT_i) + d_4(Venture\ Capital_i) + \omega_i. \quad (9)$$

The economic intuition and predicted signs of determinants are discussed next. In early literature, researchers argue that mispricing is mainly due to the fundamental risk of issuing firms Ibbotson (1975) and the problem of information asymmetry (Benveniste and Wilhelm, 1990; Chemmanur, 1993; Welch, 1989, 1992; Habib and Ljungqvist, 2001), and predict that underpricing is positively related to uncertainty due to the degree of firms' fundamental risk and/or asymmetric information. Both Carter and Manaster (1990) and Carter, Dark and Singh (1998) provide evidence that IPOs managed by more reputable underwriters are associated with less underpricing. Since Carter and Manaster (1990) argue that the prestige of underwriters selected by issuing firms can reveal their riskiness to the market, i.e., the higher the prestige of underwriters they choose, the lower the probability they will fail, and the less likely they are to be undervalued at the time of offering. In this study, the prestige of underwriters is represented by a ranking, scaled from 0 to 9.[8]

As for the remaining underpricing variables, following Koop and Li (2001) we include an Up dummy variable which equals 1 if the issue date of the IPO is outside the range of dates in which the U.S. economy is classified as being in a recession by the National Bureau of Economic Research (NBER) and 0 if the issue date is during a recession. Choe, Masulis and Nanda (1993) argue that adverse selection issues are mitigated when more promising conditions for new investment exist; consequently we expect less underpricing when the economy is in an upswing and hence a negative coefficient on the NBER Up dummy. As suggested by Ritter (1984), a HOT index is also included to control for the hot market effect. Following Banerjee, Dai and Shrestha (2011), the HOT index is computed as the ratio of the number of IPOs in a specific year over the total number of IPOs during the sample period. As argued by Ritter (1984), Ljungqvist et al. (2006) and Banerjee et al. (2011), the expected sign of the HOT index is positive — that is, we expect greater underpricing in hot issue periods. Finally, we include a Venture Capital dummy variable which equals 1 if our reading of the prospectus indicates any backing by a known venture capital firm and 0 otherwise. A-priori, we expect venture capital investors to maximize their returns and hold

[8] Carter and Manaster (1990) and Carter et al. (1998) proposed the particular methodology of ranking underwriters. Loughran and Ritter (2004) updated the rankings for 1992-2003 using their methodology and Jay R. Ritter maintains an updated post-2003 database of these rankings, which is post in his website: http://bear.warrington.ufl.edu/ ritter/ipodata.htm.

out for a higher IPO offer price; consequently we expect less underpricing with venture capital involvement and a negative coefficient on the Venture Capital dummy.

4. Data

The primary IPO data over the 1999 to 2010 period is collected from the "Firm Database of Emerging Growth Initial Public Offerings (IPOs) from 1990 through 2010" which are provided by Martin Kenney and Donald Patton. Emerging Growth in this database refers to the firms that are newly established or not based on older firms by being a spinoff or subsidiary operation. Particularly, the emerging growth status was established by checking the prospectus, particularly in the prospectus summary where the firm describes its activities, history, and business.[9] There are 1369 Emerging Growth IPOs in the US from 1999 to 2010. Besides general company information, this dataset contains the basic issuing information for each IPO, such as shares offered, total shares outstanding after the offering, initial offer price and underwriter discount, such that the initial market value of issuing firms, the age of issuing firms and underwriters compensation and commission rates can be computed accordingly. Other financial data of issuing firms, including total assets, total long-term debt and R&D expenditure in the fiscal year prior to the IPOs, is collected from the Compustat database. In addition, insider ownership before and after the offering and underwriter names are manually collected from firms' prospectuses, which are found on the SEC's EDGAR database. The rankings of underwriters are determined according to IPO Underwriter Reputation Rankings (1980-2014) collected from Jay R. Ritter's database.

Similar to previous literature (e.g., Loughran and Ritter, 2004), the following criteria are imposed to obtain the final sample: (1) the initial offer price should exceed \$5, which leads to the exclusion of 2 firms from the database; (2) 109

[9] The guidelines employed to determine whether a firm is emerging growth are as follows: 1. Companies that are partnerships, such as an oil pipeline company, are considered emerging growth unless the partnership was formed by another company. 2. Companies that are the product of a merger are considered emerging growth if they have had some history of operation prior to the IPO. Similarly, companies that have made acquisitions of other firms are considered emerging growth unless the company is simply a product of acquisitions assembled for the purpose of going public. 3. Companies that are simply reorganizations of existing firms are not considered emerging growth. 4. Companies that at some point in their history were a division of another firm are not considered emerging growth. Basically, any firm that originated as a new, independent entity and remained independent throughout its history is considered as an emerging growth firm.

financial firms and 2 unit offerings are excluded[10]; (3) because of missing insider ownership information, 12 firms are excluded; (4) 5 firms are excluded since the underwriter ranking is zero or unavailable. Finally, accounting data should be available for the issuing firms in the year prior to the offering. In particular, accounting information for 119 firms was wholly or partially unavailable in the Compustat database. This lack of availability of either total assets, total debt or R&D expense in the fiscal year prior to the IPO further reduces the number of IPO firms in our study to 1120, around 18.2% attrition from the original sample size.

Table 1: Descriptive Statistic of IPO Characteristics

	Mean	STD	Minimum	$Q1$	Median	$Q3$	Maximum
Panel A: Firm Characteristics							
Q ($ Millions)	481.70	677.47	13.20	195.48	311.99	534.38	11975.50
Total Assets ($ Millions)	162.98	573.05	0.09	14.84	31.68	94.88	9436.50
Total Debt ($ Millions)	79.42	335.40	0.00	0.19	2.95	19.75	6329.40
R&D Expense ($ Millions)	9.15	16.30	0.00	2.05	5.22	10.91	339.34
Commission Rate	0.07	0.01	0.03	0.07	0.07	0.07	0.10
Retention Ratio	0.75	0.12	0.05	0.70	0.76	0.82	0.98
Age	11.08	15.34	0.00	4.00	7.00	11.00	138.00
Post-IPO Insider Ownership (%)	44.26	20.20	0.00	30.65	44.70	59.35	98.30
Panel B: Determinants of Underpricing							
Underwriter Rank	8.28	1.26	1.00	8.00	9.00	9.00	9.00
Up Dummy	0.95	0.23	0.00	1.00	1.00	1.00	1.00
HOT Index	0.16	0.10	0.01	0.09	0.20	0.28	0.28
Venture Capital Dummy	0.62	0.49	0.00	0.00	1.00	1.00	1.00

Notes: Q is the a-priori market value of the firm, defined as the offer price × total number of outstanding shares after the offering. Total Assets, total debt and r&d expense are for the last fiscal year prior to the offer date. The commission rate is computed as underwriter compensation/(offer price × shares offered in IPO). The retention ratio is defined as (1 - shares offered in IPO/total number of outstanding shares after the offering), and post-IPO insider ownership is defined as projected number of shares held by officers and directors after IPO is completed (as indicated in the prospectus)/total number of outstanding shares after the offering. The underwriter rank is determined according to IPO Underwriter Reputation Rankings (1980-2014) collected from Jay R. Ritter's database. The up dummy is defined as 1 if the U.S. economy is not in recession on the offer date and 0 otherwise. The HOT index is computed as the ratio of the number of IPOs in a specific year over the total number of IPOs during the sample period. The venture capital dummy equals 1 if our reading of the prospectus indicates any backing by a known venture capital firm and 0 otherwise.

[10] After applying criteria (1) & (2), there are 1256 firms in our sample, i.e., 1256 non-financial de novo IPOs with offer price no less than $5 during 1999-2010. By exploring Dr. Jay Ritter's database, we find that there are 1865 non-financial IPOs with offer price no less than $5 during the same period. Thus, during 1999-2010, around 68.8% IPOs are de novo IPOs.

In our model, the dependent variable of the frontier model is the total market value of firms' common equity, *Q*, which is computed as the product of the initial offer price and a firms' total outstanding shares after offering. As shown in panel A of Table 1, the market value of firms' common equity *Q* is right-skewed, and the mean and median are $482 million and $312 million respectively. Similar to *Q*, firms' total assets and total debt are also right-skewed. In particular, the median and 3rd quartile of firms' total assets (debt) in the fiscal year prior to offering are, $32 ($3) million and $95 ($20) million, respectively, whereas the mean is $163 ($79) million. Clearly, in our sample, more than 75% non-financial de novo firms are small firms, and the average firm size is driven by less than 25% of large firms. Given the right-skewed distribution of firm size, it is very natural to expect that large firms also drives the mean of R&D expenditure. Consistent with our expectation, the mean of R&D expenditure is $9 million, but the median is only $5 million.

To a lesser extent, firm age is also right-skewed, with a mean and median of 11 years and 7 years, respectively. However, the remaining firm characteristic variables, i.e. the commission rate, retention ratio and post-IPO insider ownership, exhibit little evidence of skewness given that the means and medians of these variables are all close to each other. Specifically, a typical firm pays 7% of the proceeds to the underwriters which is basically the same as what reported by Dr. Jay Ritter. As measurements of asymmetry information problem, the retention ratio and insider ownership after the offering of a typical firm are 75% and 44% respectively.

Panel B of Table 1 reports the descriptive statistics of the determinants of the underpricing in IPOs. Specifically, underwriters' reputation is represented by a ranking which is on a 1 to 9 scale. In this study, if some sample firms have multiple underwriters or multiple lead underwriters, their rank is determined by the rank of the bookrunner or the highest-ranking joint book-runner. Accordingly, an average firm has an underwriter ranking of 8.25, i.e., a typical firm employs an underwriter ranking 8 or 9 at the offering. The mean of the Up Dummy indicates that 95% of IPOs took place when the U.S. economy was not in recession. Similarly, the mean for the Venture

Capital Dummy indicates that 62% of the IPOs in our sample have some venture capital backing. Finally and not unexpectedly, given how the Hot Index is constructed, the descriptive statistics for this variable are consistent with the notion that a disproportionate number of IPOs in our sample occur in years in which the Hot Index is high. Further information on this relation is provided in Table 4.

5. Empirical Analysis

The frontier model specified in Equation (8) and Equation (9) is estimated by using the FRONTIER Version 4.1 software.[11] Table 2 reports the estimates for the whole sample consisting of 1,120 nonfinancial de novo IPOs from 1999 to 2010. Specifically, panel A presents the estimates for the market value frontier given in Equation (8); panel B presents the estimates of coefficients corresponding to the determinants of underpricing given in Equation (9); and panel C presents diagnostic statistics for the model. In panel C, the likelihood ratio statistic rejects the null hypothesis that $u = 0$.[12]

From panel A, we note that the coefficient estimate for the log of total assets is positive and highly significant, which is consistent with our expectation that a firm's market value is positively related to the book value of its assets. The same as total assets, the log of debt is found to be positively related to market value in our model at 10% level of significance. As we discussed before, the firms we study in this paper are emerging growth firm, and most of them are young firms. The level of debt plays two possible roles in valuing firms. On the one hand, it is employed as the proxy for operating risks, as other studies did, which negatively affects the valuation of firms; on the other hand, it implicates growth potential believed by the lenders which tends to positively affect the valuation of firms. Thus, the positive coefficient estimate for the debt indicates that the latter effect dominates, i.e., the log of total long-term debt plays positive role in firm valuation. Another proxy for the growth potential, R&D expenditure, is also positively related with firm value, although it is insignificant.

In accordance with expectations, there is a strong and highly statistically significant inverse relation between the commission rate paid to the underwriter(s) and market value. Because the commission rate may proxy for valuation risk, this finding is consistent with the idea that firms with greater valuation risk have lower

[11] The software was downloaded from Center for Efficiency and Productivity Analysis, i.e., http://www.uq.edu. au/economics/cepa/software.php.

[12] According to Battese and Coelli (1993), the *LR* test statistic has a mixed chi-square distribution with the number of degrees of freedom equal to the number of parameters assumed to be zero. In this study, the restrictions are $\gamma = 0$ and $d_i = 0$ *for* $i \in \{0, 1, 2, 3, 4\}$, where γ is defined in footnote 2. Thus, the number of degrees of freedom of the *LR* test is 6. The likelihood ratio listed in the panel C of Table 2 suggests that the one-sided error term is statistically different from zero and there exists underpricing in our sample firms during 1999-2010.

Table 2: Stochastic Market Value Frontier Model Estimates

	Estimates	Standard Error	t-statistic
Panel A: Firm Characteristics			
Constant	10.720***	0.318	33.718
ln(Total Assets)	0.232***	0.015	15.011
ln(Total Debt)	0.009*	0.005	1.849
ln(R&D Expense)	0.001	0.005	0.246
Commission Rate (%)	-31.337***	3.392	-9.238
Retention Ratio (%)	2.789***	0.167	16.725
ln(Age)	-0.105***	0.024	-4.419
Post-IPO Insider Ownership (%)	0.001	0.001	1.287
Chemicals, Oil and Gas	-0.107*	0.063	-1.710
Computers	0.045	0.049	0.918
Electronics	0.123*	0.068	1.810
Health and Scientific	-0.086	0.069	-1.248
Communications	0.207***	0.077	2.677
Retail	-0.021	0.083	-0.247
Boom	0.228**	0.097	2.357
Crash	0.087	0.067	1.299
Financial Crisis	0.024	0.079	0.309
Panel B: Determinants of Underpricing			
Constant	1.991***	0.163	12.228
Underwriter Rank	-0.186***	0.015	-12.245
Up Dummy	-0.235***	0.082	-2.877
Hot Index	0.904*	0.493	1.832
Venture Capital Dummy	0.030	0.038	0.788
Panel C: Diagnostics			
LR Test of u = 0 (χ^2)			150.396***
Sigma-squared	0.267***	0.011	23.427
Gamma	0.0001	0.035	0.003
# of Firms	1120		

Note: Sigma-squared is the variance of disturbance term in frontier model, i.e., σ_E^2, which equals the sum of σ_v^2 and σ_u^2 because $\varepsilon_{\mathrm{t}} = v_i - u_{\mathrm{a}}$ and $\mathrm{cov}(v_i, u_1) = 0$. Gamms is the ratio of σ_{w}^2 to σ_{E}^2, i.e., $\gamma = \sigma_u^2/\sigma_{\mathrm{s}}^2$. * ** and *** denote that the corresponding parameters are significant at the 10%, 5% and 1% levels respectively.

offering prices, given other things equal. Another variable that is found to strongly impact a firm's market value is the retention ratio, essentially defined as the proportion of shares kept by the original owners of the firm immediately after the firm goes public. Indeed, based on the t-statistic, this is the single most important firm characteristic in the entire model and indicates that the signal sent by former shareholders that they are willing to retain a larger proportion of the shares after firm going public exerts a strong positive influence on the offer price (and by extension, the market value based on the offer price). In contrast, the proportion of post-IPO shares that will be held by officers and directors, while as expected positively associated with market value, is not quite statistically significant.

Panel A in Table 2 also reveals a negative association between firm age and market value, indicating that the longer the time that has elapsed between a firm's

founding and its going public, the lower its market value. The only interpretation we can offer is that the negative signal offered by advanced age (the firm is unexciting and has less upside potential) outweighs the positive signal (the firm is stable and has lower risk). The coefficients on the industry dummies in panel A indicate that firms in the communications or electronics industry were associated with significantly higher market value during our sample period, while the firms in the chemical or oil and gas industry had lower market values, ceteris paribus. Finally, relative to the IPOs issued during January 2002-June 2008, the positive and significant coefficient on the *Boom* dummy indicates that investors were willing to pay more for the IPOs issued in the boom period of the Dot-com bubble, whereas the *Crash* and *Financial Crisis* dummies indicates that investors did not exhibit higher or lower passion on the IPOs issued in these two periods.

Panel B of Table 2 reveals that, as expected, the coefficient of underwriter rank is negative and highly significant, showing that higher underwriter reputation results in less underpricing in IPOs. Similarly, in accordance with expectations, the negative coefficient on the *Up* Dummy indicates that IPOs that issued when the U.S. economy is not in recession are associated with less underpricing. However, contrary to expectations, the positive and significant coefficient on the *Hot* Index indicates that underpricing appears to actually be greater (ceteris paribus) in hot new issue markets, and we find no statistically significant relation between venture capital backing and underpricing.

To shed further light on whether coefficient estimates are stable over time, we next divide our sample of 1,120 IPOs into four subperiods based on offer date. The four subsamples we chose are the Dot-com bubble period (Boom), the Dot-com bubble crashing period (Crash), pre-financial crisis period (After Crash), and the latest financial crisis period and its immediate aftermath (Financial Crisis).[13]

The subperiod estimation results are reported in Table 3. As in Table 2, coefficient estimates on firm characteristics are reported in panel A, coefficients on underpricing determinants are in panel B, and model diagnostics are in panel C. The Up Dummy is omitted for the Dot-com bubble boom period because the U.S. economy was not in a recession at any point during these years. The likelihood ratio tests for all four subperiods reject the null hypothesis, indicating that there is a statistically significant underpricing in all of them. For the firm valuation part,

[13] Following Aggarwal et al. (2009), Dot-com bubble period is from January 1999 to March 2000, while Dot-com bubble crashing period from is April 2000 to December 2001. Pre-financial crisis period is from January 2002 to June 2008. The latest financial crisis period and its immediate aftermath is from July 2008 to December 2010.

Table 3: Stochastic Market Value Frontier Model Estimates, by Subsample

	Boom		Crash		After Crash		Financial Crisis	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Panel A: Firm Characteristics								
Constant	11.739***	38.442	10.370***	7.355	10.215***	26.045	11.809***	29.349
ln(Total Assets)	0.152***	6.603	0.265***	2.536	0.330***	13.570	0.350***	14.089
ln(Total Debt)	0.003	0.410	0.011	0.832	-0.007	-1.071	-0.026**	-2.109
ln(R&D Expense)	0.004	0.475	0.007	0.459	-0.009	-1.247	0.032*	1.941
Commission Rate (%)	-42.808***	-42.927	-24.585***	-4.609	-38.616***	-7.792	-59.849***	-60.334
Retention Ratio (%)	3.573***	13.227	2.446***	5.454	2.251***	9.868	2.889***	7.995
ln(Age)	-0.207***	-4.965	-0.195***	-2.836	-0.012	-0.379	-0.090	-1.059
Post-IPO Insider Ownership (%)	0.193	1.381	-0.194	-0.819	0.319***	2.742	0.126	0.343
Chemicals, Oil and Gas	-0.073	-0.397	-0.204	-1.190	0.041	0.492	-0.168	-0.783
Computers	0.166***	3.240	-0.056	-0.331	0.127	1.766	-0.194	-1.185
Electronics	0.242**	2.552	0.098	0.497	0.214*	1.929	0.279	1.262
Health and Scientific	0.191	1.053	-0.070	-0.347	0.060	0.715	-0.244	-0.707
Communications	0.503***	5.369	0.408	1.445	0.083	0.659	-0.149	-1.470
Retail	0.248**	2.362	0.269	0.377	-0.369***	-3.089	0.378	1.485
Panel B: Determinants of Underpricing								
Constant	-0.427	-1.164	3.218***	6.532	1.581***	14.037	-2.168**	-2.193
Underwriter Rank	-0.133***	-40.024	-0.320***	-5.515	-0.167***	-8.722	0.057	0.531
Up Dummy			-0.259	-0.804	-0.147	-1.664	1.809***	4.714
Hot	6.385***	14.383	0.354	0.092	1.670***	9.799	0.616	0.602
Venture Capital Dummy	0.092***	3.495	-0.406*	-1.884	0.042	0.859	0.538	1.714
Panel C: Diagnostics								
LR test of u=0 (χ^2)		64.755***		49.332***		76.427***		36.435***
Sigma-squared	0.226***	14.906	0.254***	5.029	0.210***	15.579	0.176**	1.960
Gamma	0.004***	2.789	0.006	0.045	0.000	0.002	1.000***	3748.701
Number of firms	415		202		445		58	

Note: Following Aggarwal et al. (2009), Dot-com bubble period is from January 1999 to March 2000, while Dot-com bubble crashing period from is A pril 2000 to December 2001. Pre-financial crisis period is from January 2002 to June 2008. The latest financial crisis period is from July 2008 to December 2010. Sigma-squared is the variance of disturbance term in frontier model, i.e, σ_ϵ^2, which equals the sum of σ_v^2 and σ_u^2 because $\varepsilon_i = v_i - u_i$ and $cov(v_i, u_i) = 0$. Gamma is the ratio of σ_u^2 to σ_ϵ^2, i.e., $\gamma = \sigma_\epsilon^2/\sigma_\epsilon^2$. *, ** and *** denote that the corresponding parameters are significant at the 10%, 5% and 1% levels respectively.

i.e., panel A of Table 3, while it is similar to the panel A of Table 2 for each period, we nevertheless urge caution in following places. Firstly, to interpret the estimated coefficient for the whole sample, we provide two effects of total debt on firm valuation, i.e., a positive effect due to the lenders' beliefs on firms' growth potential and a negative effect due to operating risk, and we find the positive effect dominates for the whole sample estimation. Opposite to the estimates of the whole sample and the Dot-com bubble (both boom and crash) periods, the coefficients of total debt for the *After Crash* and *Financial Crisis* period are negative, and it is insignificant for the former period but significant for the latter period. This indicates that the negative effect dominates after the Dot-com bubble period. Secondly, the coefficient of R&D expenditure is negative for *After Crash* period which is contrasted to that for the whole sample and the rest subperiods, but it is insignificant which is consistent with the whole sample estimation. Thirdly, some industry dummies don't affect firms' valuation in the same way as they exhibiting in the whole sample estimation, but their effects are insignificant.

For the shortfall part, i.e., panel B of Table 3, the determinants of underpricing work in a similar way for the whole sample period and the first three subperiods, except for the venture capital dummy for Dot-com bubble crashing period. In particular, venture capital increases the level of IPOs underpricing in Dot-com bubble booming period but decreases the underpricing during January 2002 to June 2008. Our explanation for the opposite results is the venture capitals may admit some underpricing to benefit the underwriters so that the IPOs issued smoothly, since they can enjoy a valuation bonus in Dot-com bubble booming period that largely vanishes in later periods which is captured by the period dummies in Table 2. Moreover, in comparing the *Financial Crisis* period and the first three subperiods, two differences stand out. Firstly, contrary to our prediction, the underwriter rank increases the level of IPOs underpricing, although its effect is insignificant. Secondly, the IPOs are underpriced even more when economy in upturn after July 2008. Putting them all together, we conjecture that mechanism of firm valuation and the determination of IPOs underpricing are change somehow as the outbreak of latest financial crisis.[14]

[14] The reason that we employ "conjecture" here, instead of "conclude", is that there are only 58 observations in the post-financial crisis period in this paper. Thus, the number of observations is too small to make a solid conclusion.

5.1. Underpricing Estimates

The underpricing of the firm *i* given in Equation (7) is computed for all firms in our sample. Descriptive statistics for the underpricing estimates for the whole sample and for each year are reported in Table 4. The means are the simple averages.

Table 4: Descriptive Statistics of Underpricing Estimates

	# of Firms	Mean	SD	Minimum	Q1	Median	Q3	Maximum
All Firms	1120	0.305	0.137	0.0841	0.229	0.297	0.379	0.843
Year								
1999	332	0.372	0.114	0.283	0.304	0.304	0.422	0.843
2000	244	0.303	0.100	0.229	0.252	0.252	0.379	0.797
2001	46	0.300	0.135	0.110	0.262	0.297	0.387	0.610
2002	36	0.190	0.114	0.103	0.103	0.117	0.278	0.382
2003	38	0.238	0.144	0.106	0.106	0.196	0.280	0.576
2004	100	0.260	0.145	0.150	0.163	0.175	0.315	0.809
2005	89	0.302	0.163	0.153	0.153	0.297	0.416	0.809
2006	93	0.266	0.135	0.148	0.148	0.174	0.314	0.665
2007	79	0.291	0.164	0.129	0.155	0.299	0.332	0.813
2008	8	0.315	0.075	0.274	0.285	0.295	0.295	0.500
2009	14	0.180	0.108	0.084	0.111	0.111	0.276	0.369
2010	41	0.204	0.122	0.104	0.131	0.131	0.256	0.757

Note: The firm level underpricing estimates summarized in this table are those resulting from the stochastic frontier model estimated for the entire 1999 - 2010 sample.

From Table 4, we note that our findings indicate the market values of firms are underpriced by a huge amount: the offer price falls 30.5% short of its optimal value on average, and the range of the underpricing is from 8.4% to 84.3% of the optimal value, indicating that even in the best cases there is substantial underpricing based on ex-ante data. Further, we note that, on average, the IPOs in 1999 exhibited the most underpricing while IPOs in 2009 demonstrated the least underpricing, i.e. 37.2% and 18.0% of their optimal values respectively. Moreover, as we reported in Table 4, right after the bust of Dot-com bubble and the emergence of the latest financial crisis, the average level of IPOs underpricing declines drastically from a local peak of underpricing level, i.e., in 2002 and 2009, the level of IPOs underpricing declines drastically to from 37.2% to 19% and 31.5% to 18% respectively. A similar trend is also detected by Ritter (2014), whose IPOs underpricing is calculated by equal-weighted and proceeds-weighted average first-day return. In addition, we find that the estimated underprices are

symmetrically distributed for the whole sample period,[15] but that is not the case if we observe them year by year, i.e., only the estimated underprices in 2001, 2005 and 2007 are distributed symmetrically, while that in the rest of years are right-skewed. Except in 2001, 2005 and 2007, the mean underpricing level is driven by large underpricing in the corresponding year.

The mean underpricing that we find is much greater than those have been reported in previous studies using the stochastic frontier approach: Hunt-McCool et al. (1996) report average underpricing of about 8∼9%, while Koop and Li (2001) report that IPO firms in their sample are 25∼30% underpriced on average. We believe there are several factors that explain this large discrepancy in results. First, the sample periods of these studies are completely different (i.e. they do not overlap),[16] and other measures of underpricing based on first day returns also show greater under- pricing during our sample period. Ritter (2014) provides both the number of IPOs, and average underpricing based on first day aftermarket returns, in each year between 1980 and 2016. Using equally-weighted underpricing each year, and weighting each year by issue volume, we calculate average aftermarket underpricing of 12.8% over the 1985 - 1998 period (the sample period used by Koop and Li (2001)) versus 35.8% during our 1999 - 2010 sample period - most of this difference is driven by hugely elevated first-day returns, relative to historical norms, in 1999 and 2000, which is roughly consistent with our finding in Table 4 that underpricing is highest, on average, during those years. As noted previously, another reason we would expect to find greater underpricing in our study is that we focus exclusively on emerging growth, de-novo IPOs (which are likely to be more difficult to value and exhibit greater underpricing); the two earlier studies included spinoffs and reorganizations of existing firms. As we will explain in more detail in the next section, this difference in the composition of our sample can account for a further 7.7% difference in first-day aftermarket returns. Finally, there are subtle but possibly crucial methodological differences that may also contribute to our finding of greater underpricing. Hunt-McCool et al. (1996) use the offer price per share as the dependent variable, even though accounting-based independent variables in their model appear to be specified in an aggregated (rather than on a per share) basis. In our opinion, this choice may render their conclusions suspect. Because, generally, we expect that the market value of a firm is significantly related to its

[15] The definition of "symmetrical distributed" here is that the difference between mean underpricing and median underpricing is less than 1%.

[16] The sample period of Hunt-McCool et al. (1996) is from 1975 to 1984, while that of Koop and Li (2001) is from 1985 to 1998.

book value, or market price per share is related to its book value per share, but not expect a relationship between price per share and aggregate value. While Koop and Li (2001), similar to our study, do use *Q* (the product of the offer price and the total number of shares outstanding after the IPO) as their dependent variable, one of their independent variables is the total fees paid by the issuing firm to the underwriters. Since the total fees paid will be primarily determined by the size of the offering, which in turn is closely related to the dependent variable *Q*, we believe the primary direction of causation in Koop and Li (2001)'s model runs from the market value to fees paid, raising substantial statistical bias issues.[17] We get around this problem by using the commission rate, in place of total fees, to proxy for the valuation risk of the firm, and thus believe that inferences from our model are more reliable.

5.2. Relations between Ex-Ante Underpricing and First Day Returns

Subsequent to our estimation of the efficient frontier model solely using ex-ante data, we obtained aftermarket stock price data for each IPO in our sample.[18] The aftermarket stock price data is from the Center for Research in Security Prices (CRSP). We calculate a first day return as: (close price/offer price)-1. The first day return is a commonly used traditional measure of ex-post underpricing.

Descriptive statistics for the aftermarket first day returns for our entire sample and by year are provided in Table 5. We note that the mean ex-ante underpricing generated by our stochastic frontier model for all years is 30.5%, which is 13% lower than the mean first day return, i.e., 43.5%. Moreover, the distributions of estimated ex-ante underpricing and the ex-post returns are very different as well. We note that the standard deviation of the first day returns is considerably larger, both for the entire sample combined and for each individual year: there are numerous instances of negative first day returns, and also many instances of extremely high first day returns, particularly in 1999 and 2000. Another noteworthy aspect of the results arises from comparing our overall 43.5% mean first day return to the 35.8% mean first day return over the years 1999 - 2010 (weighting each year by issue volume) in Ritter's (2014) broader IPO database. Since the main difference in the composition of the samples is that we exclude spinoffs and reorganizations, the implication is that our focus on de-novo IPOs likely results in mean first day returns that are 7.7% higher.

[17] It is noteworthy that the t-statistic on the fees coefficient reported by (Koop and Li, 2001, Table 5) appears to be around 75.

[18] We were unable to obtain this data for 2 firms.

Table 5: Descriptive Statistics of Aftermarket First Day Returns

	# of Firms	Mean	SD	Minimum	Q1	Median	Q3	Maximum
All Years	1120	0.435	0.742	-0.746	0.012	0.171	0.511	6.975
Year								
1999	332	0.761	0.984	-0.746	0.060	0.440	1.112	6.975
2000	244	0.657	0.861	-0.278	0.051	0.346	1.000	5.075
2001	46	0.170	0.190	-0.136	0.017	0.146	0.305	0.767
2002	36	0.110	0.168	-0.331	0.013	0.115	0.162	0.667
2003	38	0.156	0.161	-0.155	0.039	0.132	0.285	0.471
2004	100	0.145	0.179	-0.110	0.001	0.092	0.244	0.657
2005	89	0.105	0.176	-0.125	-0.001	0.061	0.168	0.946
2006	93	0.121	0.175	-0.295	0.005	0.085	0.176	0.777
2007	79	0.178	0.244	-0.197	0.000	0.115	0.308	0.972
2008	8	0.116	0.247	-0.199	-0.053	0.072	0.257	0.575
2009	14	0.173	0.201	-0.127	0.004	0.135	0.251	0.595
2010	41	0.109	0.151	-0.108	0.000	0.050	0.162	0.553

Note: the first day return for each firm is calculated as (close price/offer price)-1.

We next examine the statistical relations at the firm level between the ex-post first day returns and the estimates of ex-ante underpricing provided by our model. If the traditional interpretation that the positive first day returns in IPOs are due to deliberate underpricing is correct, then we would expect a significant positive relation at the firm level between the model-based estimate of the underpricing and the first day return. The time series of yearly average ex-ante underpricing provided by our model and yearly average ex-post underpricing measured by the first day return are reported in Table 4 and Table 5 respectively. We find that the correlation coefficient of them is 0.59.[19] Hunt-McCool et al. (1996), for their 1975-1984 sample, do find a significant positive relation between ex-ante underpricing and first day return. However, they also report a very low R^2 from their regression, and when they segregate their sample into hot and non-hot issue periods they find that the significant positive relation exists only during the hot periods.

To investigate the relationship between the ex-ante underpricing provided by our model and the first day return in further step, we matched our predicted underpricing and the first day return for each IPO in our sample to estimate

[19] The correlation coefficient reported above is computed based on the equal-weighted average underpricing. The correlation coefficient based on the proceeds-weighted average underpricing is computed as well, which is 0.75.

Equation (10) whose result is reported in Table 6. In particular, Equation (10) is defined as:

$$FDRET_i = \beta_0 + \beta_1 UDPR_i + e_i, \quad (10)$$

where $FDRET_i$ is the first day return for firm i, $UDPR_i$ is the ex-ante estimate of underpricing of firm i based on our stochastic frontier model.

Table 6: OLS Estimates of IPO First Day Returns as a Function of Underpricing

	(1) full1	(2) full2	(3) boom	(4) crash	(5) after boom	(6) financial crisis
UDPR	0.054	-0.719***	-1.951***	-0.711***	-0.148**	-0.228**
	(0.162)	(0.161)	(0.427)	(0.340)	(0.061)	(0.191)
2000_yr		-0.153***	0.254*			
		(0.058)	(0.124)			
2001_yr		-0.642***		-0.243***		
		(0.107)		(0.083)		
2002_yr		-0.782***				
		(0.123)				
2003_yr		-0.702***			0.053*	
		(0.118)			(0.044)	
2004_yr		-0.696***			0.045*	
		(0.080)			(0.037)	
2005_yr		-0.706***			0.011	
		(0.082)			(0.038)	
2006_yr		-0.716***			0.022	
		(0.081)			(0.037)	
2007_yr		-0.641***			0.083*	
		(0.086)			(0.038)	
2008_yr		-0.686***			0.107	
		(0.243)			(0.090)	
2009_yr		-0.726***				0.167
		(0.188)				(0.107)
2010_yr		-0.773***				0.108
		(0.116)				(0.100)
Constant	0.419***	1.028***	1.487***	0.627***	0.138***	0.047
	(0.054)	(0.071)	(0.168)	(0.108)	(0.034)	(0.110)
Observations	1120	1120	415	207	440	58
R-squared	0.000	0.171	0.068	0.060	0.033	0.088

Notes: FDRETi = first day return for firm *i*, UDPRi = ex-ante estimate of underpricing of firm *i* based on stochastic frontier model, ## yr = year dummy, ## is the year which equals from 2000 to 2010. Following Aggarwal et al. (2009), Dot-com bubble period is January 1999 to March 2000; Dot-com bubble crashing period is April 2000 to December 2001; after Dot-com bubble period is January 2001 to June 2008; and the latest financial crisis period is from July 2008 to December 2010. *, ** and *** denote that the corresponding parameters are significant at the 10%, 5% and 1% levels respectively.

The estimation result of entire sample is reported in the first and second column of Table 6. According to the estimated coefficient of *UDPR* reported in the first column, it seems that our predicted underpricing is positively related with the first day return although it is insignificant, which is the same as what have been reported in Hunt-McCool et al. (1996). However, when year fixed effect is added into the model, we find a significantly negative relation between our predicted underpricing and the first day return, which is inconsistent with our expectation and the conclusion in previous study. The coefficients of year dummies in column (2), on the contrary, are consistent with our expectation that the first day return for the IPOs issued after 1999 is less than those issued in 1999. The R^2 for the model in column (2) is significantly higher than that in column (1), i.e., 0.17 vs 0. Thus, we doubt that the year effect is not negligible when we study the relationship between ex-ante underpricing and the first day return.

To check the robustness of our estimation, we divided the sample into four groups, i.e., Dot-com bubble period, Dot-com bubble crashing period, after Dot-com period and the latest financial crisis period.[20] The estimation results of the subsamples are reported in the column (3) - (6) of Table 6. We note that although the estimated coefficient of *UDPR* is not significant for the latest financial crisis period, it is negative for all four groups which is the same as the whole sample estimation result reported in column (2). The coefficients of year dummies for four groups are consistent with our expectation as well. Based on the estimated coefficients of *UDPR* in Table 6, we don't think the first day return of IPOs is a proper ex-post measurement of underpricing, otherwise the ex-ante underpricing and the ex-post one should consistently exhibit a positive relationship. Moreover, based on the estimated coefficients of year dummies in Table 6, we conjecture that, except for firms' individual features, the determinants of IPOs' first day return are those factors with significant yearly feature, like yearly GDP growth rate.

And HOT_i is the value of the hot index during the year of the IPO's offer date. We estimate Equation (10) for our entire sample and for each of three subsamples depending on offer date: January 1999 - December 2000, January 2001 - June 2008 and July 2008 - December 2010. Equation (11) is motivated by Hunt-

[20] Following Aggarwal et al. (2009), Dot-com bubble period is from January 1999 to March 2000; Dot-com bubble crashing period is from April 2000 to December 2001; after Dot-com bubble period is from January 2001 to June 2008; and the latest financial crisis period is from July 2008 to December 2010.

McCool et al. (1996)'s finding that the relation between first day returns and ex-ante undepricing differs based on the hotness of the market for new issues.

$$FDRET_i = \beta_0 + \beta_1 UDPR_i + \beta_2 HOT_i + \beta_3 (HOT_i \times UDPR_i) + e_i \quad (11)$$

The results of Equation (10) do show a positive coefficient on $FDRET_i$ for the full sample, but this relation is not statistically significant. Moreover, this result appears somewhat confounding because when we estimate model 10 for the three subsamples, the coefficient on $UDPR_i$ becomes negative and highly significant for the first two subsamples (IPOs issued Jan. 1999 - Dec. 2000 and Jan. 2001 - Jun. 2008), and remains negative (albeit insignificant) in the third. Taken together, the model 10 results indicate that a variable that is strongly associated with both the first day returns and ex-ante underpricing - and varies by subperiod - is missing from the model. Therefore, in light of the previously mentioned findings of (Hunt-McCool et al., 1996, Table 4), we also provide results for Equation (11) for the full sample. Equation (11) includes the hot index value related to the issue year of each IPO and an interaction effect between the hot index and the firm-level underpricing. These results show a marginally significant negative constant term, a positive but insignificant coefficient on $UDPR_i$, a hugely significant positive coefficient on HOT_i, and a hugely significant negative coefficient on $HOT_i \times UDPR_i$, the interaction effect. We interpret these results as follows: first day returns tend to be close to zero (or even negative on average) and there is no relation between first day return and ex-ante underpricing during the coolest periods (hot index close to zero). However, as the market for new issues heats up, average first day returns markedly increase, but they increase more for firms that show less ex-ante underpricing. In this respect our findings are the polar opposite of Hunt-McCool et al. (1996), because the negative coefficient on the interaction effect implies a negative relation between ex-ante underpricing and subsequent first day returns during hot new issue periods. We also note that the regression results for model 11 are consistent with our finding in Table 2 that there is more ex-ante underpricing as the hot index increases.

6. Conclusion

Following two earlier studies but using a different, non-overlapping sample period, this study estimates the magnitude of the underpricing in IPOs for 1,221 firms during the 1999-2010 period by constructing a market value stochastic frontier model. In particular, the value of a firm's under- pricing is estimated by the mean of the inefficiency term, the one-sided error term, conditional on the entire error.

Our stochastic market value frontier model estimates, for both our entire sample and for subsamples based on offer date, indicate that the most important positive ex-ante determinants of a firm's market value are the book value of its assets and the retention ratio. The latter is simply the portion of shares retained by the original owners immediately after the IPO is completed; a higher retention ratio apparently sends a strong signal to the market that the existing owners of the privately-held firm are optimistic regarding the firm's future prospects. We find that the most important negative determinant of market value is the commission rate paid to the underwriters. This finding is intriguing because the commission rate likely proxies for valuation risk, implying that firms with greater valuation risk have lower market values. In addition to estimating the market value frontier, we also investigate the determinants of underpricing in IPOs. Confirming previous studies, we show that the most important determinant is underwriter rank: the higher the underwriter rank, the lower the underpricing. Because firms with greater information asymmetry and greater valuation risk are likely to attract lower-ranked underwriters, these results are consistent with theoretical models hypothesizing that greater valuation risk is likely associated with greater deliberate underpricing.

We observe that the offering price of a new issue of an average firm with an initial public offering in the U.S. between 1999 and 2010 falls 39.7% short from its optimal value. While this estimate of ex-ante underpricing greatly exceeds those from two previous studies using a methodology similar to ours, it is consistent with much greater first day aftermarket returns during our sample period and also with the composition of our sample, which, unlike in the case of the two earlier studies, excludes spinoffs and reorganizations of existing publicly-traded firms. We show, however, that while the mean of the model-based, ex-ante underpricing in our sample is close to the mean of the first day aftermarket returns (43.5% for the firms in our sample), there is not a statistically significant positive relation at the firm level between the ex-ante underpricing and the first day return. If anything, taking into account the interaction between the hotness of the market for new issues and the model-based underpricing estimates, we find a negative association at the firm level between underpricing and subsequent first day returns in hot markets. Our interpretation of these results is that while there likely is (as theory predicts) deliberate underpricing in IPOs, first day aftermarket returns at the firm level are not explained by this underpricing and are, instead, likely due to market inefficiencies.

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