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Searching for Google's Value: Using Prediction Markets to Forecast Market Capitalization Prior to an Initial Public Offering

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We conducted prediction markets designed to forecast post-initial public offering (IPO) valuations before a particularly unique IPO: Google. The prediction markets forecast Google's post-IPO market capitalization relatively accurately. While Google's auction-based IPO price was 15.3% below the first-day closing market capitalization, the final prediction market forecast was only 4.0% above it. The forecast also accorded with the level of over-subscription in the IPO auction. Evidence available to both outsiders (from the prediction market forecasts) and insiders (through the orders in Google's auction) predicted similar degrees of underpricing. We argue that, with repetition, such markets could provide useful information for understanding the IPO process.

Key words: initial public offering; underpricing; asymmetric information; prediction markets
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1. Introduction

Pricing an initial public offering (IPO) is a challenging and high-stakes proposition. Companies spend millions of dollars on investment bankers, engaging in time- and money-consuming "book-building" processes (see Jenkinson and Ljungqvist 2001). Chen and Ritter (2000) document that typical spreads (i.e., fees) earned by investment bankers are around 7%, between \$1.4 and \$5.6 million per deal for their "moderate" sized IPO range (\$20–\$80 million issued). Google's IPO in August of 2004 raised nearly \$1.4 billion for Google and resulted in fees of more than \$45 million for its investment bankers.

As high as fees are, systematic underpricing of IPOs—when issue prices fall significantly short of first-day closing prices in the secondary market—is even more costly to companies. Jenkinson and Ljungqvist (2001, p. 27) report average underpricing of 15.3% for U.S. IPOs. This difference represents significant money "left on the table" (\$3.1–\$12.2 million for IPOs of \$20–\$80 million). In Google's case, the actual underpricing of 15.3% left nearly \$350 million on the table (see Table 1 in §4.5).

Pervasive underpricing has led to the development of many theories to explain the phenomenon. Some argue that underpricing is a rational response to information asymmetries across investors (e.g., Rock 1986) or between issuers and investors (e.g., Chemmanur 1993, Benveniste and Spindt 1989, Sherman and Titman 2002). In such models, large payments to investors (in the form of underpricing) are required to overcome the asymmetries. Other models rely on different factors such as future benefits of underpricing. Examples include improved secondary offerings (Welch 1989), ownership dispersion (Booth and Chua 1996), and reduced potential legal liabilities (Tinic 1988, Hughes and Thakor 1992).[1]

Here we analyze prediction markets run in advance of Google's IPO, which were intended to predict the post-IPO value of the company. These markets are in

[1] There are many other types of theories. For example, Loughran and Ritter (2002) discuss a role for prospect theory and Khanna et al. (2005) discuss the role of labor market shortages for investment bankers. We do not discuss these models because our evidence does not address them. The interested reader can see a more complete survey in Ritter and Welch (2002).

the spirit of other prediction markets, using contracts specifically designed to aggregate information about a future event. The prototypical examples are markets designed to predict election outcomes (e.g., Forsythe et al. 1992), but such markets have proven accurate over a wide range of events.[2] They combine the power of laboratory markets with the real-world link of field studies.

Prediction markets are small-scale, real-money markets designed to forecast future events. They have proven accurate in aggregating and revealing the information held by traders.[3] Surowiecki (2004) points out that the average forecasts from a group are frequently more accurate than individual forecasts. Like surveys, prediction markets aggregate information from groups. However, they have several advantages over simple surveys. First, prediction markets give incentives to gather or create information. Second, traders can express their strength of conviction through their intensity of trading. Well informed traders can trade more; less informed traders can abstain. Traders self-select. Evidence shows that traders who self-select into price setting roles earn larger returns than average traders (Oliven and Rietz 2004). Third, traders can incorporate into their own forecasts the forecasts of others as summarized by observable market prices. Finally, prediction markets can respond quickly to information events (e.g., Berg and Rietz 2006). The end result is an efficient, dynamic mechanism for aggregating information.

Here, we use prediction markets to infer information held by corporate outsiders. This allows a test of the ability of prediction markets to forecast this post-IPO capitalization and to provide a "proof of concept" that prediction markets can be used to test IPO underpricing theories that rely on the otherwise unobservable distribution of information across agents.

Prediction markets on IPO's have several potential applications. First, they allow one to determine whether outsiders (market traders) can predict post-IPO values. Second, companies may be able to use them as a tool to help set initial price ranges or actual IPO prices. Third, prediction markets aggregate information across traders, and the predictions of such markets can be compared to information known by the issuers. We view the current market as a proof of concept that prediction markets can be used to evaluate economic theories that rely on asymmetric information.

Prediction markets on IPOs and the Google IPO in particular are an especially interesting case. Google's specific and clearly stated goal was to avoid IPO underpricing by using an auction mechanism to gather information, set prices, and allocate shares.[4] The auction and other post-IPO information allow estimation of the excess demand for Google stock at the issue price and a portion of the demand curve. Thus, we can infer part of the demand curve for the Google IPO. The degree of excess demand at the issue price suggests Google knew the auction was underpricing the issue.[5] Google successively revealed information through a series of amended U.S. Securities and Exchange Commission (SEC) filings. This allowed assessment of the forecasting ability of prediction markets for IPOs well in advance of the IPO and under conditions of sparse information, as well as the evolution of uncertainty about the post-IPO valuation as information was revealed.

The prediction markets were designed to forecast the market capitalization of Google at the close of the first day of trading. Market capitalization was used because our markets opened well in advance of Google announcing the expected number of post-IPO shares or initial price ranges. The markets yield three interesting results. First, the markets were relatively accurate. The final forecast exceeded the actual first-day closing market capitalization by 4.0% (using the first-day closing price as the basis). This was far closer to the actual value than the IPO price, which fell short by 15.3%. The forecast was also relatively accurate far in advance of the IPO. During the time period

[2] Plott (2000, p. 14) concludes that prediction markets have "an amazing ability to perform." Like other prediction markets, the Iowa Electronic Markets (IEM) have been shown to (1) predict well both shortly before an event (Berg et al. 2008b) and through time (Berg et al. 2008a); (2) forecast better than alternative means (Berg et al. 2008a) and in a variety of contexts (Wolfers and Zitzewitz 2004); and (3) be accurate not just on average, but on a case-by-case, contract-by-contract basis (e.g., Figure 1 in Berg et al. 2008b).

[3] Although the evidence on prediction markets specifically is relatively recent, prediction markets are a special form of betting markets, where evidence spans a much longer time period. In general, betting markets are accurate in predicting outcomes, except in the tails, where there is a longshot bias (see Thaler and Ziemba 1988, Sauer 1998).

[4] That the auction would eliminate underpricing might reasonably be expected. Some theories of IPO underpricing rely on particular features of the usual book-building process that were eliminated in the auction. Specifically, the auction severely restricted the investment bankers' discretion in issuing shares, and the auction did not allow a precommitment to underpricing. Because of this, underpricing in Google's case cannot be explained by models relying on either of these features. However, there is also a case that an auction will not eliminate underpricing. See, for example, Sherman (2005). In the end, it did not eliminate underpricing.

[5] We note here and later that the auction allows us and Google to infer the degree of excess demand. Google did not publicly release, nor were we able to obtain, the demand schedule from the auction. The excess demand could have resulted from deliberate pricing below market clearing (as Google's prospectus allowed them to do) or from (extreme) lumpiness in the demand schedule. Whatever the cause, we merely argue that Google knew that the issue price was associated with excess demand and, hence, was below a true market clearing price.

before Google announced their initial preliminary price range and share quantity, the market forecast averaged 6.6% higher than the actual capitalization. Second, by comparing the forecasts to information from the IPO auction, we can compare information of "outsiders" (the prediction market traders) and "insiders" (Google and their investment bankers). The degree of excess demand at the issue price suggests Google knew the auction was underpricing the issue. In fact, the demand we estimate from available information about unfilled orders suggests about the same degree of underpricing as the prediction market forecast does. Third, in addition to running the markets to get point estimates of the eventual market capitalization, we develop a method for estimating the uncertainty inherent in the forecasts. We find that the inherent uncertainty drops dramatically as the IPO process unfolds and, in particular, drops significantly on days that prospectus amendments are filed with the SEC. This indicates that the amendments contain significant, value-relevant information.

Our work is related to two extant strands of research. First, there are pre-IPO markets in other countries. These "when-issued" markets (often called "gray" markets) allow forward trading in IPOs. Such markets are not allowed under U.S. security laws, but some gray markets have a good record in forecasting post-IPO trading prices in the last few days preceding an IPO (Löffler et al. 2005, Aussenegg et al. 2006, Cornelli et al. 2006). The gray markets in Europe are diverse in their microstructure and, consequently, can be quite different from a prediction market. The German gray markets, for example, trade forward contracts with physical delivery and do not officially open until the issuer gives an initial IPO price range, typically a week before the IPO (Aussenegg et al. 2006). Because price ranges must be set before when-issued trading commences (Aussenegg et al. 2006), when-issued markets cannot be used to help set initial ranges. Furthermore, revisions of initial ranges are "very rare" in German IPOs (Löffler et al. 2005, p. 468) even when when-issued trading might suggest a revision in the range.

Second, our work is related to prior prediction market research. We extend the research to a new arena: predicting post-IPO trading values. We also develop a means of generating forecast distributions from sets of prediction market prices that are designed to forecast probabilities of events being in ranges. Finally we argue that, because of the incentives for prediction market traders to reveal their information through prices, prediction markets can be used to test a variety of economic theories that rely on asymmetric information. Testing theories of IPO underpricing that rely on asymmetric information is one such use, but there are many other potential uses of prediction markets for testing theories.

The rest of this paper is organized as follows: In §2, we outline the history and unique features of the Google IPO. In §3, we describe the specific prediction markets we conducted to predict the post-IPO Google value. In §4, we present our results, and we conclude in §5.

2. Google IPO

2.1. Timeline of Events

The Google IPO was closely watched.[6] Google's potential IPO was first reported by the *Wall Street Journal* on October 24, 2003 (Sidel and Mangalindan 2003). Google made an initial filing with the SEC on April 29, 2004 (SEC file no. 333-114984) and filed nine amended prospectuses. Its final prospectus was approved on August 18, 2004 and officially filed the next day. The online supporting materials (provided in the e-companion)[7] list the filing dates and summarize major changes included in each amendment.

The initial filing contained little information about quantities of shares.[8] There was no initial price range and no target IPO date. The fourth amended filing on July 26 supplied projected share quantities, the initial price range ($108–$135), and an August targeted, IPO date. Issue quantities were revised in Amendment 5 on August 9 and in Amendment 9 on August 18. Amendment 9 also adjusted the initial price range down to $85–$95. The final prospectus, declared effective on August 18 and filed on August 19, set the IPO price at $85. On August 19, Google's stock opened trading in the secondary market at $100.00 and closed at $100.34.

2.2. Unique Features and Stated Goals of the Google IPO

Google used an auction mechanism to gather information and generate binding bids in its IPO. Auction mechanisms are uncommon in the United States, especially for an IPO of Google's size. Google's spe-

[6] A search of Lexis/Nexis for the words "Google" with "IPO" or "initial public offering" within 25 words, yields 769 hits between October 24, 2003 (when the potential for an IPO was first mentioned in the *Wall Street Journal*) and August 19, 2004 (when trading in the stock began).

[7] An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

[8] Missing were the total quantity of shares expected after the offering, the number sold to the public by the company, the number sold by existing shareholders, the size of the overallotment option, and the numbers of shares subject to various lock up rules. Although the joint issue of new shares and sales by existing shareholders may seem unusual, Jenkinson and Ljungqvist (2001, p. 3) point out that "many" IPOs share this feature.

cific auction mechanism was similar to a second price auction: there would be a single market price with all bids above that price receiving shares at that price.[9]

The stated goal was to set an IPO price close to the ensuing secondary market price. Specifically, Google's stated purpose was to set "an initial public offering price that results in the trading price for our Class A common stock not moving significantly up or down relative to the market in the days following our offering" (p. 28 of the initial S-1 filing); "to have a share price that reflects a fair market valuation of Google" (p. v of the initial S-1 filing); and to avoid "boom-bust cycles" (p. v of the initial S-1 filing).[10] Thus, the stated goal was to set the IPO price near the actual market price in the days following the IPO, avoiding the typical underpricing that characterizes most IPOs.[11] Given this, Google's IPO provides a natural benchmark for the performance of prediction markets: we can compare the difference between Google's IPO valuation and the post-IPO market valuation to the difference between the prediction market forecast and the post-IPO market valuation.

Although Google's auction process was used to gauge interest from potential shareholders and, with sufficient confirmation, used to generate binding orders for shares, it differs somewhat from a typical auction. For example, Google retained the right to reject bids they found manipulative or disruptive at their sole discretion without notifying bidders who submitted these bids. Moreover, the prospectus clearly states that the IPO price need not be the auction clearing price. Page 38 of the amended S-1 filing on August 13, 2004 (the day the auction began) states (emphasis added):

> The initial public offering price will be determined by us and our underwriters after the auction closes. We intend to use the auction clearing price to determine the initial public offering price and, therefore, to set an initial public offering price that is equal to the clearing price. *However, we and our underwriters have discretion to set the initial public offering price below the auction clearing price.*

Thus, the IPO price could fall below the actual auction market clearing price creating excess demand.[12] Excess demand could also come from "lumpiness" of the demand schedule, with large quantities of bids at particular prices. Two allocation mechanisms to address excess demand were described in the prospectus, with the decision about which would be used was left to management discretion. Because the auction order book and clearing prices have not been made public (in accordance with prospectus rules), we do not know precisely how much "discretion" was exercised, how far the IPO price may have been set below the auction's clearing price, or whether there was a lumpy demand schedule. Nor do we know exactly how close the auction market clearing price may have been to eventual trading prices. However, we can estimate the excess demand at the IPO price and a segment of Google's demand curve using information from Google's prospectus and information released by investors after the IPO.

3. Iowa Electronic Markets Google IPO Markets

3.1. Description of the Google IPO Markets

The IEM conducted two markets associated with the Google IPO. Both markets traded contracts with liquidation values based on the total market capitalization implied by the closing price of Google stock at the end of the first day of trading. Contracts were based on total market capitalization rather than share price so that the markets could open before initial price ranges and share quantities were announced. The market structure was the same as other IEM markets. Details can be found at the IEM website (http://www.biz.uiowa.edu/iem) and in other references (see, for example, Forsythe et al. 1992, 1999).

IEM Google contract prices extract trader information and forecast Google's capitalization. We use these forecasts, the quantity of stock issued, the IPO price, and the first-day closing price of Google to

1. assess the information and expectation of "outsiders" (i.e., IEM traders);
2. determine the impact of announcements or news on both the forecasted level of capitalization and on the ex ante uncertainty surrounding the forecast during the course of the prediction market;
3. determine whether the forecasted market capitalization was closer to the actual post-IPO capitalization than that implied by the IPO price;

[9] Interested readers can obtain details of the Google auction process from the prospectus available at the SEC through EDGAR (http://www.sec.gov/edgar.shtml) by searching for file no. 333-114984.

[10] To further emphasize this objective, the prospectus and amendments also state "Our goal is to have an efficient market price—a rational price set by informed buyers and sellers—for our shares at the IPO and afterward. Our goal is to achieve a relatively stable price in the days following the IPO" (p. v of the initial S-1 filing).

[11] We note that another possible reason for using the auction mechanism is to decrease underwriting fees. According to Google's final prospectus, underwriting discounts and commissions accounted for \$2.3839 of the \$85 offer price, or 2.8%. Only one IPO in Chen and Ritter's (2000) data set on fees in IPOs approaches Google's size. The fees on this \$1.3 billion IPO were 2.97%. The next two largest IPOs had fees of 4%. So, while fees for smaller IPOs typically average 7%, the fee here seems in line after considering IPO size.

[12] Market clearing is the bid price at which all shares, including the overallotment option, are sold. When we estimate the demand curve below, we are consistent with this, though we recognize that Google sold no shares itself in the overallotment (all shares sold in the overallotment were sold by prior existing shareholders).

4. learn about how and when the price formation process aggregated information for these markets;

5. analyze (using forecasts from two different markets we conduct) whether contract structure matters for prediction markets.

3.1.1. Google Linear Market. The Google Linear market opened on June 29, 2004 with two contracts.[13] Contract liquidation values were determined as follows:

Contract	Contract liquidation values
IPO_UP	= \$0 if the IPO does not take place by March 31, 2005;
	= (Market Cap.)/\$100 billion if \$0 billion < Market Cap. ≤ \$100 billion;
	= \$1 if Market Cap. > \$100 billion
IPO_DN	= \$1 if the IPO does not take place by March 31, 2005;
	= (\$100 billion-Market Cap.)/\$100 billion if \$0 billion < Market Cap. ≤ \$100 billion;
	= \$0 if Market Cap. > \$100 billion

In the absence of hedging demand, prices should equal expected values in this market.[14] Thus, the price of IPO_UP × \$100 billion is the IEM's forecast of the market capitalization of Google stock after the first day of trading according to the closing market price.[15]

3.1.2. Winner-Takes-All Market. The Google winner-takes-all (WTA) market opened on June 29, 2004 with six "interval" contracts. Liquidation values of the initial contracts were determined as follows:

Contract	Contract liquidation values
IPO_0–20	\$1 if market cap is less than or equal to \$20 billion or if the IPO does not occur by March 31, 2005
IPO_20–25	\$1 if market cap is greater than \$20 billion but less than or equal to \$25 billion
IPO_25–30	\$1 if market cap is greater than \$25 billion but less than or equal to \$30 billion
IPO_30–35	\$1 if market cap is greater than \$30 billion but less than or equal to \$35 billion
IPO_35–40	\$1 if market cap is greater than \$35 billion but less than or equal to \$40 billion
IPO_gt40	\$1 if market cap is greater than \$40 billion

On August 5, the IPO_gt40 contract was split into three contracts: IPO_40–45, IPO_45–50, and IPO_gt50, each with a \$1 payoff in the associated capitalization range.[16] Expected value pricing implies that the price of each contract should equal the probability that the actual market capitalization will be in the associated capitalization range (E(value)= $p \times \$1 + (1-p) \times \$0 = p$, where p is the probability of being in the range). Thus, at each point in time, prices map out discrete parts of a forecast distribution for the future market capitalization.

3.2. Fitting a Forecast Distribution with the WTA Market

The WTA market provides a forecast distribution of future market capitalizations, not just a point estimate. The WTA price vector is a vector of (risk-neutral) probabilities of six events (and after August 4, eight events). Because the highest interval (greater than \$40 billion prior to August 4 and greater than \$50 billion afterward) is unbounded from above, some assumption must be made about the distribution of outcomes in this range when this contract trades above a zero price. We assume that at any point in time, t, the future (unknown) capitalization is distributed log normally with mean μ_t and standard deviation σ_t. We further assume that the probability of no IPO equals zero.[17]

[13] The online supporting materials contain the prospectuses for both markets.

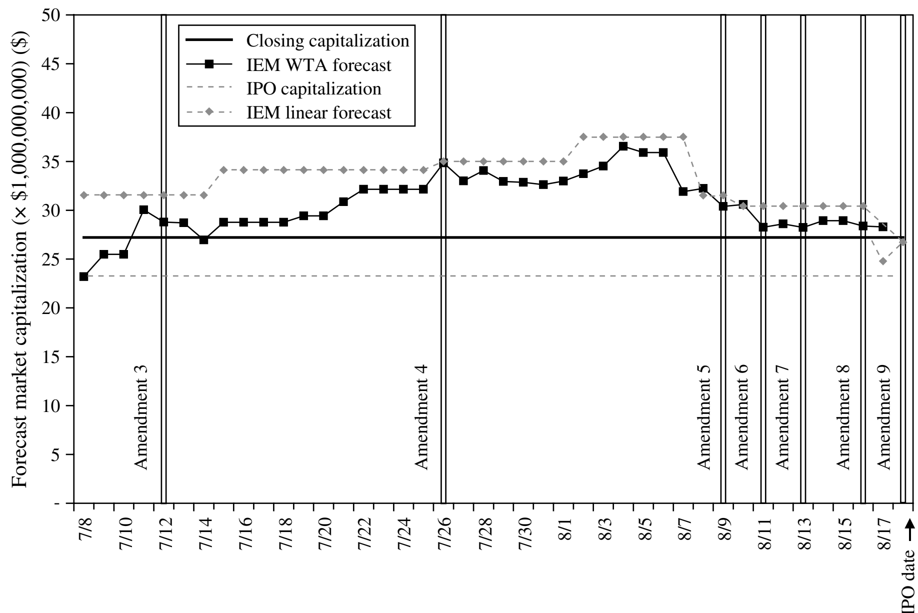
[14] This argument can be made in numerous ways. One might think risk aversion would lead to prices that differ from expected values, but this is not the case here. Intuitively, one wants to argue that risk aversion will lead traders to price a contract below expected value to compensate for risk. This would be the case for a single contract in isolation, but fails because of the contract-bundle method of issuing claims here. If one contract in a bundle is priced below expected value, then the arbitrage restriction will force the price of at least one other contract above its expected value. This is inconsistent with the argument that contracts should be priced below expected value. This can be argued theoretically as well. See Caspi (1974) and Malinvaud (1974) for general equilibrium proofs.

[15] Technically, we need two further assumptions to make this the forecasting relationship. We need to assume that the probability of no IPO before the end of March 2005 is zero, which is consistent with Google's stated strong intention to issue in the summer of 2004. We also need to assume that the probability of a market capitalization greater than \$100 billion is effectively zero. Below, we will estimate a distribution of expected market capitalizations from the other IEM market we ran. This distribution is consistent with essentially zero likelihood of a market capitalization above \$100 billion.

[16] This was done because of sustained high prices for the IPO_gt40 contract. It expands the price ranges covered by contracts to more closely match the apparent range of potential outcomes forecast by our traders.

[17] The log normal distribution is uncontroversial while assuming that the probability of no IPO is zero is consistent with Google's stated strong intention to issue in the summer of 2004 and the long horizon on the contracts.

Figure 1 Predicted Google Market Capitalization from Normalized Closing Prices in the IEM Google Linear Market (IEM Linear Forecast) and the Winner-Takes-All Market (IEM WTA Forecast, the Forecast We Use for Most of Our Analysis)



Notes. For comparison, the actual market capitalization according to the IPO price (IPO capitalization) and the first-day closing price (closing capitalization, what the IEM prices are designed to forecast) are shown. For context, S1 amendment filing dates are also shown.

The normalized contract closing prices on date t reflect estimates of the probabilities of observing outcomes in each range on date t. For a given μ_t and σ_t, integrating the log normal distribution over each range yields predicted probabilities of being in each range. We derive estimates of the distribution mean and standard deviation by minimizing the distance between observed and predicted probabilities.

Formally, assume there are K securities traded each day and that they have a payoff, X_i, of

$$X_i = \$1 \quad \text{if } Z_{i-1} < \textit{Market Capitalization } (MC) \le Z_i, \\ = \$0 \quad \text{otherwise}, \\ \text{for } i = 1, \dots, K. \quad (1)$$

For concreteness assume that $Z_0 = 0$ and that $Z_K = \infty$. The probability that MC lies in interval i is

$$P_t(\theta_t) = F(Z_i \mid \theta_t) - F(Z_{i-1} \mid \theta_t), \quad (2)$$

where F is the cumulative distribution function of the random variable MC. One of these securities is redundant because both the normalized prices and actual probabilities of being in each range sum to one.

On date t, the log normal distribution parameter vector (θ_t) consists of mean (μ_t) and the standard deviation (σ_t). Several methods could be used to estimate θ_t. We chose a minimum χ^2 criterion as the method, although we also estimated the parameters using generalized method of moments and maximum average log likelihood criteria to see whether any significant differences existed. None were found.

Specifically, for each day, denote the objective function as $V(\theta_t)$ and solve the following for the estimates of μ_t and σ_t:

$$\hat{\theta}_t = \operatorname*{Arg\,Min}_{\theta_t} V(\theta_t) = \sum_{i=1}^{K} \frac{(p_{i,t} - P_i(\theta_t))^2}{P_i(\theta_t)}, \quad (3)$$

where $p_{i,t}$ is the price of security i (the market based probability forecast for range i) on date t and $P_i(\theta_t)$ is its expected value according to the estimated log normal distribution. This results in both a forecast of the post-IPO market capitalization and a direct measure of uncertainty surrounding this forecast.

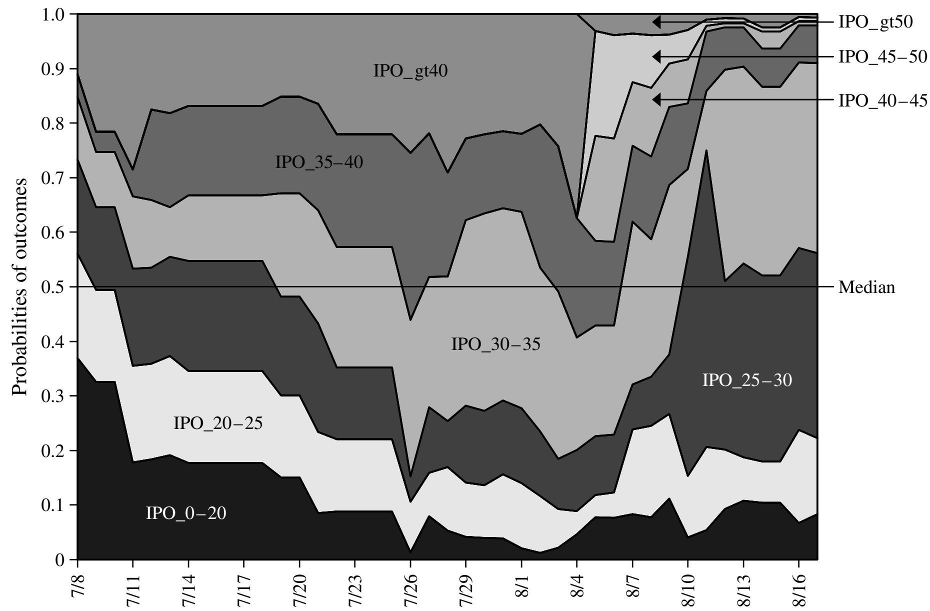
4. Results

4.1. Market Performance

Figure 1 shows forecasts from both the lightly traded linear market and the more heavily traded WTA market (which we will use as the basis for most of our analysis later in the paper).[18] The forecasts from the linear market are the normalized prices of the IPO_UP

[18] Thin trading does not necessarily imply an inefficient market. Prediction market research typically relies on higher volume markets with thick queues in the argument for efficiency (e.g., Berg et al. 1996). However, experimental research suggests that even small double-auction markets (e.g., with as few as four traders) can converge to efficient outcomes (e.g., Smith et al. 1982).

Figure 2 Prices of IEM Google WTA Contracts



Notes. This is an area chart. Each band corresponds to the price of one contract. The width of the band is the normalized price of the contract. Each contract price is interpreted as the probability that Google's market capitalization will be within the associated range (in billions of dollar) after the first day of trading. The sum of normalized prices (probabilities) equals one.

contract.[19] From July 8 to August 17, the day before the final registration statement was approved, 143 contracts traded in the linear market, with no discernable trend in prices (i.e., there is no general drift). Prices generally imply a higher market capitalization than ultimately occurred. However, from Amendment 5 on, the prices imply a market capitalization well below the top, and often below the bottom, of the range indicated by the preliminary prices in the prospectuses.[20] This differs from the typical pattern in the German when-issued markets as documented in Aussenegg et al. (2006).

The lowest normalized closing price for the IPO_UP contract was $0.248 and the highest was $0.375, implying forecast market capitalizations of $24.8–$37.5 billion. On August 18, the date the prospectus was declared effective, trading volume was 228 contracts and the normalized closing price was $0.267, implying a forecast market capitalization of $26.7 billion. The capitalization according to the August 18 IPO price was considerably below this ($23.1 billion), but Google's market capitalization at the open on August 19 was $27.1 billion. It closed at a market capitalization of $27.2 billion (resulting in contract payoffs of $0.272). Thus, the final forecast was 1.8% below the actual closing capitalization on the first day of trading (a much lower deviation than the 15.3% deviation in the IPO price from the closing capitalization).

Trading in the Google WTA market was much heavier than in the linear market. From July 8 to August 17, 3,021 contracts traded in total (~76 contracts per day). Figure 2 shows prices of the WTA contracts as an area chart. Each band represents one of the contracts. The width of the band is the normalized price of the contract. Each contract price is interpreted as the probability that Google's market capitalization would be within the associated range (in billions of dollars) after the first day of trading. The sum of normalized prices (forecast probabilities) equals one. The actual first-day closing market capitalization of Google was $27.2 billion. Figure 2 shows that the median of the predicted distribution was in the range corresponding to the actual market capitalization from August 8 to August 17 (the end of the market).

As news came out, IEM contract prices changed. Late in the market (around August 10), IPO_25–30 and IPO_30–35 emerged as the most likely outcomes and the median of the distribution fell in the

[19] Note that the price of IPO_UP should equal one minus the price of the IPO_DN contract. However, due to asynchronous trading and bid/ask bounce, prices of IPO_UP and IPO_DN do not necessarily sum to exactly $1 at any given point in time. To adjust for this, we use normalized prices. The normalized price of each contract is the price of the contract divided by the sum of contract prices. The graph starts with July 8, the first day by which all contracts had traded.

[20] Amendment 4 set the first preliminary price range and forecast post-IPO number of shares implying a capitalization range of $29.00–$36.25 billion. Amendment 5 changed both the price range and the total number of post-IPO shares forecast, changing the capitalization range to $29.29–$36.61 billion. Amendment 9 dropped the capitalization range to $23.05–$25.77 billion.

25–30 billion range (as shown in Figure 2). On August 18, the volume of trade on the IEM Google WTA market was 3,148 contracts. Prices collapsed to less than $0.05 for all but the IPO_20–25 and IPO_25–30 contracts and most queues were cleared (i.e., most limit orders traded were cancelled by traders or expired).

Figure 1 also shows the expected market capitalization according to the distribution estimated from the WTA prices each day. The forecasts from the WTA market follow the linear market forecasts quite closely (correlation = 0.71). The WTA low forecast was $23.2 billion and the high was $36.5 billion. On August 18 (the day of the final S-1 approval), several WTA contract prices fell to zero, which made identification of the two parameters imprecise without finer contract intervals. However, from August 11 to August 17, the estimates of market capitalization fell between $28.2 and $28.9 billion and closed at $28.3 billion on August 17. This exceeded the actual capitalization by 4.0%.

Although volumes differ considerably, forecast market capitalizations are similar across the two IEM prediction markets through time. They are highly correlated even though the different contract structures and thin trading in the linear market make intermarket arbitrage difficult at best. A similar analysis of data from the 2004 WTA presidential election markets on the IEM shows a similar intermarket pattern. The election market analysis suggests that, while forecasts are similar, those derived from WTA markets may be more stable than those derived from the linear markets. This evidence, combined with the higher volumes in the WTA market, leads us to have more confidence in the estimates from the Google WTA market predictions. Therefore, we will focus on the WTA predictions throughout the rest of the paper.

As Figure 1 shows, the predictions were remarkably accurate. This accords with prior evidence on prediction markets (e.g., Berg et al. 2008a, b; Wolfers and Zitzewitz 2004). Accuracy here, especially in the early period of the market, shows the utility of prediction markets even when operating with sparse information. As noted above, there was no information about quantities of shares and price ranges in early versions of the prospectus. Even though all such information is known at the time when when-issued markets open, Löffler et al. (2005) document that when-issued markets are only informative in the last few days of trading. Nevertheless, from July 8 (the first day after which all contracts had traded) to July 25 (the day before the filing of Amendment 4, which contained the first estimates of share quantities and price ranges), the forecasted market capitalization from the WTA market ranged from $23.2 to $32.1 billion with an average of $29.0 billion. This is higher than most independent estimates reported in the press.[21] The actual market capitalization on the close of the first day of trading (August 19) was $27.2 billion, making the average prediction only 6.6% higher than the eventual capitalization over this early forecast period. By the next day, the market capitalization had risen to $29.4 billion, significantly closer to the early IEM forecasts. This early indication of market capitalization would be valuable in setting initial price ranges and, as a result, makes these prediction markets different from existing when-issued markets in Germany.

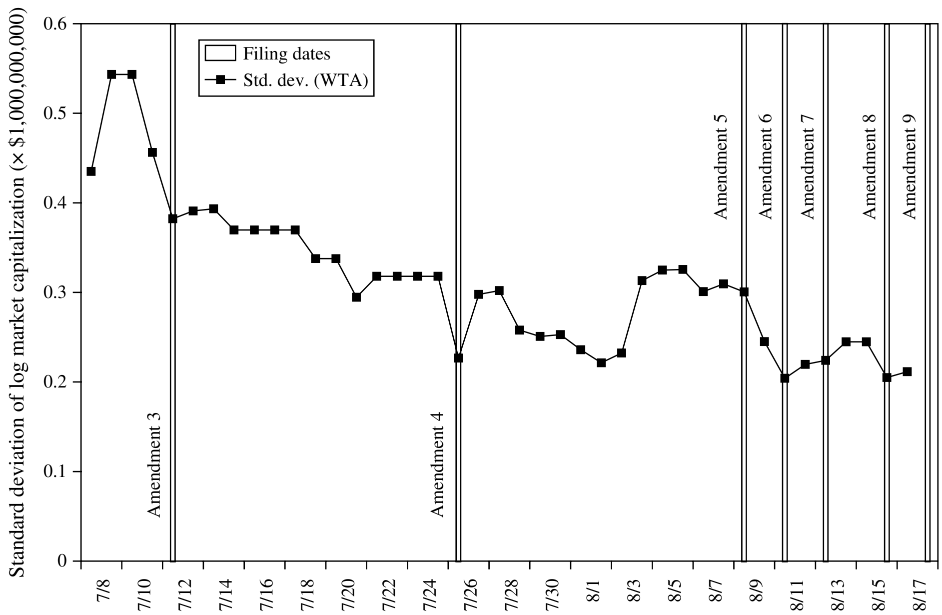
After Amendment 4 was filed on July 26, the IEM forecasted market capitalization rose, likely in response to the relatively high preliminary price range ($108–$135 per share). This indicated a capitalization range of $29.3 billion–$36.6 billion with a midpoint of $33.0 billion. The IEM prices gave an average prediction of $33.9 billion from July 26 to August 8. That this is near the midpoint of the price range (instead of at or above the top of the range) contrasts with what one would expect from the German when-issued market evidence. There, the eventual (i.e., at the close of the opening day) market capitalization of typical IPOs significantly exceeds the top of the indicated range (Aussenegg et al. 2006).

The IEM predicted market capitalization had fallen to $30.4 billion by the date of Amendment 5 (August 9) and to $28.3 billion by the date of Amendment 6 (August 11). From August 11 to August 17, the IEM forecasts ranged from $28.2 to $28.9 billion and averaged $28.5 billion, just 4.8% above the actual August 19 capitalization of $27.2 billion (a price of $100.34 per share). The IEM closing prices the night before the final prospectus was approved forecasted a market capitalization of $28.3 billion and, given the number of shares in the prospectus, a market price of $104.34. This final IEM forecast exceed the actual closing market capitalization by 4.0%.[22] This accuracy is not surprising given the mounting evidence

[21] Two news reports forecasted a maximum market capitalization of Google at $30 billion, whereas typical reports forecasted a maximum of $20–$25 billion. Stories in the *Wall Street Journal* (Sidel and Mangalindan 2003, Delaney and Mangalindan 2004, Sidel and Delaney 2004, Grimes 2004, Eisinger 2004, Lahart 2004) all capped the estimated market capitalization at $25 billion. A story in the *Wall Street Journal* (Thurm 2004) estimated the range to be $20–$22 billion. A story in the *Washington Post* (Witte 2004) estimated the market capitalization at $15–$20 billion. Stories in the *Wall Street Journal* (Sidel 2004) and the *Washington Post* (2004) both give a maximum of $30 billion. Later articles did not make independent capitalization estimates. Most articles simply quoted price and capitalization ranges that were derived from Google's own indicated price range and quantities as given in their prospectus.

[22] This uses the closing price as the basis, as is common in IPO research. The difference is 3.8% using the forecast price as the basis, as is common for prediction markets research.

Figure 3 Estimated (log) Google Market Capitalization Forecast Volatility from the IEM Google Winner-Takes-All Market



on prediction markets. Because the prediction market can only aggregate the information of its traders, we conclude that the traders (outsiders to the company) had accurate assessments of Google's eventual market capitalization. Furthermore, they revealed this information for very little profit (zero profit on average by design, and an observed maximum of $241 for a single trader).

4.2. Evolution of Uncertainty Surrounding the IPO

By documenting a forecast distribution through time, we document the degree of uncertainty and its reduction as the IPO unfolded. This information is derived from the range structure of the WTA contracts and, as a result, is not available from prices in typical forward markets.

In Figure 3, we plot the estimated (implied) volatility of the WTA market forecast ($\widehat{\sigma}_t$). Implied volatility (i.e., uncertainty about the market capitalization forecast) is high, but falls dramatically as the IPO date approaches. Volatility, measured by the standard deviation of the logarithm of the forecasted market capitalization, declined by about two thirds from a high point (the day after all contracts had traded in the market) to the day before the SEC's final approval.

Significant changes in uncertainty follow events with significant informational content. Whether prospectus revisions contain significant informational content is a debatable, empirical issue. Our markets provide direct evidence on whether the degree of uncertainty traders had in their own forecasts improved as a result of amendments. Uncertainty peaked shortly after all contracts had traded in the markets (on July 9 and 10). The largest reductions in uncertainty occurred when announcements and amendments resolved important issues. Volatility fell on every amendment filing date except one: Amendment 7, the amendment in which the potential fallout from Playboy's interview of Google's founders (Sheff 2004, potentially violating "quiet period" rules) was addressed. Every other amendment reduced uncertainty, especially Amendment 4 (which outlined the initial price range and quantities expected to be offered, resulting in the largest single daily reduction) and Amendment 3 (which resolved uncertainty about where Google would be listed, resulting in the third largest single daily reduction). Also of note was the settlement of a potential Yahoo lawsuit, which was reported in newspapers on August 10 and appeared in Amendment 6 on August 11 (resulting in the fourth and seventh largest single daily reductions in uncertainty, respectively). Overall, the average change in uncertainty (change in $\widehat{\sigma}_t$) on days of amendment filings was -0.07. The change on other days averaged less than 0.001. According to a Mann-Whitney two-sample rank sum statistic, this difference is significant ($z = 2.717$, p-value $= 0.0066$). This correspondence between the reductions in uncertainty implied by prices and what one would expect from significant information releases leads further credence to prediction market prices as efficient forecasts.

4.3. Estimating the Demand Curve for the Google IPO

If we knew the demand curve for Google stock, we could determine whether the IEM-predicted post-IPO market price could have been a feasible market clearing price for the IPO. Although Google has not released information about the bids in its auction, publicly available information combined with Google's allocation mechanism, allows us to estimate a segment of the demand curve.

Google expected the auction to result in a market clearing price with little or no excess demand. Page 40 of the amended S-1 filing on August 13, 2004 (the day the auction began) states, "If the initial public offering price is equal to the auction clearing price, all successful bidders will be offered share allocations that are equal or nearly equal to the number of shares represented by their successful bids." If the auction resulted in a lumpy demand schedule or if Google set the price lower than the auction market clearing price, the prospectus stated that Google would ration shares using one of two mechanisms (pro rata or maximum share allocation) with a goal of allocating successful bidders at least 80% of their bid quantities. Google expected significant rationing to result only from pricing the IPO below the auction market clearing price, not from traders deliberately bidding below their true values and generating a lumpy demand schedule.[23] But, whatever the cause, Google would be aware of the degree of excess demand in advance of the issue.

Was there excess demand at the IPO price? Yes. On August 20, a *Wall Street Journal* article (Lucchetti et al. 2004) reported that Turner Investment Partners bid for one million shares at $85 per share and received only 700,000 shares or 70% of its bid. Internet reports (e.g., Kawamoto and Olsen 2004 and messages at the Google Stock discussion board at http://www.google-ipo.com) stated that small bidders were also rationed and put the percentage at up to 75%. This indicates that Google used the pro rata allocation process, which means that the quantity sold (22,545,809 shares including the overallotment option) was 70%–75% of the total bid quantity at a price of $85. This would imply total bids of 30,061,079–32,208,299 shares at or above $85 per share (i.e., an excess demand of 33.3%–42.9% of the quantity sold). These allocations show that there was significant excess demand and that the auction mechanism underpriced the shares significantly (whether it was deliberate or due to a lumpy demand schedule).

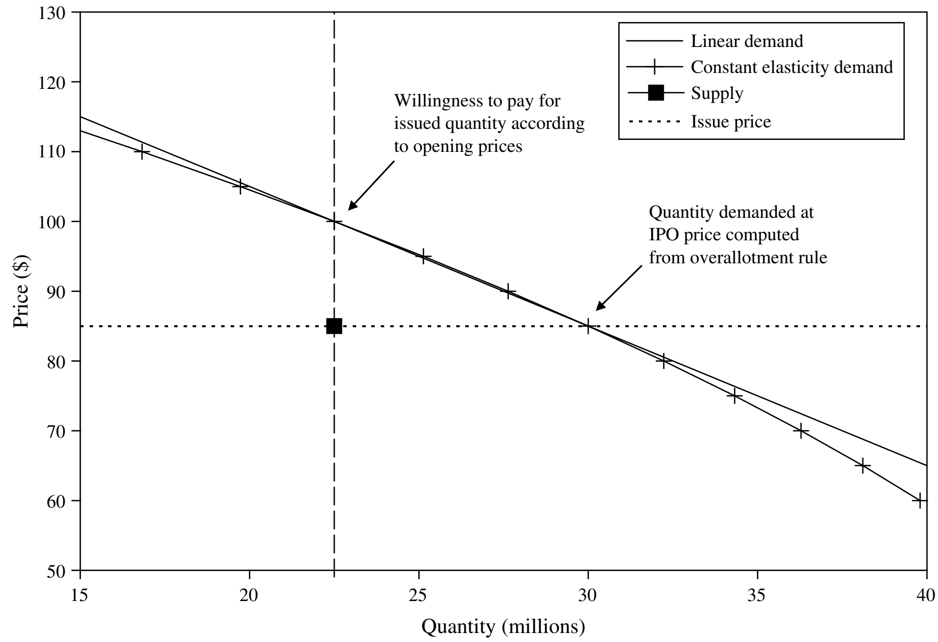
Thus, investors were willing to buy roughly 30 million shares at a price of $85 according to the allocation information available. The next day's opening price implied that they were willing to buy the actual 22.5 million shares (including the overallotment option that had been issued) at about $100. Assuming overnight information changed the demand curve little, we can estimate the demand curve. Google had no direct interest in selling the overallotment. The exercise of the overallotment option left Google's revenues unchanged because all overallotment shares were committed by other existing shareholders.[24]

Because of this, we ask whether Google could have expected to sell the originally committed 19.6 million shares at the IEM suggested price of $104.34. Solving for a linear demand curve (as an approximation) given the two points ($85, 30 million shares) and ($100, 22.5 million shares) gives a demand curve of Q^D (in millions) $= 72.5 - 0.5P$. Using the IEM suggested price of $104.34 yields a predicted sales quantity of 20.33 million, exceeding the 19.6 million commitment. A constant elasticity demand curve (fit to the same data points) gives a predicted sales quantity of 20.10 million, which also exceeds the commitment of 19.6 million. Figure 4 shows the estimated demand curves. This suggests that the IEM implication of foregone revenues of greater than $300 million (see Table 1) is reasonable. Because Google had the bid schedule, Google was aware of the degree of excess demand before the IPO. Thus, both outsiders (IEM traders) and issuers (Google and their investment bankers) could project that the $85 issue price was below a true market clearing price.

[23] This accords with theory. While a full analysis of the equilibria under Google's auction rules is beyond the scope of this paper, the pro rata allocation mechanism without price priority appears to break equilibria with prices set significantly below market clearing. For example, consider Milgrom's (2004, Chap. 7) "$N+1$" auction equilibrium where agents bid their true values for N units in an auction and all bid some amount lower (even zero) for any units beyond N, where N is the number of units auctioned. The key to Milgrom's equilibrium is that the price on all shares rises when a marginal trader raises his or her bid, but the allocation of shares does not change, resulting in a net loss for the trader. With the pro rata allocation rule used by Google, the allocation also changes, breaking the equilibrium. To see why, work with a simple case: Assume 15 million bidders each submit a bid for one share at $100 and one share at $85. This is similar to Milgrom's example on p. 260 and corresponds to the apparent quantities and values in the Google auction. This would lead to a market clearing price of $85, rationing at approximately 70% and net profits of $2 \times 0.7 \times (100 - 85) = \$21$ per trader if $100 per share was the true value. But it is not an equilibrium. If a trader increased his bid on his second share to $85.01, it may not increase the market clearing price. In this case, the trader's price, allocation, and profits are unaffected. However, it may increase the clearing price to $85.01, but in this case, he would receive a full allocation of shares, making for a profit of $2 \times 1 \times (100 - 85.01) = \$29.98$. So, unlike the equilibrium in Milgrom, the traders here each have an incentive to raise the bid on the marginal share. Furthermore, Sherman (2005, p. 629) argues that such an equilibrium is unlikely even in the $N+1$ clearing case with no rationing and any coordination on a collusive equilibrium difficult given the large numbers of bidders potentially involved in large IPO auctions.

[24] Also note that whether the overallotment option was exercised or not also has no effect on the total market capitalization (the benchmark forecast by IEM traders). Market capitalization depends on total shares, not the number of shares sold to the public.

Figure 4 Estimated Demand Curves for Google Stock Computed from the Apparent Quantity Demanded at the Issue Price According to the Allocation Rule and the Apparent Willingness to Pay for the Actual Issue Quantity According to Opening Prices



4.4. Potential Application: Evidence on Theories of IPO Underpricing

Prediction markets can be used to aggregate information from various parties. As a result, prediction markets can be used to test economic theories that rely on asymmetric information. We view the current market as a proof of concept for this idea. Many theories suggest that IPO underpricing is a means of making payments to IPO purchasers to counter problems caused by asymmetric information between issuers and outsiders.[25] The prediction market appeared to reveal essentially the same information as the auction without requiring a large payment to the IEM traders. The highest net profit earned by any single trader was $241, and the average profit across traders in the market was $0 by design. This evidence does not imply that there is no asymmetric information. However, it does show that large payments may not be required for outsiders to gather or reveal information. If this pattern of revealing information without requiring a large payment was replicated in a larger data set, it would provide evidence against theories of IPO underpricing where large payments to outside investors are required to overcome problems caused by asymmetric information. In contrast, our evidence is consistent with models that explain underpricing using other reasons such as future benefits to underpricing. In these models, both the issuers and the outsiders know the degree of underpricing at the time of the IPO, and the IPO underpricing is not viewed as a payment to equalize information across parties, which is consistent with our evidence.[26]

4.5. Potential Application: Setting IPO Prices or Price Ranges

Prediction markets and other pre-IPO markets, such as when-issued markets, might also help in setting IPO prices.

Table 1 shows the difference that setting IPO prices according to our prediction market forecasts might have made. Google actually set an IPO price of $85, implying a market capitalization of $23.1 billion. The closing market price and market capitalization were 18% above this after the first day of trading.

[25] There are a variety of such models, with various types of asymmetric information and reasons for the payment. See Ritter and Welch (2002) for a survey.

[26] For example, in Booth and Chua's (1996) model, issuers deliberately underprice to achieve ownership dispersion. Interestingly, Google's prospectus states that, counter to its primary goal of price stability, it may have chosen to underprice its shares deliberately to "achieve a broader distribution of our Class A common stock" (final prospectus, p. 38). Alternatively, Tinic (1988) and Hughes and Thakor (1992) model underpricing to avoid potential future lawsuits that may result if prices fall dramatically after the IPO. Consistent with this, Google's prospectus goes on to state that it may have chosen to underprice its shares deliberately to "potentially reduce the downward price volatility in the trading price of our shares in the period shortly following our offering relative to what would be experienced if the initial public offering price were set at the auction clearing price" (final prospectus, pp. 38–39). Welch (1989) argues that high quality firms will underprice IPO's deliberately to signal firm quality and drive bad firms from the market in a fully revealing separating equilibrium. They will recoup their losses in subsequent secondary offerings. Note that Google made a secondary offering on September 14, 2005 at a price of $295 per share, raising more than $4.18 billion.

Table 1 Potential Google IPO Prices and Proceeds

	Google share prices					
	Actual IPO (col. 1)	First-day closing price (col. 2)	IEM prediction* (col. 3)	First-day close − IPO price (col. 4)	IEM prediction* − IPO price (col. 5)	IEM prediction* − First-day close (col. 6)
Actual or forecast price ($)	85.00	100.34	104.34	15.34	19.34	4.00
Price as a percentage of the first-day close (%)	84.71	100.00	103.99	15.29	19.28	3.99
Spread (@2.8%) ($)	2.3839	2.8141	2.9264	0.4302	0.5425	0.1122
Per share proceeds to Google and existing shareholders ($)	82.6161	97.5259	101.4152	14.9098	18.7991	3.8894
Quantities and total proceeds without exercise of overallotment option (x1 million)						
Quantity sold by Google	14.142	14.142	14.142	14.142	14.142	14.142
Quantity sold by existing shareholders	5.463	5.463	5.463	5.463	5.463	5.463
Total proceeds to Google ($)	1,168.3680	1,379.2241	1,434.2279	210.8561	265.8598	55.0038
Total proceeds to existing shareholders ($)	451.3249	532.7758	554.0230	81.4509	102.6981	21.2472
Total proceeds to investment bankers ($)	46.7365	55.1710	57.3713	8.4346	10.6348	2.2002
Total proceeds ($)	1,666.4294	1,967.1709	2,045.6222	300.7415	379.1927	78.4512
Quantities and proceeds with exercise of overallotment option (x1 million)						
Quantity sold by Google	14.142	14.142	14.142	14.142	14.142	14.142
Quantity sold by existing shareholders ($)	8.404	8.404	8.404	8.404	8.404	8.404
Proceeds to Google ($)	1,168.3680	1,379.2241	1,434.2279	210.8561	265.8598	55.0038
Proceeds to existing shareholders ($)	694.2788	819.5757	852.2605	125.2969	157.9818	32.6849
Proceeds to investment bankers ($)	53.7470	63.4467	65.9770	9.6997	12.2300	2.5303
Total proceeds ($)	1,916.3938	2,262.2465	2,352.4654	345.8527	436.0716	90.2189

*IEM predictions are for the first-day closing price and are derived from the mean of the distribution estimated from the WTA market.

Google sold 14,142,135 shares and existing shareholders sold 5,462,917 shares for a total of 19,605,052 shares at a net price of $82.6161. At the IPO price, Google raised $1,168.4 million for itself and selling shareholders received $451.3 million (Table 1, column 1). Had Google set the price equal to the closing price on the first day, sold the same number of shares, and paid the same percentage spread to investment bankers, Google would have raised $210.9 million more for itself and Google's existing shareholders would have received $81.5 million more, without the exercise of the overallotment option.[27] Adding the difference in investment bank proceeds brings the total difference to $300.7 million (see calculations in Table 1, column 4). Had Google set its IPO price at the IEM forecast and managed to sell the same number of shares, including the overallotment option, the total foregone proceeds increases to $379.19 million (calculations in Table 1, column 5).[28]

There are two possible explanations for this underpricing: First, Google deliberately left this much money on the table by setting their IPO price below market clearing. They might do this to achieve future benefits. If it is indeed an equilibrium to underprice by a given amount, prediction markets can serve a valuable role as low cost mechanisms for forecasting post-IPO market prices. These forecasts could be used to set IPO prices to achieve desired levels of underpricing. Alternatively, Google may have been forced to effectively underprice by the rules of their auction mechanism and an extremely lumpy demand schedule. Here, if obvious strategic manipulation problems could be overcome, the double-auction nature of a prediction market could serve as a viable alternative to a one-sided auction in helping to determine an effective market clearing price.

[27] The entire overallotment option was sold by existing shareholders. Had they sold the full overallotment at the IEM predicted net price (assuming the same spread) instead of the actual $82.6161, existing shareholders would have made $158.0 million more than they actually did.

[28] We have already discussed how the excess demand information can be used to judge the likelihood that the same number of shares could have been sold at the IEM predicted price. In addition, Google closed above the IEM forecasted price on the second day of trading and has risen above this level even after the exercise of the overallotment option had been made public.

In neither case would we argue that prediction markets should replace road shows, book building, and other means of gathering information. Instead we argue that prediction markets can supplement other mechanisms, providing an additional information source. In a competitive environment for information, we speculate that use of pre-IPO prediction markets may reduce the overall cost of information acquisition for companies making stock issues. Given the stakes involved, any mechanism that provides additional information or lowers its cost could prove valuable.

5. Conclusion and Discussion

The distinctive features of the Google IPO and the IEM prediction markets run in advance of the IPO provide a unique opportunity to study the ability of inside and outside agents to predict the value of a company after an IPO. These markets indicate that the information necessary to forecast the post-IPO price of Google's stock existed in traders' information sets and could be cheaply aggregated well in advance of the IPO. Evidence about the auction demand curve suggests the degree of excess demand and, hence, underpricing was predictable to Google (whether deliberate or as an unavoidable result of the auction rules). Combined, the evidence allows us to compare expectations likely held by both insiders and outsiders. Here, the information held by both insiders and outsiders predicted similar first-day closing capitalizations for Google. Furthermore, the outsiders revealed the information in the IEM without requiring a large payment. If this pattern is repeated in larger data sets, it would lean against theories of IPO underpricing that rely on asymmetric information. In contrast, the evidence is consistent with theories that rely on future benefits of underpricing.

From a practical point of view, we show how prediction markets can be used to test theories that rely on differential, otherwise "unobservable," information. We also show how uncertainty evolves throughout the IPO process. Finally, there are a number of mechanisms that may help firms set IPO prices closer to market values or set them closer to optimal underpricing. We introduce the idea of using a prediction market to do so. Our evidence suggests that such markets can be successful in forecasting post-IPO values of stocks. The forecasts were quite accurate for Google even before many aspects of the issue (e.g., the number of shares, initial price range indications, etc.) were revealed.[29]

What can explain the accuracy of these prediction markets? At one level, given pervasive IPO underpricing, one might argue that prediction markets perform well by simply forecasting a market capitalization higher than that indicated using preliminary price ranges from the prospectus. However, two pieces of evidence run counter to this assertion. First, IEM prices predicted well even before preliminary price ranges and share quantities were available. Second, shortly after the initial ranges were announced, the IEM prices predicted a market capitalization near the average of the price range, not above the range, and the prediction fell long before the price range was revised downward. Thus, the prediction market traders did more than simply "mark up" preliminary price ranges from the prospectus. Why might this be possible? Recent evidence suggests that the degree of underpricing may be predicted from publicly available information that underwriters and/or companies do not build into prices (e.g., Bradley and Jordan 2002, Loughran and Ritter 2002, Lowry and Schwert 2004). Participants in prediction markets may be able to incorporate this information without the biases and conflicts frequently hypothesized to affect firms, investment bankers, and investors.

Researchers have a long history of studying the properties of prediction markets (e.g., their efficiency as markets, their information aggregation properties, and their predictive power). Here we show how they can be used to inform economic theory regarding other phenomenon. They can be used to extract information from sets (or subsets) of agents who may otherwise not reveal their information to test theories that depend on the distribution of information held by agents. In the case of IPO underpricing, they inform theory by providing evidence about the validity of assumed information distributions. Given the apparent success of this market and the high stakes involved in IPOs, we suggest that the SEC and Commodity Futures Trading Commission should allow more research on IPO prediction markets or that investment bankers run private prediction markets as a supplementary means of gathering information before an IPO.

6. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

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[29] Of course, to use these markets in practice, obvious strategic manipulation problems will need to be resolved.

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