IN TIMES OF TURBULENCE

HOW MARKET VOLATILITY SHAPES THE PRICING OF INITIAL PUBLIC OFFERINGS

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In Times of Turbulence: How Market Volatility Shapes the Pricing of Initial Public Offerings

Abstract:

Examining initial public offerings (IPOs) in the U.S. between 2000 and 2024, this paper provides evidence that both realized and implied market volatility during the 21 trading days prior to the IPO positively affect underpricing and its dispersion across firms. Extending the analysis to market volatility in additional time windows, the results indicate that implied volatility has a positive impact on price revision, seemingly by affecting the initial price range. Although definitive conclusions cannot be drawn, the results suggest that market volatility makes IPO pricing more difficult, prompting conservative pricing to ensure successful listings. The findings also suggest firms weigh historical and forward-looking uncertainty differently across the IPO pricing process. Together, this paper provides perspectives on how market uncertainty shapes IPO pricing decisions.

Keywords:

Initial public offering, Underpricing, Price revision, Realized market volatility, Implied market volatility

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1 Introduction

The initial public offering (IPO) represents a key milestone for a company, providing access to public equity markets and a broader investor base. A central challenge in the IPO process is to determine the offer price at which investors are willing to subscribe to the offering. To accomplish this, the issuing firm and its underwriters engage in a price discovery process. This starts with establishing an initial price range and is followed by a book-building process[1], during which the issuer markets its offering to potential investors and gathers information on demand. Based on the new information, the final offer price is set. The deviation of this price from the midpoint of the initial range is known as a price revision. Once the offer price is determined, the shares are listed on the stock exchange. On average, the newly issued firm experiences a price increase on the first trading day, a phenomenon widely referred to as underpricing.

Previous literature has long sought to understand the driving forces behind underpricing and price revision. One strand of the literature examines IPO pricing through the lens of firm-specific uncertainty arising from asymmetric information between issuers and investors (Ritter, 1984; Rock, 1986; Tian, 2011; Loughran and McDonald, 2013). In contrast, another stream of research focuses on market-wide factors, examining how variables such as market returns and investor sentiment influence IPO underpricing and price revision (Loughran and Ritter, 2002; Lowry and Schwert, 2004; Derrien, 2005; Duong, Goyal, Kallinterakis, and Veeraraghavan, 2022).

This study will build on the market-wide-focused strand by exploring how volatility in the secondary market spills over into IPO pricing. This is interesting in a contemporary setting, as markets have experienced several spikes in volatility in recent times, including during the COVID-19 pandemic and in response to the Liberation Day tariffs. While Lowry, Officer, and Schwert (2010) examine the relationship between realized market volatility and underpricing as part of a broader study, the area remains rather underexplored. This paper aims to contribute to filling this gap by providing a more focused study on market volatility and IPO pricing with the following research question:

How does market volatility influence underpricing and price revision in IPOs?

This paper contributes to the literature by exploring the findings of Lowry et al. (2010) in a contemporary setting, studying how realized market volatility affects underpricing and its dispersion. Furthermore, it extends the literature by incorporating implied volatility as an explanatory variable, offering an additional perspective on the relationship between market volatility and underpricing. In addition, by examining not only underpricing but also price revision, the study provides a more comprehensive understanding of how market volatility influences different stages of the IPO pricing process.

The empirical analysis is based on IPOs on NASDAQ and the New York Stock Exchange in the U.S. between 2000 and 2024. The IPO data is retrieved from Securities Data Company (SDC) Platinum, S&P Capital IQ Pro, and data compiled by Professor Jay Ritter, as well as

[1] Although the formal book-building generally occurs over a limited number of days, this paper refers to the book-building process as the broader period between the filing of the initial price range and the offer date.

market returns and volatility data from Center for Research in Security Prices (CRSP) and the Federal Reserve Bank of St. Louis (FRED). After cleaning the data, the sample comprises 1774 IPO observations for the main regressions.

The study begins by partially replicating the methodology of Lowry et al. (2010). Specifically, it employs both a maximum likelihood estimation (MLE) and an ordinary least squares (OLS) model to examine how the realized volatility of the equally-weighted NASDAQ portfolio during the 21 trading days preceding the offer date influences the mean and dispersion of underpricing. The models control for the firm- and deal-specific variables used in Lowry et al. (2010). Similar to Dicle and Levendis (2018), who analyzes how market volatility affects IPO volume, this paper incorporates implied volatility alongside realized volatility. Specifically, it examines how the average VIX over the same 21-day window influences the mean and dispersion of underpricing. Moreover, the paper examines how both realized and implied volatility affect price revision using OLS regressions. Similar to Lowry and Schwert (2004), the effect of these volatility measures is examined across different time windows surrounding the period when the initial price range is usually set, as well as the period immediately preceding the offer date. The purpose of this is to identify the stages at which market volatility may be the most relevant. Finally, to ensure the results are not driven by variations in IPO activity and firm quality across periods, the paper includes additional control variables in a robustness check.

The results show that both realized and implied market volatility have significant and positive effects on the mean underpricing and its dispersion across issuing firms. These effects remain robust after incorporating the additional control variables. Similar to what is found in Lowry et al. (2010), this suggests that heightened market volatility leads to greater underpricing and wider variation across issuing firms. Considering price revision, the results indicate that only the implied market volatility observed in the earlier time windows has a positive and significant effect on price revision. This suggests that the implied volatility in periods roughly overlapping with the typical period for establishing the initial price range positively influences price revision.

According to Lowry et al. (2010), dispersion in underpricing serves as an indicator of IPO pricing difficulty. Interpreted through this lens, the finding that underpricing is more dispersed in volatile market conditions suggests that heightened market uncertainty makes IPOs inherently more challenging to value accurately. This, in turn, implies that the increased underpricing under higher volatility may stem from increased pricing conservatism adopted in response to the pricing difficulties. Similarly, the positive relationship between implied market volatility and price revision may be another result of conservative pricing behavior. The findings suggest that volatility primarily affects the range-setting stage rather than the subsequent offer-price adjustment. An interpretation is therefore that higher early volatility may lead underwriters to set more conservative initial ranges, resulting in positive revisions as demand becomes clearer. Nonetheless, uncertainty about the timing of range-setting and the persistence of market volatility suggests that this interpretation should be treated with caution.

A puzzling finding is that implied volatility appears to be a better predictor of price revision than realized volatility, suggesting that the involved actors may be more interested in expected future volatility than historical volatility when setting the initial price range.

Overall, it is important to note that the study examines a relatively small sample of successful IPOs on the major U.S. exchanges, and its findings should therefore not be used to draw overly broad conclusions. The results may also be subject to selection bias due to the exclusion of withdrawn offerings and observations removed due to missing data. In addition, there is a risk of omitted-variable bias. These dimensions would benefit from closer examination in further studies. Nevertheless, the initial findings and potential interpretations offered by this study may be valuable for the various actors involved in the IPO process and their respective strategic considerations.

2 Related literature

Historically, IPO research has emphasized information asymmetry as the primary driver of underpricing. More recent studies, however, have broadened this perspective by examining a wider set of uncertainty-related determinants, including market dynamics. In this context, Duong et al. (2022) investigate how investor sentiment, proxied by the Consumer Confidence Index, affects IPO underpricing across different political systems for the period 1990-2020. They find that higher consumer confidence is associated with greater underpricing, suggesting that optimistic market-wide expectations amplify initial returns. Lowry et al. (2010) is another paper considering the relationship between market dynamics and IPO underpricing. Studying U.S. data from 1965 to 2005, the authors find that higher time-series realized volatility[2] of the NASDAQ index in the 21 days leading up to the offer date is associated with higher underpricing. They also find that the realized volatility appears to have a positive effect on the dispersion of underpricing across firms. The paper attributes the effect of market volatility on IPO underpricing to the increased difficulty it creates for issuing firms and underwriters in accurately valuing the IPOs.

Alongside studying factors affecting IPO underpricing, several researchers have also examined various drivers of IPO price revision, providing a more comprehensive understanding of the IPO pricing process. Loughran and McDonald (2013) study how uncertainty, proxied by the language in S-1 filings, affect price revision. Studying the U.S. IPO market between 1997 and 2010, they find that more uncertain language results in higher absolute price revisions. Earlier literature, such as Lowry and Schwert (2004), have instead studied how market returns, in different time windows prior to the offer date, affect price revision. Examining IPOs in the U.S. between 1985 and 1997, the authors find that market returns before the initial range is set and between the initial range and the offer date positively affect price revision.

This paper contributes to the literature that examines market-wide factors as drivers of IPO underpricing by building on Lowry et al. (2010) and analyzing realized market volatility in a contemporary context. In addition, it examines implied market volatility to evaluate its involvement in underpricing. Furthermore, it extends prior research by examining how both volatility measures, observed at different time periods before the offer date, affect price revision. Over-

[2]This paper will refer to the time-series realized volatility used in Lowry et al. (2010), as simply realized volatility going forward.

all, the study aims to shed additional light on the involvement of market uncertainty in the IPO pricing process.

3 Data and sample construction

3.1 IPO sample

The IPO data were gathered from Securities Data Company (SDC) Platinum Global New Issues[3] and cover the period from January 1, 2000, to December 31, 2024. This time period reflects a modern context while still offering a sufficiently long and heterogeneous time frame, covering varying economic conditions. The sample includes IPOs listed on NASDAQ and the New York Stock Exchange (NYSE) in the United States. The purpose of this delimitation is to focus on one of the world's most mature equity markets and its major exchanges, which have regulatory consistency and high disclosure standards. Limiting the sample to one country also removes cross-country variation that could obscure the relationship under study and ensures comparability with prior IPO research, such as Lowry et al. (2010).

To ensure the sample represents standard operating-company IPOs and aligns with previous IPO literature, several categories of non-standard firms and offerings were excluded. Specifically, following Lowry et al. (2010), firms with deviating regulatory or financial structures, including Real Estate Investment Trusts (REITs) and closed-end funds, were excluded, as were offerings issued through foreign listing instruments such as American Depository Receipts (ADRs). Also, following Lowry et al. (2010), unit offerings were removed due to their non-standard structure, and IPOs priced below $5, as such issues typically represent particularly small and speculative penny stock firms. In addition, other types of non-conventional listings were removed, including spin-offs and Special Purpose Acquisition Companies (SPACs), consistent with the standard IPO literature filtering criteria recommended by Tian (2011). The output generated from SDC Platinum consisted of 3026 IPO observations.

The following data items were extracted from the SDC Platinum database: *Issue date, Issuer name, Ticker, CUSIP, Year founded, Exchange name, Number of shares offered, Offer price (USD), First trading day closing price (USD), Bookrunners*[4]*, Venture-capital-backed flag, Primary high-tech industry, Total assets before offering (USD millions), Total revenues before offering (USD millions), EPS last twelve months before offering (USD).* These data items were used to construct both dependent variables and independent control variables (see definitions in the methodology section).

To address missing data, the gathered dataset was supplemented by data from S&P Capital IQ Pro and Professor Jay Ritter's IPO data collection[5], frequently used in the IPO literature. From Capital IQ, data on *First-day price change* were collected to supplement missing data in SDC Platinum, using the SDC Platinum data firsthand. In addition, Capital IQ provided

[3]The SDC Platinum database was accessed through the Swedish House of Finance.

[4]Note that the bookrunner is a specific type of underwriter, and the two terms are used interchangeably throughout this paper.

[5]Jay Ritter's IPO data collection, available at: https://site.warrington.ufl.edu/ritter/ipo-data/

all the data on *Price revision*. Furthermore, Capital IQ and Professor Jay Ritter's IPO dataset provided supplementary data on *Year founded*, using, in first hand, data from SDC Platinum, in second hand, Capital IQ, and in third hand, Professor Jay Ritter's data. Furthermore, the data on *Underwriter reputation scores* was provided by Professor Jay Ritter. The data from Capital IQ and Professor Jay Ritter were merged directly into the data file using *CUSIP* as the common identifier.

3.2 Cleaning of IPO data

From the initial output of 3026 entries, duplicate observations were removed, ensuring there is no more than one observation per IPO, resulting in 2853 remaining entries. Firms listed on multiple exchanges were also removed due to the risk that they could have pricing information from other markets, distorting comparability across the sample. After this, the sample consisted of 2780 observations. Furthermore, observations were excluded if data necessary to create the dependent variables and independent control variables[6] were still missing after supplementing with data from S&P Capital IQ and the data compiled by Professor Jay Ritter.

The final sample contains 1774 observations. Compared with Lowry et al. (2010), who studied a sample of 8759 IPOs, this sample can be considered small. However, it is important to note that the observation period in this study is significantly shorter and focuses only on listings on NASDAQ and NYSE. Furthermore, to ensure comparability with Lowry et al. (2010), inclusion of the same firm- and deal-specific control variables was prioritized, despite the consequent reduction in the final sample size. The limited sample may make it more difficult to detect effects in the regressions in the study, and also reduce the generalizability of the findings.

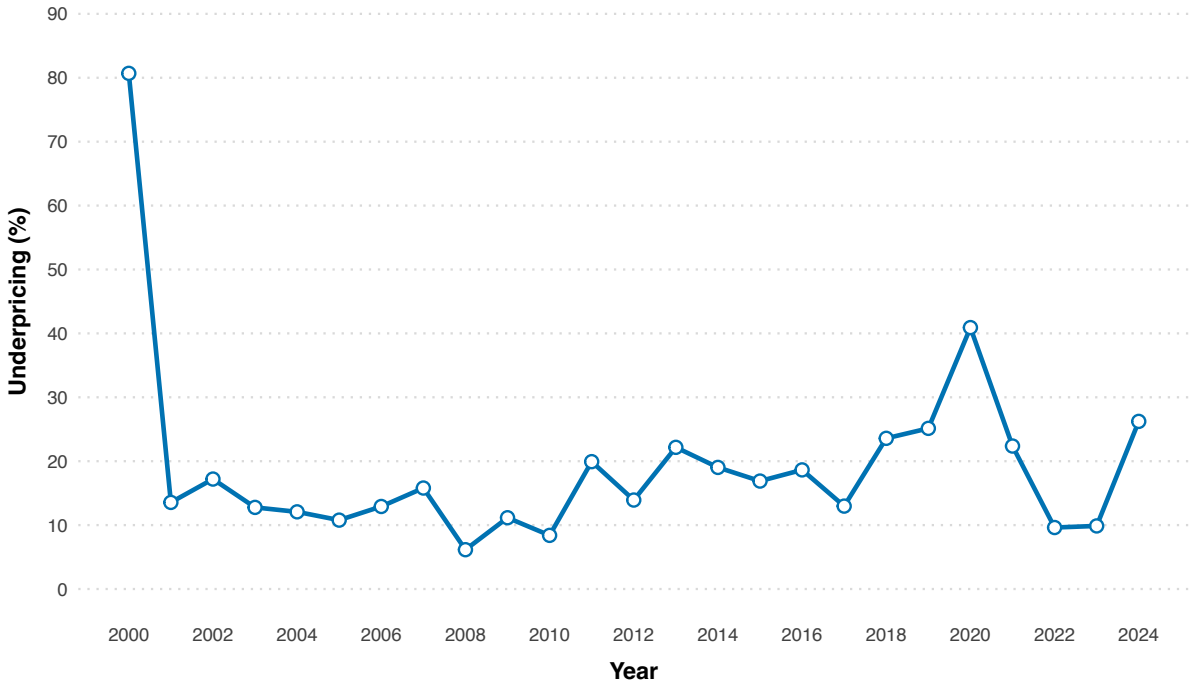
As noted by Lowry and Schwert (2004), the removal of observations with insufficient data may introduce biased data. As shown in Appendix A, when compared to the final sample, a compiled dataset consisting of the observations removed due to insufficient data differs with regard to the mean of several variables. For example, consistent with what was detected in Lowry and Schwert (2004), the average underpricing differs, with significance, from the mean in the final sample. Therefore, the results of this study and their implications should be taken with caution.

[6]This includes: First trading day closing price (USD), Number of shares offered, Year founded, Primary high-tech industry, Venture-capital-backed flag, Exchange name, Bookrunners, Price revision

3.3 IPO pricing over the sample period

Figure 1: Average IPO underpricing by year (2000–2024)

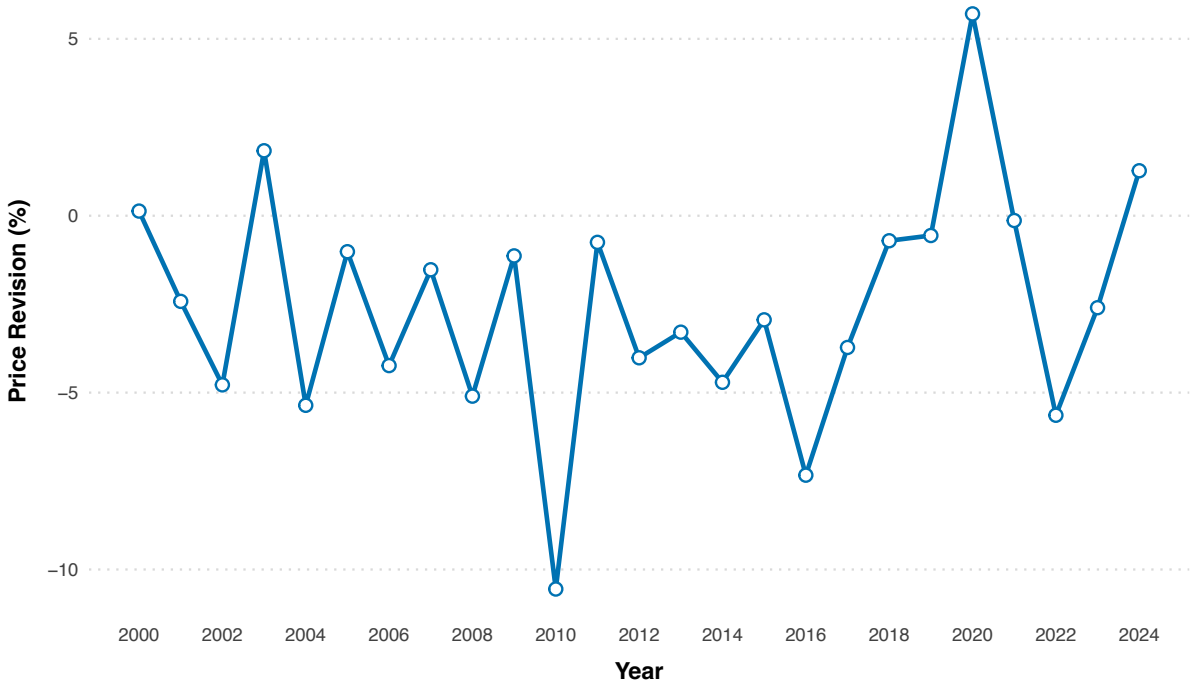
The figure illustrates the yearly average underpricing for the sample IPOs, each year between 2000 and 2024. Underpricing is defined as the percentage change between the offer price and the closing price on the first day of trading. The underpricing variable has been winsorized at the 1st and 99th percentiles to remove substantial outliers.



The sample data show that the average underpricing between 2000 and 2024 has varied substantially, as shown in Figure 1. For instance, in 2000, there was a spike in underpricing driven by the IPO bubble, as discussed in Lowry et al. (2010). Moreover, in 2020, a smaller spike was observed during the COVID-19 pandemic and the IPO frenzy it sparked, as discussed in Zhang and Neupane (2024). While underpricing appears to be a persistent phenomenon, it has evidently undergone significant shifts over time, sparking interest in understanding the driving factors behind these fluctuations.

Figure 2: Average price revision by year (2000–2024)

The figure shows the average price revision for the sample IPOs, each year between 2000 and 2024. Price revision is defined as the percentage change between the the offer price and midpoint of initial price range. The price revision variable has been winsorized at the 1st and 99th percentiles to remove substantial outliers.



Moreover, as evident in Figures 1 and 2, the sample data appear to show that years with high underpricing also feature more positive price revision. For example, the years 2000, 2020, and 2024 exhibit both above-average underpricing and positive average price revision. However, unlike underpricing, the price revision did not show a similarly extreme spike during the 2000 IPO bubble. Overall, the correlation between underpricing and price revision in the sample appears significant at 0.309 (Appendix B). This supports the partial-adjustment theory formulated by Hanley (1993), which finds that price revisions are good predictors of initial returns.

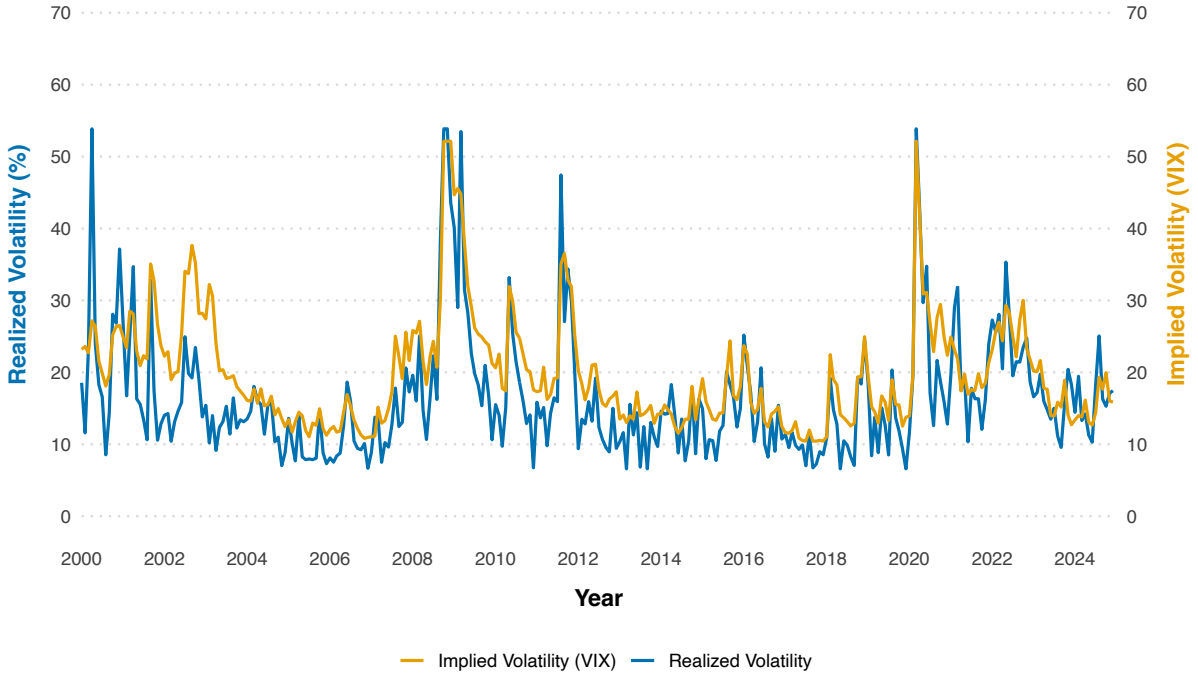
3.4 Market volatility data

To capture market-wide uncertainty, data used to form the primary independent variables, realized volatility, and implied volatility, were gathered. To construct the realized volatility variable, data on daily NASDAQ returns from the Center for Research in Security Prices (CRSP) were collected in accordance with Lowry et al. (2010). The equal-weighted index, including dividends, was used for the period from October 4, 1999, to December 31, 2024.

For the implied volatility, data were collected from the Federal Reserve Bank of St. Louis (FRED), which provides daily data on the CBOE Volatility Index (VIX) derived from option prices on the S&P 500 index. The data gathered covers the period October 4, 1999, to December 31, 2024.

Figure 3: Realized volatility and implied volatility (2000–2024)

The figure presents the movements of realized and implied volatility (VIX) during the sample period 2000-2024. Realized volatility is defined as the volatility of daily returns of the equally-weighted NASDAQ index, aggregated at a monthly level, and reported in annualized %. Implied volatility (VIX) is defined as the average VIX level in a given month. The volatility variables have been winsorized at the 1st and 99th percentiles to remove substantial outliers.



Realized volatility and implied volatility (VIX) appear to have broadly followed similar movement patterns over the sample period, as shown in Figure 3. This is consistent with their significant correlation of approximately 0.804[7]. (Appendix B). Figure 3 illustrates how the VIX index reached exceptionally high levels during, for instance, the Global Financial Crisis in 2008 and the COVID-19 pandemic in 2020, times when realized volatility also spiked. In addition, realized volatility was particularly high around the year 2000. Lowry et al. (2010) similarly documented a sharp increase in realized volatility around the time of the IPO bubble ending in 2000. Importantly, some of the periods with heightened volatility, such as 2000 and 2020, also appear to feature high average underpricing and more positive average price revision (as shown in Figures 1 and 2), strengthening the motivation to study this relationship further.

[7]Note that this value is based on the logarithm of the realized and implied volatility measures, calculated over the 21 trading days preceding each IPO's offer date.

3.5 Summary statistics

Table 1: Descriptive statistics for sample variables

This table reports summary statistics for the variables used in the study[8]. Underpricing is the percentage change between the offer price and the first-day closing price. Price revision is the percentage change between the offer price and the midpoint of the initial filing range. Shares offered refers to the number of shares offered in the IPO (in millions). Firm age is the number of years between founding year and offer date. The high-tech dummy equals 1 if the firm belongs to a high-tech industry (SDC Platinum), and 0 otherwise. The VC-backed dummy equals 1 if the firm is backed by a venture capital firm (SDC Platinum) and 0 otherwise. The NASDAQ dummy equals 1 if the firm is listed on NASDAQ and 0 if listed on NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8, during any year between 2000–2024, and otherwise 0. IPO activity is the number of IPOs in same month as IPO *i*. Firm assets and firm revenue represent total assets and total accumulated revenues at the offer date (USD millions). Positive EPS dummy equals 1 if EPS was positive in the LTM before offering , and 0 otherwise. Realized volatility [21,1] is the volatility of daily returns of the equally-weighted NASDAQ index over the 21 days preceding the offer date, reported in annualized percentage. Implied volatility [21,1] is the average VIX level during the 21 trading days preceding the IPO. All non-dummy variables are winsorized at the 1st and 99th percentiles to remove substantial outliers.

Variable	Mean	Standard Deviation	25th Percentile	Median	75th Percentile	Min	Max
Underpricing (%)	22.240	44.952	0.000	10.335	29.888	-30.270	312.104
Price revision (%)	-2.114	14.526	-9.091	0.000	7.143	-50.000	25.642
Shares offered (millions)	10.054	9.629	5.000	6.916	11.420	0.615	58.540
Firm age (years)	13.080	16.813	4.000	8.000	14.000	0.000	99.270
High-tech dummy	0.631	0.483	0.000	1.000	1.000	0.000	1.000
VC-backed dummy	0.556	0.497	0.000	1.000	1.000	0.000	1.000
NASDAQ dummy	0.743	0.437	0.000	1.000	1.000	0.000	1.000
Reputable bookrunner dummy	0.814	0.389	1.000	1.000	1.000	0.000	1.000
IPO activity	16.068	9.728	10.000	14.000	22.000	1.000	43.010
Firm assets (USD millions)	583.942	1410.852	42.000	112.050	399.550	1.300	9619.868
Firm revenue (USD millions)	230.080	630.137	0.000	17.500	151.400	0.000	4486.078
Positive EPS dummy	0.225	0.418	0.000	0.000	0.000	0.000	1.000
Realized volatility$_{[21,1]}$ (%)	14.412	5.959	10.052	13.221	16.787	6.252	34.862
Implied volatility$_{[21,1]}$	17.585	5.222	13.622	16.518	20.086	10.190	33.512

The average underpricing in the sample is 22.2%, while the median is 10.3% (Table 1), indicating that a number of IPOs exhibit extraordinarily high underpricing. This is similar to what was observed by Loughran and McDonald (2013), who found an average underpricing of 34.8% with a median of 13.3% between 1997 and 2010. The underpricing can also be compared with the levels in the sample of Lowry et al. (2010), finding an average underpricing of 22% across their full sample between 1965 and 2005[9]. Considering price revision, an average level of -2.1% was identified, highlighting how revisions are, on average, made slightly downwards. This is similar to the findings in Lowry and Schwert (2002), seeing an average price revision of -3.6% between 1985 and 1997, as well as Cumming, Köchling, Neukirchen, and Posch (2024) finding an average of -2.8% between 2001 and 2018 for U.S. IPOs. Moreover, realized volatility has a mean of 14.4%, while implied volatility, measured as VIX, averages a level of 17.6.[10]

[8] Market volatility over additional time windows will be introduced in later sections of the paper.

[9] Defined in Lowry et al. (2010) as the 21 trading-day post-IPO price change.

[10] The averages are based on the 21 trading-day pre-IPO volatility measures calculated individually for all 1774 IPOs, from which the cross-sectional mean is derived.

Table 2: Correlation – Monthly aggregated underpricing and cross–sectional dispersion

The table shows statistics for the monthly aggregated mean underpricing and cross-sectional dispersion in underpricing. Underpricing is defined as the percentage change between the offer price and the closing price on the first day of trading. Similar to Lowry et al. (2010), the cross-sectional dispersion has been calculated as the dispersion in underpricing between firms listing in the same month and excluded those months with fewer than four IPOs. The underpricing variable, used to form the statistics in this table, has been winsorized at the 1st and 99th percentiles to remove substantial outliers.

Statistic	Mean	Median	SD	Correlation
Monthly mean underpricing	19.103	14.758	26.571	
Cross-sectional dispersion	29.051	21.128	26.024	0.808

When aggregating the underpricing on a monthly basis over the sample period (2000-2024), the correlation between the mean underpricing and the within-month cross-sectional dispersion of underpricing is 0.808, as reported in Table 2. This implies that months with higher average underpricing also show larger differences in underpricing across the firms listed during the month. The correlation is within the range of correlations Lowry et al. (2010) report across different periods, ranging from 0.542 in 1981-1990 to 0.925 in 1991-2005. It is also close to the overall correlation of 0.877 reported by Lowry et al. (2010) for the period 1965-2005.

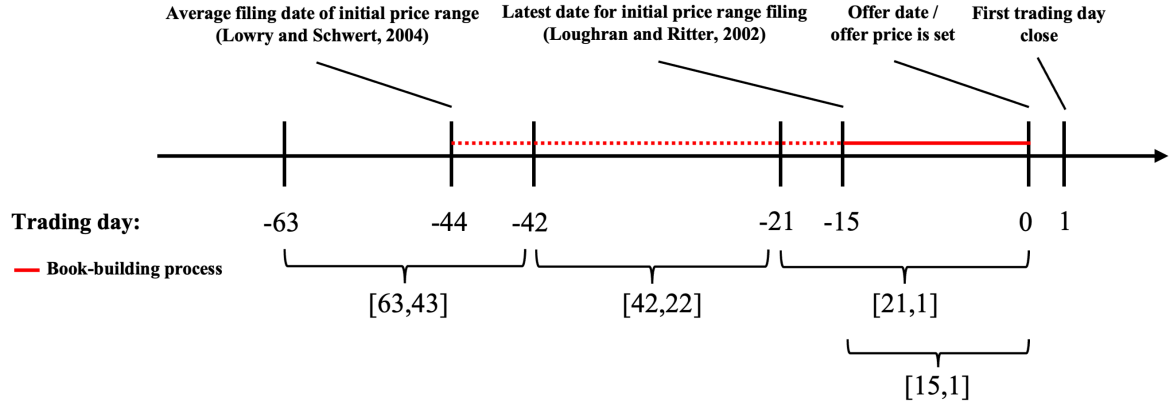
Since the level of underpricing and its dispersion tend to move together, this suggests that some periods feature greater pricing difficulty and higher average underpricing. Meanwhile, other periods are more stable, exhibiting lower underpricing and more consistent pricing behavior between issuers. Having established this connection, it becomes natural to examine whether market volatility contributes to this phenomenon.

4 Methodology

This section outlines the empirical framework used to investigate the research question, including the definition of the variables, the estimation approach, the model specification, and robustness checks. To provide a clearer overview of the IPO pricing process and the time windows used to measure market volatility, Figure 4 illustrates a timeline.

Figure 4: IPO pricing process – Timeline

The figure shows the key events of the IPO pricing process focused on in this paper. In Lowry and Schwert (2004) it is found that the filing date of the initial price range is on average 44 days prior to the offer date. Moreover, Loughran and Ritter (2002) claims that the 15 days prior to IPO represents the minimum time period between the establishment of the initial price range and the subsequent offer price. The authors of both these papers also claim that the offer price generally is determined in close proximity with the offer date (trading day 0). The time-windows [63,43], [42,22], [21,1] and [15,1], represent the windows studied in different parts of this paper. [63,43], [42,22], [21,1], all roughly represent roughly a month of trading days, while [15,1] covers the time period claimed relevant by Loughran and Ritter (2002), as previously discussed. The red colored line represents the broader book-building process between the filing of the initial price range and the offer date.



4.1 Defining underpricing and price revision

4.1.1 Underpricing

In the baseline model, the study defines underpricing in line with Loughran and McDonald (2013), considering the difference between the offer price and the closing price on the first day of trading (Figure 4). This can be compared to the definition used by Lowry et al. (2010). They define underpricing as the difference between the offer price and the closing price on the 21st day of trading. While acknowledging the problem of the first-day definition related to underwriters' price-stabilization efforts presented in Lowry et al. (2010), this paper prioritizes capturing the instant market reaction to the offer price and avoiding noise from post-IPO factors unrelated to the IPO pricing process. In addition, it is the standard definition used in the IPO literature, making results based on it more useful in light of the existing literature. Ljungqvist (2007) also emphasizes that full underpricing should be visible by the first trading day in developed capital markets without fluctuation restrictions, with later prices adding little value.

The measure of underpricing used in the study is thus defined as the percentage change between the offer price and the closing market price on the first trading day:

$$\text{Underpricing}_i = \frac{P_i^{close} - P_i^{offer}}{P_i^{offer}} \times 100$$

where P_i^{close} is the closing price of the first trading day for the issuing firm *i*, and P_i^{offer} is the offer price at the issue date for the issuing firm *i*.

4.1.2 Price revision

Influenced by prior literature (Lowry and Schwert, 2004; Loughran and McDonald, 2013), this paper also examines price revision to evaluate the effects of market volatility on pricing decisions made earlier in the IPO process. Price revision is the phenomenon where the underwriters revise the offer price in relation to the initial price range set in previous filings (Figure 4). In line with the mentioned papers, price revision is defined as the percentage change between the midpoint of the initial price range and the final offer price:

$$\text{Price revision}_i = \frac{P_i^{offer} - P_i^{mid}}{P_i^{mid}} \times 100$$

where P_i^{offer} is the offer price at the issue date, and P_i^{mid} is the midpoint of the initial price range, for the issuing firm *i*.

4.2 Defining market volatility

4.2.1 Realized volatility

Realized volatility is a measure of market uncertainty that accounts for historical variation in stock returns. In this study, the realized volatility is calculated in the same manner as in Lowry et al. (2010), using the daily returns of the equally-weighted NASDAQ[11] index including dividends, over *k* trading days, at an annualized level:

$$\text{Realized volatility}_{i,k} = \sqrt{\frac{\sum_{d=1}^{k}(r_{m,i-d} - \bar{r}_{m,i,k})^2}{k-1}} \sqrt{252} \times 100$$

where $r_{m,i-d}$ is the daily market return d days before IPO i, and $\bar{r}_{m,i,k}$ is the average market return over the k-days window.

4.2.2 Implied volatility

Another type of market volatility is implied volatility, a forward-looking measure of market uncertainty derived from option prices and representing investors' expectations of future volatility. To empirically capture implied volatility, the CBOE Volatility Index (VIX) is used. The VIX index measures the expected volatility of the S&P 500 over the next 30 days. It is regarded as the standard measure of forward-looking volatility for U.S. markets and is thus an appropriate gauge of implied volatility.

[11] Lowry et al. (2010) indicate that estimating volatility from other market portfolios, including the NYSE, would not yield any material differences in the results.

The rationale for extending Lowry et al. (2010) with an implied volatility measure is to further explore how IPO pricing responds to different dimensions of market volatility, both historical and forward-looking. Evidence from Dicle and Levendis (2018) indicates that the two measures may drive different outcomes in the IPO context. The authors find a significant relationship between implied volatility and IPO activity, but not for realized volatility, which further motivates including implied volatility in this study.

To keep the implied volatility measurement similar to that for realized volatility, it is also captured over the same pre-IPO windows. By taking the average level of the VIX index over this period, short-term fluctuations are smoothed out, providing a measure of the overall market uncertainty experienced by the price-setters. For IPO *i*, the implied volatility is measured over a window of k trading days, defined as:

$$\text{Implied volatility}_{i,k} = \frac{\sum(VIX_{i-d})}{k}$$

where VIX_{i-d} is the closing level of the VIX index d days before IPO i, and k is the number of trading days included in the window.

4.3 Control variables

To isolate the effect of market volatility in the study, several control variables are included to account for firm- and deal-specific dimensions, consistent with the variables included in Lowry et al. (2010).

i) Log(Shares offered)
Log(Shares offered) is defined as the logarithm of the number of shares offered by the issuing firm in the IPO. Shares offered are included to control for differences in size across offerings, as larger offerings often indicate more established firms, broader analyst coverage, and greater investor attention.

ii) Log(Age + 1)
Log(Age + 1) is defined as the logarithm of the number of years between the offer date and the year the issuing firm was founded (plus one). This variable is included because younger firms may be perceived as riskier.

iii) High-tech dummy
The high-tech dummy is set to 1 if the firm is categorized as a high-tech firm and 0 otherwise, as defined by the SDC Platinum database. This variable is included because high-tech firms may be perceived as riskier and more uncertain.

iv) VC-backed dummy
The VC-backed dummy is deemed 1 if the firm is VC-backed and 0 otherwise, as defined by the SDC Platinum database. This variable is included, rather than other forms of ownership, because VC involvement has a long-established theoretical link to information asymmetry and certification (e.g., Barry, Peavy, Vetsuypens, and Muscarella, 1990), in which VCs typically back younger, riskier firms, thereby playing a more important role as a certifier.

v) NASDAQ dummy

The NASDAQ dummy is 1 if the firm is listed on NASDAQ and 0 if it is listed on NYSE. The dummy variable is included to ensure that the estimated effects are not driven by systematic differences between the two exchanges, including listing requirements, firm characteristics, and investor compositions.

vi) Reputable bookrunner dummy

The reputable bookrunner dummy is 1 if the IPO had at least one bookrunner that had an underwriter rank equal to 8 or above during at least one year between 2000–2024, based on the Carter and Manaster (1990) rank, updated by Carter, Dark, and Singh (1998) and subsequently by Loughran and Ritter (2004). This ranking system is widely used in the IPO literature, but due to missing data points in the most recent years, this definition differs slightly from the one used in Lowry et al. (2010). The variable is included because using a reputable underwriter may signal higher quality to the market, thereby reducing uncertainty surrounding the IPO.

vii) Abs(Price revision)

Abs(Price revision) is defined as the absolute value[12] of the percentage change between the offer price and the midpoint of the initial filing price range. The motivation for including this variable is that it controls for information revealed during the book-building process. Since prior studies, e.g., Hanley (1993), have found that this new information is only partly reflected in the offer price, known as the partial adjustment phenomenon, the remaining information that is not adjusted for may also affect underpricing.

4.4 Winsorization and outliers

The raw IPO sample exhibits high kurtosis for several variables (Appendix C), suggesting that outliers might distort the results. To address this issue consistently, all non-dummy variables are winsorized at the 1st and 99th percentiles. When winsorized at this level, the kurtosis decreases, for example, from 1135 to 19, for the underpricing variable. This resulting kurtosis level is comparable to the one reported by Lowry et al. (2010) for their sample, excluding the IPO bubble period between 1998 and 2000. In contrast to Lowry et al. (2010) and consistent with Loughran and McDonald (2013), this paper does not exclude any years based on unusual IPO dynamics in the main regressions. However, appendix D shows that the results for underpricing remain when excluding the period from January to August 2000, which falls within the IPO bubble period studied separately by Lowry et al. (2010). This is the same period that exhibited an unusually high underpricing in Figure 1.

4.5 Estimating underpricing

Following Lowry et al. (2010), a maximum likelihood estimation (MLE) model is used to jointly estimate the mean underpricing and the variance of the error term. Measuring the variance of the error term provides insight into how market volatility affects the dispersion in underpricing

[12] The absolute value is only applied to the price revision when used as a control variable.

across firms. This introduces another feature of the model, which is that it does not require homoskedastic error terms. Since the error terms differ substantially across IPOs, an MLE framework that models this variation may yield efficiency gains over simple linear regressions if correctly specified. In addition, following Lowry et al. (2010), a cross-sectional ordinary least squares (OLS) model is used to benchmark against the MLE results.

The mean underpricing, and for the MLE also variance, is regressed on the independent variables, with one model for the realized volatility$_{[21,1]}$ which refers to the 21 days leading up to the IPO and one for the implied volatility$_{[21,1]}$ measured over the same period. This corresponds to the time period employed by Lowry et al. (2010). The reason this paper studies underpricing based on market volatility in only one time window, as opposed to how price revision is studied, is that it only directly involves one pricing decision (Figure 4). The equations for the mean and variance[13] models are specified below:

i) Realized volatility

$$\begin{aligned}\text{Underpricing}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC-backed dummy}_i \\ + \beta_4 \text{abs(Price revision)}_i + \beta_5 \text{NASDAQ dummy}_i + \beta_6 \log(\text{Age}_i + 1) \\ + \beta_7 \text{Reputable bookrunner dummy}_i + \beta_8 \log(\text{Realized volatility}_{[21,1]_i}) + \varepsilon_i\end{aligned}$$

ii) Implied volatility

$$\begin{aligned}\text{Underpricing}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC-backed dummy}_i \\ + \beta_4 \text{abs(Price revision)}_i + \beta_5 \text{NASDAQ dummy}_i + \beta_6 \log(\text{Age}_i + 1) \\ + \beta_7 \text{Reputable bookrunner dummy}_i + \beta_8 \log(\text{Implied volatility}_{[21,1]_i}) + \varepsilon_i\end{aligned}$$

iii) Realized volatility

$$\begin{aligned}\log(\text{std}(\varepsilon_i)) = \gamma_0 + \gamma_1 \log(\text{Shares offered}_i) + \gamma_2 \text{High-tech dummy}_i + \gamma_3 \text{VC-backed dummy}_i \\ + \gamma_4 \text{abs(Price revision)}_i + \gamma_5 \text{NASDAQ dummy}_i + \gamma_6 \log(\text{Age}_i + 1) \\ + \gamma_7 \text{Reputable bookrunner dummy}_i + \gamma_8 \log(\text{Realized volatility}_{[21,1]_i})\end{aligned}$$

iv) Implied volatility

$$\begin{aligned}\log(\text{std}(\varepsilon_i)) = \gamma_0 + \gamma_1 \log(\text{Shares offered}_i) + \gamma_2 \text{High-tech dummy}_i + \gamma_3 \text{VC-backed dummy}_i \\ + \gamma_4 \text{abs(Price revision)}_i + \gamma_5 \text{NASDAQ dummy}_i + \gamma_6 \log(\text{Age}_i + 1) \\ + \gamma_7 \text{Reputable bookrunner dummy}_i + \gamma_8 \log(\text{Implied volatility}_{[21,1]_i})\end{aligned}$$

4.6 Estimating price revision

Some literature, including Loughran and McDonald (2013), considers either only upward revisions or absolute price revision. Other literature, such as Loughran and Ritter (2002) and Lowry and Schwert (2004), studies the signed price revision. When studying price revision as a dependent variable, this paper follows the latter approach. This allows both upward and downward

[13] Note that while the MLE conceptually models the error variance, the empirical specification models the log of the standard deviation of the error term. This results in an identical economic interpretation, differing only by a constant scaling factor of 2.

adjustments to be captured, providing insight into how market volatility affects the direction of the price revision, not just its magnitude.

This study seeks to understand not only if, but also at which stage market volatility primarily influences price revision, acknowledging that it may affect the establishment of the initial price range, and not only during the book-building process. However, the available databases lack reliable data on the date when the initial range is decided. It is noted in Lowry and Schwert (2004) that not all issuing firms include the initial price range in the original filing and instead often file an amended prospectus that includes the initial price range at a later stage, for which the date is seldom captured in the databases. Given this constraint, volatility is measured over different time windows prior to the offer date, similar to Lowry and Schwert (2004). By comparing which periods show a stronger effect, it might be possible to infer whether market volatility affects the initial range setting, the book-building process, or both.

Firstly, the volatility during the 15 trading days prior to the offer date (referred to as [15,1]) is evaluated, as Loughran and Ritter (2002) argue that this represents the minimum length of time between the setting of the initial price range and the offer date. Thus, this window isolates how the volatility after the initial range is set affects the price revision. Secondly, the volatility during the 21 trading days before the IPO (referred to as [21,1]) is considered, consistent with the horizon used when studying underpricing. Thirdly, volatility during the period 42 to 22 trading days before the IPO is examined (referred to as [42,22]). Lastly, volatility during the 63 to 43 trading days before the IPO (referred to as [63,43]) is evaluated. As the average time between the time when the initial range is set and the offer date is 44 days, according to Lowry and Schwert (2004), the earliest two windows are more likely to coincide with the setting of the initial price range rather than with the subsequent book-building process. See Figure 4 for a visual overview of the different events and time windows.

The effects of realized and implied volatility on price revision during these different time windows are estimated using a cross-sectional ordinary least squares (OLS) model. This is consistent with prior price revision studies, such as Loughran and McDonald (2013), which rely on standard linear regressions. The equations for the models are shown below, where d_1 and d_2 denote the days that define the boundaries of the respective time windows:

v) Realized volatility

$$\begin{aligned}\text{Price revision}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC-backed dummy}_i \\ + \beta_4 \text{NASDAQ dummy}_i + \beta_5 \log(\text{Age}_i + 1) + \beta_6 \text{Reputable bookrunner dummy}_i \\ + \beta_7 \log(\text{Realized volatility}_{[d_1,d_2]_i}) + \varepsilon_i\end{aligned}$$

vi) Implied volatility

$$\begin{aligned}\text{Price revision}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC-backed dummy}_i \\ + \beta_4 \text{NASDAQ dummy}_i + \beta_5 \log(\text{Age}_i + 1) + \beta_6 \text{Reputable bookrunner dummy}_i \\ + \beta_7 \log(\text{Implied volatility}_{[d_1,d_2]_i}) + \varepsilon_i\end{aligned}$$

4.7 Robustness checks

To verify the robustness of the results, additional control variables for IPO activity and firm financial characteristics are added to the cross-sectional OLS and MLE models for underpricing and the cross-sectional OLS models for price revision[14]. The extended model specifications can be found in Appendix E. Because some observations are missing data used to construct the additional control variables, the sample used in the robustness check is reduced to 1626 observations.

4.7.1 Controlling for IPO activity

Periods of high IPO activity, when many firms go public, are in the IPO literature referred to as "hot IPO markets" (Helwege and Liang, 2004). Lowry et al. (2010) find that their sample exhibits lower average underpricing when the IPO bubble, characterized by exceptionally high IPO activity, is omitted, suggesting that volumes and underpricing may be related. In addition, it is not unlikely that IPO activity also affects price revision. Furthermore, IPO activity has been found to be related to market volatility (Pástor and Veronesi, 2005), and it may therefore be necessary to control for this variable to ensure that the effect attributed to market volatility is not merely an effect of IPO activity. To account for this, and with the aim to further isolate the relationship between market volatility and IPO pricing, from the potential effect of IPO activity, the following variable is included:

i) IPO activity
IPO activity is defined as the number of IPOs in the same calendar month as IPO *i*. Similar to Helwege and Liang (2004), this paper uses a larger dataset of IPOs for this variable, including those with insufficient data, to better capture the true IPO activity.

4.7.2 Controlling for firm quality and riskiness

It has been established in the IPO literature that the quality and riskiness of the issuing firms affect IPO pricing (Rock, 1986). Furthermore, Lowry and Schwert (2002) find that certain types of firms, often similar in quality and riskiness, tend to go public at the same time, suggesting that similar firms may cluster around certain volatility levels. This notion could affect the relationship this paper seeks to study. While venture-capital backing and underwriter reputation, included in the baseline models, to some degree control for firm quality and riskiness, it is deemed prudent to include additional, more direct proxies related to more firm-specific financials. Drawing on previous IPO literature, such as Loughran and McDonald (2013), and Tian (2011), the following variables have been included:

ii) Log(Firm assets)
Log(Firm assets) is defined as the logarithm of the firm's total assets in USD millions, at the

[14]Note that the additional robustness control variables have been winsorized at the 1st and 99th percentiles in line with the other variables of the study.

time of the IPO.

iii) Log(Firm revenue + 1)
Log(Firm revenue +1) is defined as the logarithm of the firm's revenue in USD millions, accumulated from the founding date until the IPO, plus one.

iv) Positive EPS dummy
The positive EPS dummy is 1 if the firm had positive EPS in the 12 months before the IPO and 0 otherwise, following the definition used in Loughran and McDonald (2013).

5 Empirical results

5.1 Baseline results

In this section, the results of the baseline regressions are presented, examining how market volatility influences underpricing and price revision. To begin with, Table 3 outlines the MLE and OLS regressions, estimating the mean and variance of underpricing. The MLE regression (c) shows that the realized volatility$_{[21,1]}$ has a positive and significant effect on the mean underpricing. This is consistent with both the results in the OLS regression[15] (a) and the results of Lowry et al. (2010), finding that the realized market volatility had a significant and positive effect on the mean underpricing. The coefficient of 6.401 in regression (c) means that a 1% increase in realized volatility$_{[21,1]}$ would lead to a 0.064 percentage point increase in mean underpricing. Viewed in the context of the descriptive statistics (Table 1), a one standard-deviation increase in realized volatility$_{[21,1]}$ from the mean would increase the mean underpricing by 2.65 percentage points. Furthermore, the MLE regression (d) in Table 3 shows that implied volatility$_{[21,1]}$ has a positive and significant effect on the mean underpricing with a coefficient of 11.588. This implies that a 1% increase in implied volatility$_{[21,1]}$ results in a 0.116 percentage point increase in mean underpricing. This, in turn, suggests that a one standard deviation increase from the mean of implied volatility$_{[21,1]}$would increase the mean underpricing by 3.44 percentage points.

[15]Overall, the OLS models in this study exhibit low R-squared values, which is common in the IPO literature. For instance, Lowry et al. (2010) had R-squared ranging between 0.030-0.240 when regressing on different time periods of their sample

Table 3: OLS and MLE regressions – Underpricing

This table reports the results of the OLS and MLE models estimating the effect of realized and implied volatility on underpricing. (a)-(b) show OLS regressions of underpricing on realized and implied volatility, respectively, including controls. (c)-(d) show MLE regressions of mean underpricing on realized and implied volatility, respectively, including controls. (e)-(f) show MLE regressions of the $\log(\text{std}(\varepsilon_i))$ regressed on realized and implied volatility, respectively, including controls. Underpricing is the percentage change between the offer price and the first-day closing price. Abs(Price revision) is the absolute percentage change between the offer price and the midpoint of the initial price range. Log(Shares offered) is the log of the number of shares offered. Log(Age + 1) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. Log(Realized volatility$_{[21,1]}$) is the log of the annualized volatility of daily returns of the equally weighted NASDAQ index during the 21 trading days before the IPO. Log(Implied volatility$_{[21,1]}$) is the mean VIX level over the same window. All non-dummy variables are winsorized at the 1st and 99th percentiles. The table reports coefficients with standard errors in parentheses. The sample includes 1774 observations. ***, **, and * denote significance at the 0.1%, 1% and 5% levels, respectively.

	OLS		MLE mean		MLE variance	
	(a)	(b)	(c)	(d)	(e)	(f)
Intercept	-7.264	-40.345	-2.260	-22.792	5.072***	3.372***
	(25.023)	(26.213)	(18.274)	(18.446)	(0.357)	(0.399)
Abs(Price revision)	-0.096	-0.085	0.281**	0.160	0.014***	0.010***
	(0.107)	(0.106)	(0.108)	(0.098)	(0.002)	(0.002)
Log(Shares offered)	-0.661	-0.521	-0.564	-0.233	-0.201***	-0.182***
	(1.514)	(1.507)	(1.105)	(1.064)	(0.022)	(0.022)
Log(Age + 1)	1.027	1.083	1.944**	2.265***	0.074***	0.107***
	(1.127)	(1.121)	(0.651)	(0.628)	(0.020)	(0.020)
High-tech dummy	1.188	1.134	3.334	2.978	0.157***	0.149***
	(2.646)	(2.628)	(1.938)	(1.869)	(0.045)	(0.044)
VC-backed dummy	13.621***	13.516***	12.418***	11.887***	0.302***	0.316***
	(2.590)	(2.578)	(2.083)	(1.988)	(0.040)	(0.039)
NASDAQ dummy	2.351	2.247	2.220	1.427	0.215***	0.185***
	(2.773)	(2.760)	(1.805)	(1.717)	(0.050)	(0.049)
Reputable bookrunner dummy	2.364	2.201	-0.757	-0.646	-0.174***	-0.223***
	(3.018)	(3.004)	(2.752)	(2.647)	(0.050)	(0.050)
Log(Realized volatility$_{[21,1]}$)	10.305***		6.401**		0.442***	
	(2.833)		(2.255)		(0.047)	
Log(Implied volatility$_{[21,1]}$)		20.404***		11.588***		0.902***
		(3.745)		(3.002)		(0.068)
R-squared	0.038	0.047				
Log-likelihood			-8994.244	-8945.735		

Consistent with Lowry et al. (2010), regression (e) in Table 3 shows that realized volatility$_{[21,1]}$ has a positive and significant effect on the dispersion of underpricing between firms. The coefficient of 0.442 means that a 1% increase in realized volatility$_{[21,1]}$ would increase the dispersion (measured as standard deviation) by 0.442%. This means that a one standard deviation increase in realized volatility$_{[21,1]}$ from the mean would increase the dispersion by 18.3%. Similarly, the implied volatility$_{[21,1]}$ shows a positive and significant effect on the dispersion of underpricing with a coefficient of 0.902. This indicates that a one standard deviation increase from the mean would increase the dispersion by 26.8%.

These results support the notion that heightened market volatility, as measured by both realized and implied volatility, increases both the mean underpricing and the dispersion across issuing firms. The higher level of underpricing suggests that firms tend to set their offer prices more conservatively relative to the market valuation. At the same time, the higher dispersion suggests it is more difficult to price consistently.

In Figure 1, the year 2000 stands out with exceptionally high average underpricing, consistent with the IPO bubble described in Lowry et al. (2010). Following their approach, classifying offerings prior to September 2000 as part of this bubble, the baseline model is re-estimated on a subsample excluding these observations (see Appendix D). The results for both the OLS and MLE specifications outlined above remain robust, indicating that the main findings are not solely driven by the bubble period.

Moving back a step in the IPO pricing process, Table 4 presents the results of the OLS regressions estimating the relationship between market volatility and price revision. Neither realized volatility$_{[15,1]}$ nor implied volatility$_{[15,1]}$ show a significant effect on price revision. This suggests that market volatility occurring after the initial price range has been set, which Loughran and Ritter (2002) note is decided at the very latest 15 trading days before the offer date, does not influence the subsequent price revision.

The realized volatility$_{[21,1]}$ does not show a significant effect on price revision. However, the implied volatility$_{[21,1]}$ shows a positively significant effect, where a 1% increase in implied volatility provides a 0.025 percentage points more positive price revision. This implies that a one standard deviation increase in implied volatility$_{[21,1]}$ (Table 1) from the mean increases the price revision by 0.75 percentage points. Considering the earlier time window of roughly two months before the IPO, realized volatility$_{[42,22]}$ displays no significance, but implied volatility$_{[42,22]}$ exhibits a significantly positive effect. The implied volatility$_{[42,22]}$ shows a stronger effect on price revision than implied volatility$_{[21,1]}$. Its coefficient implies that a 1% increase in implied volatility$_{[42,22]}$, leads to a 0.033 percentage points increase in price revision.

Both realized volatility$_{[63,43]}$ and implied volatility$_{[63,43]}$ show significant and positive effects on price revision. A 1% increase in realized volatility$_{[63,43]}$ gives a 0.017 percentage points increase in price revision, and a 1% increase in implied volatility$_{[63,43]}$ results in a 0.032 percentage points higher price revision. Noteworthy is that the implied volatility$_{[63,43]}$ has a slightly smaller effect than implied volatility$_{[42,22]}$.

Overall, the results indicate that volatility during the earlier time windows seems to be more influential on the price revision. This implies that the volatility that matters seems to coincide with the price range setting, rather than with the subsequent book-building process.

Table 4: OLS regressions – Price revision

The table illustrates the results from the OLS regression estimating the effect of realized and implied volatility on price revision, in several different time windows for firm *i*. These include under the 15 tradings days prior to listing, the 21 trading days prior to listing, the window between the 42 and 22 trading days prior to listing and the window between the 63 and 43 trading days prior to listing. Price revision is defined as the percentage change between the offer price and the midpoint of the initial price range. Log(Shares offered) is the log of the number of shares offered. Log(Age + 1)) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. Log(Realized volatility$_{[d_1,d_2]}$) is the log of the annualized volatility of daily returns of the equally-weighted NASDAQ index for the respective time window before the IPO. Log(Implied volatility$_{[d_1,d_2]}$) is the average VIX level over the same time windows. All non-dummy variables are winsorized at the 1st and 99th percentiles. The table reports coefficients with standard errors in parentheses. The sample includes 1774 observations. ***, **, and * denote significance at the 0.1%, 1% and 5% levels, respectively.

	Realized volatility				Implied volatility			
	[15,1]	[21,1]	[42,22]	[63,43]	[15,1]	[21,1]	[42,22]	[63,43]
Intercept	-25.335**	-25.549**	-30.464***	-31.570***	-33.836***	-34.273***	-36.612***	-36.311***
	(8.078)	(8.105)	(8.035)	(8.067)	(8.520)	(8.519)	(8.424)	(8.387)
Log(Shares offered)	1.443**	1.444**	1.421**	1.428**	1.440**	1.440**	1.436**	1.437**
	(0.491)	(0.491)	(0.491)	(0.490)	(0.490)	(0.490)	(0.490)	(0.490)
Log(Age + 1)	-0.100	-0.103	-0.065	-0.081	-0.068	-0.066	-0.065	-0.074
	(0.365)	(0.365)	(0.365)	(0.364)	(0.365)	(0.365)	(0.364)	(0.364)
High-tech dummy	0.687	0.678	0.527	0.559	0.491	0.490	0.496	0.525
	(0.857)	(0.858)	(0.854)	(0.853)	(0.855)	(0.855)	(0.852)	(0.852)
VC-backed dummy	1.582	1.587	1.639	1.603	1.628	1.620	1.598	1.603
	(0.839)	(0.839)	(0.838)	(0.837)	(0.838)	(0.837)	(0.836)	(0.836)
NASDAQ dummy	-1.910*	-1.906*	-2.004*	-2.015*	-1.981*	-1.988*	-2.008*	-1.994*
	(0.899)	(0.899)	(0.899)	(0.898)	(0.898)	(0.898)	(0.897)	(0.897)
Reputable bookrunner dummy	3.413***	3.420***	3.385***	3.384***	3.344***	3.339***	3.350***	3.325***
	(0.978)	(0.978)	(0.977)	(0.976)	(0.977)	(0.977)	(0.975)	(0.976)
Log(Realized volatility$_{[d_1,d_2]}$)	-0.789	-0.707	1.363	1.730*				
	(0.866)	(0.918)	(0.803)	(0.816)				
Log(Implied volatility$_{[d_1,d_2]}$)					2.357	2.513*	3.339**	3.211**
					(1.219)	(1.218)	(1.138)	(1.096)
R-squared	0.032	0.031	0.033	0.034	0.033	0.033	0.036	0.036

5.2 Robustness results

To test the robustness of the results, the models are extended with the additional control variables for IPO activity and firm financial characteristics. Table 5 presents the results from the extended versions of the previously presented MLE regressions and the corresponding OLS regressions. Even with the additional controls, both realized volatility$_{[21,1]}$ and implied volatility$_{[21,1]}$ are still significantly positive in the MLE mean regressions, which is supported by the results of the OLS regression. The magnitudes of the coefficients are somewhat reduced, with realized volatility$_{[21,1]}$ in the extended MLE having a coefficient of 5.186 (c) and implied volatility$_{[21,1]}$ having a coefficient of 9.238 (d). This can be compared to the baseline model (Table 3) where the coefficients are 6.401 and 11.588, respectively. The MLE variance regressions also features positive and significant coefficients for both realized volatility$_{[21,1]}$ and implied volatility$_{[21,1]}$. Moreover, the variance model also sees slight reductions in coefficients with realized volatility$_{[21,1]}$ in the MLE at 0.379 (e) (vs. 0.442 in Table 3) and implied volatility$_{[21,1]}$ in the MLE at 0.726 (f) (vs. 0.902 in Table 3). The conducted VIF test (Appendix F) for the OLS regressions indicates that the variables do not appear to suffer from severe multicollinearity, even after adding these additional robustness variables. This indicates that the small reduction in the coefficients is not due to multicollinearity introduced by the extended model.

The reduction in coefficient magnitudes implies that some of the variation previously attributed to volatility is now absorbed by IPO activity and the firm financial characteristics. However, the fact that the effects remain significant indicates that the primary mechanism is not simply that volatility influences which types of firms, and how many, choose to go public. Instead, market volatility appears to have a independent effect. It also implies that IPO activity is unlikely to be a major underlying confounding factor behind the volatility effect.

All in all, this emphasizes that the results reported in Table 3 are robust, even when controlling for the potential distorting involvement of IPO activity and the financial metrics. The results also verify the findings of Lowry et al. (2010), showing a positive and significant effect of realized volatility on the mean and dispersion of underpricing. This robustness test supports the notion that higher market volatility increases both the level and the dispersion of IPO underpricing.

Table 5: Extended OLS and MLE regressions – Underpricing

This table reports the results of the OLS and MLE models estimating the effect of realized and implied volatility on underpricing, including extended controls. (a)-(b) show OLS regressions of underpricing on realized and implied volatility, respectively, including controls. (c)-(d) show MLE regressions of mean underpricing on realized and implied volatility, respectively, including controls. (e)-(f) show MLE regressions of the $\log(\text{std}(\varepsilon_i))$ regressed on realized and implied volatility, respectively, including controls. Underpricing is the percentage change between the offer price and the first-day closing price. Abs(Price revision) is the absolute percentage change between the offer price and the midpoint of the initial price range. Log(Shares offered) is the log of the number of shares offered. Log(Age +1) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. IPO activity is the number of IPOs in the same month as observation *i*. Log(Firm assets) and Log(Firm revenue + 1) are log of the total assets and the total accumulated revenues (in USD millions) plus one at the offer date. Positive EPS dummy equals 1 if EPS was positive in the LTM before offering , and 0 otherwise. Log(Realized volatility$_{[21,1]}$) is the log of the annualized volatility of daily returns of the equally weighted NASDAQ index during the 21 trading days before the IPO. Log(Implied volatility$_{[21,1]}$) is the average VIX level over the same window. All non-dummy variables are winsorized at the 1st and 99th percentiles. The table reports coefficients with standard errors in parentheses. The sample includes 1626 observations. ***, **, and * denote significance at the 0.1%, 1% and 5% levels, respectively.

	OLS		MLE mean		MLE variance	
	(a)	(b)	(c)	(d)	(e)	(f)
Intercept	18.685	-17.855	-9.659	-21.691	5.271***	3.950***
	(27.195)	(28.201)	(18.077)	(18.325)	(0.478)	(0.504)
Abs(Price revision)	0.026	0.033	0.141	0.089	0.008***	0.006*
	(0.109)	(0.108)	(0.094)	(0.089)	(0.002)	(0.002)
Log(Shares offered)	-3.391	-3.254	-0.244	-0.179	-0.210***	-0.189***
	(1.754)	(1.743)	(1.173)	(1.155)	(0.032)	(0.032)
Log(Age + 1)	0.653	0.699	2.157***	2.209***	0.086***	0.098***
	(1.171)	(1.164)	(0.618)	(0.603)	(0.022)	(0.021)
High-tech dummy	0.946	0.552	3.301	3.230	0.050	0.055
	(2.767)	(2.746)	(1.780)	(1.773)	(0.048)	(0.047)
VC-backed dummy	15.852***	15.713***	12.168***	11.940***	0.403***	0.407***
	(2.676)	(2.659)	(2.014)	(1.973)	(0.045)	(0.044)
NASDAQ dummy	2.393	2.062	0.699	-0.082	0.132*	0.097
	(2.832)	(2.815)	(1.680)	(1.643)	(0.053)	(0.053)
Reputable bookrunner dummy	1.424	1.277	0.607	0.762	-0.212**	-0.197**
	(3.190)	(3.170)	(2.750)	(2.600)	(0.066)	(0.065)
IPO activity	0.722***	0.728***	0.440***	0.403***	0.020***	0.018***
	(0.111)	(0.110)	(0.095)	(0.094)	(0.002)	(0.002)
Log(Firm assets)	1.436	1.222	-0.717	-0.797	-0.053**	-0.064**
	(0.923)	(0.918)	(0.572)	(0.566)	(0.020)	(0.020)
Log(Firm revenue + 1)	1.038*	1.193*	0.663*	0.607*	0.036***	0.037***
	(0.517)	(0.515)	(0.292)	(0.287)	(0.010)	(0.010)
Positive EPS dummy	0.637	0.323	0.229	0.478	-0.025	-0.046
	(3.030)	(3.012)	(1.857)	(1.799)	(0.057)	(0.056)
Log(Realized volatility$_{[21,1]}$)	8.072**		5.186*		0.379***	
	(2.858)		(2.081)		(0.048)	
Log(Implied volatility$_{[21,1]}$)		19.946***		9.238***		0.726***
		(3.771)		(2.733)		(0.067)
R-squared	0.071	0.083				
Log-likelihood			-8099.977	-8068.707		

The same additional controls on IPO activity and firm financials are included in the price revision OLS regressions, as shown in Table 6. When controlling for these dimensions, the results are mostly in line with those presented in Table 4. However, realized volatility$_{[63,43]}$ and implied volatility$_{[21,1]}$ lose their significance, casting doubt on their impact on price revision. Together with the remaining significance for implied volatility$_{[42,22]}$ and implied volatility$_{[63,43]}$, this supports the view that implied volatility in the earlier time windows is driving price revision. In turn, this strengthens the notion that market volatility in the time periods closer to the establishment of the initial price range has greater explanatory power than that in the periods immediately preceding the offer date.

These patterns suggest that part of the effect attributed to implied implied volatility$_{[21,1]}$ and realized volatility$_{[63,43]}$ in Table 5 may have reflected differences in financial characteristics of the issuing firms or the IPO activity at the time of the offering. Meanwhile, the robust significance of the implied volatility in the [42,22] and [63,43] windows indicates that they have a more direct and independent influence, rather than simply capturing effects of issuance activity or patterns in which types of firms decide to go public in certain market conditions. However, the magnitude of the coefficients is, just like in the underpricing regressions, naturally slightly reduced from the baseline model. Implied volatility$_{[42,22]}$ reports a coefficient of 2.720 (vs. 3.339 in Table 4) and implied volatility$_{[63,43]}$ a coefficient of 2.344 (vs. 3.211 in Table 4).

Additionally, this robustness test shows that implied volatility may be a more influential predictor of price revision than realized volatility. This indicates that issuing firms and their bookrunners place greater weight on expectations of future market uncertainty than on the volatility that has already materialized.

Similar to what was established in relation to Table 6, a VIF test (Appendix F) for the full set of variables in this robustness check indicates that no serious multicollinearity issues appear. This reinforces the interpretations concerning the changes in significance and coefficients seen in relation to Table 4.

Table 6: Extended OLS regressions - Price revision

The table illustrates the results from the OLS regression, extended with additional controls, estimating the effect of realized and implied volatility on price revision, in several different time windows for firm *i*. These include under the 15 tradings days prior to listing, the 21 trading days prior to listing, the window between the 42 and 22 trading days prior to listing and the window between the 63 and 43 trading days prior to listing. Price revision is defined as the percentage change between the offer price and the midpoint of the initial price range. Log(Shares offered) is the log of the number of shares offered. Log(Age + 1) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. IPO activity is the number of IPOs in the same month as observation *i*. Log(Firm assets) and Log(Firm revenue + 1) are log of the total assets and the total accumulated revenues (in USD millions) plus one at the offer date. Positive EPS dummy equals 1 if EPS was positive in the LTM before offering , and 0 otherwise. Log(Realized volatility$_{[d_1,d_2]}$) is the log of the annualized volatility of daily returns of the equally weighted NASDAQ index for the respective time window before the IPO. Log(Implied volatility$_{[d_1,d_2]}$) is the mean VIX level over the same time windows. All non-dummy variables are winsorized at the 1st and 99th percentiles. The table reports coefficients with standard errors in parentheses. The sample includes 1626 observations. ***, **, and * denote significance at the 0.1%, 1% and 5% levels, respectively.

	Realized volatility				Implied volatility			
	[15,1]	[21,1]	[42,22]	[63,43]	[15,1]	[21,1]	[42,22]	[63,43]
Intercept	-16.395	-16.819	-22.487*	-21.826*	-26.033**	-26.548**	-27.717**	-26.579**
	(9.001)	(9.039)	(8.989)	(9.020)	(9.429)	(9.425)	(9.365)	(9.323)
Log(Shares offered)	0.434	0.438	0.454	0.454	0.464	0.464	0.479	0.472
	(0.582)	(0.582)	(0.582)	(0.582)	(0.582)	(0.582)	(0.582)	(0.582)
Log(Age + 1)	-0.447	-0.454	-0.419	-0.432	-0.424	-0.421	-0.419	-0.424
	(0.389)	(0.389)	(0.389)	(0.389)	(0.389)	(0.389)	(0.389)	(0.389)
High-tech dummy	1.553	1.529	1.350	1.410	1.285	1.283	1.304	1.340
	(0.919)	(0.920)	(0.917)	(0.916)	(0.918)	(0.918)	(0.916)	(0.916)
VC-backed dummy	2.658**	2.665**	2.686**	2.667**	2.685**	2.674**	2.635**	2.655**
	(0.889)	(0.889)	(0.889)	(0.889)	(0.889)	(0.889)	(0.888)	(0.888)
NASDAQ dummy	-1.228	-1.219	-1.348	-1.311	-1.345	-1.356	-1.364	-1.343
	(0.941)	(0.941)	(0.942)	(0.942)	(0.941)	(0.941)	(0.940)	(0.940)
Reputable bookrunner dummy	1.878	1.889	1.828	1.838	1.792	1.786	1.810	1.799
	(1.060)	(1.060)	(1.060)	(1.060)	(1.060)	(1.059)	(1.059)	(1.059)
IPO activity	0.158***	0.156***	0.153***	0.147***	0.153***	0.153***	0.149***	0.145***
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)
Log(Firm assets)	1.093***	1.084***	1.038***	1.049***	1.017***	1.015***	1.004***	1.016***
	(0.303)	(0.303)	(0.303)	(0.303)	(0.304)	(0.304)	(0.303)	(0.303)
Log(Firm revenue + 1)	0.266	0.275	0.285	0.287	0.309	0.309	0.306	0.300
	(0.172)	(0.172)	(0.172)	(0.172)	(0.172)	(0.172)	(0.172)	(0.172)
Positive EPS dummy	0.683	0.652	0.682	0.655	0.636	0.640	0.620	0.608
	(1.007)	(1.007)	(1.007)	(1.007)	(1.007)	(1.006)	(1.006)	(1.006)
Log(Realized volatility$_{[d_1,d_2]}$)	-1.405	-1.229	1.024	0.758				
	(0.896)	(0.950)	(0.832)	(0.866)				
Log(Implied volatility$_{[d_1,d_2]}$)					2.183	2.368	2.720*	2.344*
					(1.262)	(1.260)	(1.181)	(1.147)
R-squared	0.057	0.057	0.057	0.056	0.058	0.058	0.059	0.058

6 Discussion

6.1 Market volatility and underpricing

The results from the MLE and OLS regressions in Tables 3 and 5 support that higher realized market volatility during the 21 days prior to the offer date has a positive and significant effect on underpricing and its dispersion. This finding is consistent with Lowry et al. (2010). In addition, a similarly positive and significant effect is found for implied volatility under the same time period.

In line with Lowry et al. (2010), this study interprets cross-sectional dispersion in underpricing as an indicator of IPO pricing difficulty. Following this interpretation, the findings of this support the view that higher market volatility increases uncertainty in firm valuation, thereby making it more challenging for issuing firms to set accurate offering prices. As a result, IPOs issued in volatile market environments exhibit greater variation in first-day returns. This aligns with the argument in Lowry et al. (2010) that market-wide uncertainty creates valuation and pricing challenges.

The higher underpricing observed in more volatile markets suggests that issuing firms respond to greater pricing difficulty by setting more conservative offer prices. Under normal market conditions, several explanations for such behavior include compensating investors for information asymmetry (Rock, 1986) and reducing the risks faced by underwriters in the event of an unsuccessful IPO (Derrien, 2005). It may thus be the case that higher market volatility amplifies these phenomena, causing issuers to adopt even more cautious pricing strategies and thereby increasing underpricing. More conservative pricing may also be required by investors as compensation for the increased risk of subscribing to IPOs in more volatile markets, a risk reflected in the heightened underpricing dispersion.

Nevertheless, it is important to challenge the notion that first-day initial returns are driven solely by underpricing relative to the company's true market value as revealed on the first day of trading. This view presumes market efficiency, which may not hold in practice. Instead, as pointed out by (Derrien, 2005), high first-day initial returns may also arise from behavioral factors and overly optimistic investors. It may therefore be the case that market volatility coincides with different levels of investor sentiment and enthusiasm, which drives up the market price in relation to the offer price.

As discussed in the methodology section, there is also criticism of first-day initial returns as a measure of underpricing, given the widespread price stabilization activities undertaken by underwriters during the early trading period. This implies that the underpricing effect attributed to market volatility in the results may be distorted by underwriter activities.

6.2 Market volatility and price revision

The results from the OLS regressions support the notion that higher implied volatility in the time windows [63,43] and [42,22] has a positive and significant effect on price revision. Furthermore, the results fail to robustly support the claim that realized volatility influences price revision and that implied volatility in time windows closer to the offer date affects price revi-

sion. Although the studies examine different market variables, it is noteworthy that this pattern contrasts with Lowry and Schwert (2004), who find that market returns during both early and late stages of the pricing process affect price revision. This may imply differences in the informative nature of market returns and market volatility during the book-building process.

The fact that implied volatility affects price revision in the earlier time windows, suggests that it drives a more conservative initial price range. According to Lowry and Schwert (2004), bookrunners tend to set conservative initial ranges for riskier firms to avoid downward revisions that could signal an unsuccessful offering. As demand becomes clearer during the book-building, this conservatism naturally results in a more positive price revision. The findings in this study, with implied volatility exerting its strongest influence during the estimated price range setting phase, support the argument that increased market uncertainty amplifies this conservative behavior by making the market value of the issuing firm more uncertain.

As described in the methodology, identifying the exact timing of the initial pricing range is difficult, making it challenging to determine which windows occur before and after the range-setting date. This poses a challenge to this part of the study and implies that the results should be interpreted with caution. As the average time between the initial range being set and the offer date is 44 days according to Lowry and Schwert (2004), it is not entirely clear that the earlier windows of implied volatility, and in particular the [42,22] window, actually affect the initial price range. It is plausible that implied volatility$_{[42,22]}$ to a certain extent occurs after the initial price range is set, and thus rather affects the book-building process. However, although not a definite proof, the lack of significance of implied volatility$_{[21,1]}$, and implied volatility$_{[15,1]}$, implies that market volatility does not affect the book-building process. Another possible interpretation is that the strong persistence in implied volatility leads to implied volatility$_{[63,43]}$ confounding the relationship between implied volatility$_{[42,22]}$ and price revision. Since implied volatility$_{[42,22]}$ is significantly correlated with implied volatility$_{[63,43]}$ at a level of 0.891 (Appendix G), the significance of implied volatility$_{[42,22]}$ may simply reflect volatility conditions captured in implied volatility$_{[63,43]}$.

6.3 Realized and implied volatility

Both realized volatility and implied volatility have a significant effect on underpricing in our regressions. However, the results do not support that realized volatility affects price revision, which sheds light on the difference between how implied and realized volatility are taken into account in the IPO pricing process. This is similar to what was found in Dicle and Levendis (2018) regarding the difference in the effect of realized and implied market volatility on IPO activity.

One plausible explanation for these dynamics is that, because implied volatility is inherently forward-looking, it plays a more important role in the early-stage setting of the initial price range. Since this range must remain relevant up until the offer date, typically around two months later, underwriters may rely more heavily on expectations of future market conditions when determining it. Realized volatility, by contrast, is backward-looking and may therefore be a less informative input when setting a range intended to reflect conditions several weeks ahead.

However, it is important to note that implied volatility may also be a proxy for omitted market-wide factors, such as investor sentiment. For example, periods of low implied volatility may coincide with higher investor optimism, which could influence price-setting independently of implied volatility itself.

The finding that both volatility measures significantly predict underpricing and its dispersion can instead possibly be understood by considering the timing of the final offer price. As the final offer price is set close to the first trading day, both realized and implied volatility may serve as relevant indicators of risk in the current market environment.

6.4 Limitations and further studies

A primary limitation of the study is the narrow sample. With a limited number of observations, the models may have reduced statistical power, making it more difficult to detect significant relationships. The relatively small sample size also suggests that the results should not be used to draw overly general conclusions about IPO pricing beyond this specific context. Moreover, IPO data in the most frequently used databases, such as SDC Platinum, have been reported to show slight inconsistencies, as documented by Ritter (2019). This also has the potential to influence the results. Moreover, as outlined in the methodology section, the means of the aggregated missing data differed significantly from those of the sample data for some variables. This introduces a potential selection bias, which further motivates cautious interpretations of the results.

Another limitation of the study is that it includes only successful IPOs and excludes withdrawn offerings. This introduces an additional selection bias, implying that the findings are generalizable only to successful IPOs. The direction of this bias is not straightforward. On one hand, IPOs that proceed during periods of high market volatility may be those willing to reduce their offer prices more aggressively, thereby amplifying the observed effects. On the other hand, it may be that successful IPOs in volatile markets are predominantly of higher quality and lower risk that still attract investor demand, suggesting that the effect attributed to volatility is underestimated. The variables used to control for firm characteristics and IPO activity address differences within the sample of successful IPOs, but they do not solve the problem of selection bias.

Additional studies could further address this selection bias by including unsuccessful IPOs in the sample. One interesting angle would be to build a model that explicitly examines the withdrawal rate at different levels of market volatility. It could also examine whether certain types of firms are overrepresented among those that withdraw during periods of heightened market volatility. This would clarify the importance and interplay of the aforementioned selection bias.

As with most empirical studies, the results may also be subject to omitted-variable bias. While controlling for some of the most evident firm-specific, deal-specific, and timing-specific factors that may be involved in the relationship between market volatility, there are certainly additional unobserved dimensions at play. Such variables could include investor sentiment, market returns, and macroeconomic variables such as interest rates. The findings should therefore not be interpreted as being based on perfectly isolated relationships.

7 Conclusion

Studying firms listed on NASDAQ and NYSE between 2000 and 2024, this paper finds that realized and implied volatility during the 21 trading days pre-offer date appear to have a positive effect on both the mean and the dispersion of underpricing. Furthermore, implied volatility during the windows 63 to 43 and 42 to 22, trading days preceding the offer date, appears to positively affect price revision. The study highlights that these effects seem to be independent of important firm-specific, deal-specific, and IPO-cycle effects.

Referring back to the research question, the results indicate that market volatility amplifies pricing difficulty in the IPO process, and that issuing firms and underwriters seemingly respond by setting both initial price ranges and final offer prices more cautiously. The findings support the overall argument that market volatility affects IPO pricing by inducing greater pricing conservatism.

Moreover, the contrasting effects of realized and implied volatility on underpricing and price revision suggest that issuing firms consider historical and forward-looking uncertainty differently across the different stages of the IPO pricing process.

Building primarily on Lowry et al. (2010), this paper contributes to the literature by providing a more granular examination of how different measures of market volatility interact with IPO pricing dynamics. By distinguishing between realized and implied volatility and introducing additional controls, the analysis sharpens the understanding of the specific channels through which market uncertainty influences IPO pricing outcomes. Moreover, by extending the focus beyond underpricing to include price revision, the study explores how market volatility influences pricing across multiple phases of the IPO process.

By connecting market volatility to IPO pricing outcomes, the findings offer a perspective on how market uncertainty may shape capital markets. In turn, these findings suggest possible implications for issuers, underwriters, and investors in their strategic decisions related to IPO timing, pricing, and risk assessment under varying market conditions.

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Appendix

Appendix A

Table 7: T-Test mean comparison – Sample compared to insufficient data

This table compares the mean of the variables in the sample used in the regressions (Sample mean) and the means of the variables for the observations that were removed due to insufficient data (Mean insufficient data). The t-statistic show if the difference between the respective means are significantly different from 0. Underpricing is the percentage change between the offer price and the first-day closing price. Price revision is the percentage change between the offer price and the midpoint of the initial price range. Shares offered refers to the number of shares offered in the IPO (in millions). Firm age is the number of years between founding year and offer date. The high-tech dummy equals 1 if the firm belongs to a high-tech industry (SDC Platinum), and 0 otherwise. The VC-backed dummy equals 1 if the firm is backed by a venture capital firm (SDC Platinum) and 0 otherwise. The NASDAQ dummy equals 1 if the firm is listed on NASDAQ and 0 if listed on NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8, during any year between 2000–2024, and otherwise 0. Realized volatility$_{[21,1]}$ is the volatility of daily returns of the equally-weighted NASDAQ index over the same window, reported in annualized percentage. Implied volatility$_{[21,1]}$ is the average VIX level during the 21 trading days preceding the IPO. All non-dummy variables are winsorized at the 1st and 99th percentiles to remove substantial outliers

Variable	Sample mean	Mean insufficient data	t-statistic
Underpricing (%)	22.240	31.778	-2.219
Price revision	-2.114	-4.881	0.577
Shares offered (millions)	10.054	9.342	1.648
Firm Age	13.080	46.587	-3.736
High-tech dummy	0.631	0.526	5.358
VC-backed dummy	0.556	0.395	8.301
NASDAQ dummy	0.743	0.763	-1.207
Reputable bookrunner dummy	0.814	0.661	8.710
Realized volatility$_{[21,1]}$	14.412	15.883	-10.397
Implied volatility$_{[21,1]}$	17.585	18.189	-2.924

Appendix B

Table 8: Correlation matrix

This table shows the correlations between the variables used in the regressions. Underpricing is the percentage change between the offer price and the first-day closing price. Price revision is the percentage change between the offer price and the midpoint of the initial price range. Abs(Price revision) is the absolute value of the price revision. Log(Shares offered) is the log of the number of shares offered. Log(Age +1) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. IPO activity is the number of IPOs in the same month as observation *i*. Log(Firm assets) and Log(Firm revenue + 1) are log of the total assets and the total accumulated revenues (in USD millions) plus one at the offer date. Positive EPS dummy equals 1 if EPS was positive in the LTM before offering , and 0 otherwise. Log(Realized volatility$_{[21,1]}$) is the log of the annualized volatility of daily returns of the equally weighted NASDAQ index during the 21 trading days before the IPO. Log(Implied volatility$_{[21,1]}$) is the mean VIX level over the same window. All non-dummy variables are winsorized at the 1st and 99th percentiles. The sample includes 1774 observations. ***, **, and * denote significance at the 0.1%, 1% and 5% levels, respectively.

	Underpricing	Price revision	Log(Shares offered)	Log(Age+1)	High-tech dummy	VC-backed dummy	NASDAQ dummy	Reputable bookrunner dummy	Log(Firm assets)	Log(Firm revenue +1)	Positive EPS dummy	IPO activity	Abs(Price revision)	Log(Realized volatility [21,1])	Log(Implied volatility [21,1])
Underpricing	1.000***	0.309***	-0.037	0.014	0.109***	0.181***	0.069**	0.052	-0.023	0.013	-0.029	0.174***	0.003	0.088***	0.140***
Price revision	0.309***	1.000***	0.130***	-0.005	0.027	0.056*	-0.084***	0.140***	0.147***	0.111***	0.034	0.106***	-0.521***	-0.016	0.053*
Log(Shares offered)	-0.037	0.130***	1.000***	0.053*	-0.145***	-0.154***	-0.386***	0.375***	0.585***	0.357***	0.061*	0.006	-0.036	0.005	-0.016
Log(Age+1)	0.014	-0.005	0.053*	1.000***	-0.050*	-0.064**	-0.011	0.006	0.158***	0.175***	0.117***	-0.021	0.006	-0.034	-0.029
High-tech dummy	0.109***	0.027	-0.145***	-0.050*	1.000***	0.530***	0.309***	0.060*	-0.406***	-0.239***	-0.294***	0.117***	0.066**	0.115***	0.096***
VC-backed dummy	0.181***	0.056*	-0.154***	-0.064**	0.530***	1.000***	0.282***	0.160***	-0.358***	-0.223***	-0.282***	0.071***	0.074***	0.057*	0.057*
NASDAQ dummy	0.069**	-0.084***	-0.386***	-0.011	0.309***	0.282***	1.000***	-0.211***	-0.422***	-0.342***	-0.150***	0.078***	0.046*	0.063*	0.071*
Reputable bookrunner dummy	0.052	0.140***	0.375***	0.006	0.060*	0.160***	-0.211***	1.000***	0.350***	0.171***	0.010	0.022	-0.026	0.055	0.042
Log(Firm assets)	-0.023	0.147***	0.585***	0.158***	-0.406***	-0.358***	-0.422***	0.350***	1.000***	0.482***	0.283***	-0.023	-0.150***	0.002	0.003
Log(Firm revenue + 1)	0.013	0.111***	0.357***	0.175***	-0.239***	-0.223***	-0.342***	0.171***	0.482***	1.000***	0.487***	-0.053*	-0.019	-0.057*	-0.086***
Positive EPS dummy	-0.029	0.034	0.061*	0.117***	-0.294***	-0.282***	-0.150***	0.010	0.283***	0.487***	1.000***	-0.115***	-0.047	-0.058*	-0.042
IPO activity	0.174***	0.106***	0.006	-0.021	0.117***	0.071***	0.078***	0.022	-0.023	-0.053*	-0.115***	1.000***	-0.069*	0.066**	0.033
Abs(Price revision)	0.003	-0.521***	-0.036	0.006	0.066**	0.074***	0.046*	-0.026	-0.150***	-0.019	-0.047	-0.069*	1.000***	0.022	-0.005
Log(Realized volatility [21,1])	0.088***	-0.016	0.005	-0.034	0.115***	0.057*	0.063*	0.055	0.002	-0.057*	-0.058*	0.066**	0.022	1.000***	0.804***
Log(Implied volatility [21,1])	0.140***	0.053*	-0.016	-0.029	0.096***	0.057*	0.071*	0.042	0.003	-0.086***	-0.042	0.033	-0.005	0.804***	1.000***

Appendix C

Table 9: Kurtosis

This table shows the kurtosis for the non-dummy sample variables before (Raw data) and after the winsorization at the 1st and 99th percentiles (Winsorized data). Underpricing is the percentage change between the offer price and the first-day closing price. Price revision is the percentage change between the offer price and the midpoint of the initial price range. Shares offered refers to the number of shares offered in the IPO. Firm age + 1 is the number of years between founding year and offer date, plus one. IPO activity is the number of IPOs in same month as IPO *i*. Firm assets and firm revenue represent total assets and total accumulated revenues at the offer date (USD millions). Realized volatility$_{[21,1]}$ is the volatility of daily returns of the equally-weighted NASDAQ index over the same window, reported in annualized percentage. Implied volatility$_{[21,1]}$ is the average VIX level during the 21 trading days preceding the IPO.

	Kurtosis	
Variable	Raw data	Winsorized data
Underpricing (%)	1134.995	19.232
Price revision (%)	1.439	0.941
Shares offered	255.635	8.861
Firm Age + 1 (years)	18.331	11.041
IPO activity	4.603	3.578
Firm assets (USD Millions)	103.138	21.917
Firm revenue + 1 (USD Millions)	520.538	26.446
Realized volatility$_{[21,1]}$ (%)	15.454	2.264
Implied volatility$_{[21,1]}$	3.557	0.384

Appendix D

Table 10: OLS and MLE regressions – Underpricing (Excluding Jan-Aug 2000)

This table reports the results of the OLS and MLE models estimating the effect of realized and implied volatility on underpricing, excluding the period Jan-Aug 2000. (a)-(b) show OLS regressions of underpricing on realized and implied volatility, respectively, including controls. (c)-(d) show MLE regressions of mean underpricing on realized and implied volatility, respectively, including controls. (e)-(f) show MLE regressions of the $\log(\text{std}(\varepsilon_i))$ regressed on realized and implied volatility, respectively, including controls. Underpricing is the percentage change between the offer price and the first-day closing price. Abs(Price revision) is the absolute percentage change between the offer price and the midpoint of the initial price range. Log(Shares offered) is the log of the number of shares offered. Log(Age + 1) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. Log(Realized volatility$_{[21,1]}$) is the log of the annualized volatility of daily returns of the equally weighted NASDAQ index during the 21 trading days before the IPO. Log(Implied volatility$_{[21,1]}$) is the mean VIX level over the same window. All non-dummy variables are winsorized at the 1st and 99th percentiles. The table reports coefficients with standard errors in parentheses. The sample includes 1683 observations. ***, **, and * denote significance at the 0.1%, 1% and 5% levels, respectively.

	OLS		MLE mean		MLE variance	
	(a)	(b)	(c)	(d)	(e)	(f)
Intercept	-48.944*	-64.435**	-24.161	-33.075	5.707***	4.728***
	(22.030)	(22.799)	(16.830)	(16.941)	(0.409)	(0.440)
Abs(Price revision)	-0.073	-0.066	0.150	0.101	0.009***	0.007***
	(0.089)	(0.089)	(0.094)	(0.088)	(0.002)	(0.002)
Log(Shares offered)	2.700*	2.653	1.017	0.937	-0.210***	-0.210***
	(1.371)	(1.367)	(1.034)	(1.002)	(0.026)	(0.026)
Log(Age + 1)	2.105*	2.128*	2.254***	2.441***	0.122***	0.141***
	(0.934)	(0.932)	(0.626)	(0.608)	(0.021)	(0.021)
High-tech dummy	-0.117	-0.098	2.327	2.316	0.067	0.071
	(2.189)	(2.179)	(1.727)	(1.682)	(0.043)	(0.042)
VC-backed dummy	12.463***	12.389***	11.435***	11.079***	0.357***	0.363***
	(2.170)	(2.165)	(1.863)	(1.805)	(0.041)	(0.040)
NASDAQ dummy	1.047	0.990	1.891	1.446	0.059	0.040
	(2.267)	(2.262)	(1.639)	(1.583)	(0.048)	(0.048)
Reputable bookrunner dummy	0.353	0.336	-0.102	-0.242	-0.255***	-0.286***
	(2.594)	(2.589)	(2.601)	(2.532)	(0.057)	(0.056)
Log(Realized volatility$_{[21,1]}$)	5.189*		4.670*		0.256***	
	(2.416)		(1.990)		(0.047)	
Log(Realized volatility$_{[21,1]}$)		10.515***		8.098**		0.579***
		(3.146)		(2.615)		(0.064)
R-squared	0.036	0.040				
Log-likelihood			-8243.428	-8213.617		

Appendix E

Model equations with additional control variables – Underpricing

i) Realized volatility

$$\begin{aligned}\text{Underpricing}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC-backed dummy}_i \\ + \beta_4 \text{abs(Price revision)}_i + \beta_5 \text{NASDAQ dummy}_i + \beta_6 \log(\text{Age}_i + 1) \\ + \beta_7 \text{Reputable bookrunner dummy}_i + \beta_8 \text{IPO activity}_i \\ + \beta_9 \log(\text{Firm assets}_i) + \beta_{10} \log(\text{Firm revenue}_i + 1) + \beta_{11} \text{Positive EPS dummy}_i + \\ \beta_{12} \log(\text{Realized volatility}_{[21,1]_i}) + \varepsilon_i\end{aligned}$$

ii) Implied volatility

$$\begin{aligned}\text{Underpricing}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \\ \beta_3 \text{VC-backed dummy}_i + \beta_4 \text{abs(Price revision)}_i + \beta_5 \text{NASDAQ dummy}_i + \beta_6 \log(\text{Age}_i + 1) + \\ \beta_7 \text{Reputable bookrunner dummy}_i + \beta_8 \text{IPO activity}_i + \beta_9 \log(\text{Firm assets}_i) + \\ \beta_{10} \log(\text{Firm revenue}_i + 1) + \beta_{11} \text{Positive EPS dummy}_i + \beta_{12} \log(\text{Implied volatility}_{[21,1]_i}) + \varepsilon_i\end{aligned}$$

iii) Realized volatility

$$\begin{aligned}\log(\text{std}(\varepsilon_i)) = \gamma_0 + \gamma_1 \log(\text{Shares offered}_i) + \gamma_2 \text{High-tech dummy}_i + \\ \gamma_3 \text{VC-backed dummy}_i + \gamma_4 \text{abs(Price revision)}_i + \gamma_5 \text{NASDAQ dummy}_i + \gamma_6 \log(\text{Age}_i + 1) + \\ \gamma_7 \text{Reputable bookrunner dummy}_i + \gamma_8 \text{IPO activity}_i + \gamma_9 \log(\text{Firm assets}_i) + \\ \gamma_{10} \log(\text{Firm revenue}_i + 1) + \gamma_{11} (\text{Positive EPS dummy}_i) + \gamma_{12} \log(\text{Realized volatility}_{[21,1]_i})\end{aligned}$$

iv) Implied volatility

$$\begin{aligned}\log(\text{std}(\varepsilon_i)) = \gamma_0 + \gamma_1 \log(\text{Shares offered}_i) + \gamma_2 \text{High-tech dummy}_i + \\ \gamma_3 \text{VC-backed dummy}_i + \gamma_4 \text{abs(Price revision)}_i + \gamma_5 \text{NASDAQ dummy}_i + \gamma_6 \log(\text{Age}_i + 1) + \\ \gamma_7 \text{Reputable bookrunner dummy}_i + \gamma_8 \text{IPO activity}_i + \gamma_9 \log(\text{Firm assets}_i) + \\ \gamma_{10} \log(\text{Firm revenue}_i + 1) + \gamma_{11} \text{Positive EPS dummy}_i + \gamma_{12} \log(\text{Implied volatility}_{[21,1]_i})\end{aligned}$$

Model equations with additional control variables – Price revision

v) Realized volatility

$$\begin{aligned}\text{Price revision}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC dummy}_i \\ + \beta_4 \text{NASDAQ dummy}_i + \beta_5 \log(\text{Age}_i + 1) + \beta_6 \text{Reputable bookrunner dummy}_i + \\ \beta_7 \text{IPO activity}_i + \beta_8 \log(\text{Firm assets}_i) + \beta_9 \log(\text{Firm revenue}_i + 1) + \\ \beta_{10} \text{Positive EPS dummy}_i + \beta_{11} \log(\text{Realized volatility}_{[k,d]_i}) + \varepsilon_i\end{aligned}$$

vi) Implied volatility

$$\text{Price revision}_i = \beta_0 + \beta_1 \log(\text{Shares offered}_i) + \beta_2 \text{High-tech dummy}_i + \beta_3 \text{VC-backed dummy}_i + \beta_4 \text{NASDAQ dummy}_i + \beta_5 \log(\text{Age}_i + 1) + \beta_6 \text{Reputable bookrunner dummy}_i + \beta_7 \text{IPO activity}_i + \beta_8 \log(\text{Firm assets}_i) + \beta_9 \log(\text{Firm revenue}_i + 1) + \beta_{10} \text{Positive EPS dummy}_i + \beta_{11} \log(\text{Implied volatility}_{[k,d]_i}) + \varepsilon_i$$

Appendix F

Table 11: Variance inflation factor summary (for all OLS models)

This table shows the min and max VIF for each independent variable across the OLS regressions employed in this study. Underpricing is the percentage change between the offer price and the first-day closing price. Abs(Price revision) is the absolute percentage change between the offer price and the midpoint of the initial price range. Log(Shares offered) is the log of the number of shares offered. Log(Age + 1) is the log of firm age in years plus one. High-tech and VC-backed dummies equal 1 if the firm is high-tech or VC-backed, respectively. The NASDAQ dummy equals 1 for NASDAQ-listed firms and 0 for NYSE. The reputable bookrunner dummy equals 1 if at least one bookrunner has a Carter–Manaster score ≥8 at any time from 2000–2024. IPO activity is the number of IPOs in the same month as observation *i*. Log(Firm assets) and Log(Firm revenue + 1) are log of the total assets and the total accumulated revenues (in USD millions) plus one at the offer date. Positive EPS dummy equals 1 if EPS was positive in the LTM before offering , and 0 otherwise. Log(Realized volatility$_{[15,1]}$), Log(Realized volatility$_{[21,1]}$), Log(Realized volatility$_{[42,22]}$), and Log(Realized volatility$_{[63,43]}$) are the logarithms of the realized volatility of daily returns of the equally-weighted NASDAQ index measured over the periods from 15 to 1, 21 to 1, 42 to 22, and 63 to 43 trading days before the offer date, respectively. Log(Implied volatility$_{[15,1]}$), Log(Implied volatility$_{[21,1]}$), Log(Implied volatility$_{[42,22]}$), and Log(Implied volatility$_{[63,43]}$) are the logarithms of the average VIX measured over the periods from 15 to 1, 21 to 1, 42 to 22, and 63 to 43 trading days before the offer date, respectively. All non-dummy variables are winsorized at the 1st and 99th percentiles.

Variable	Min VIF	Max VIF
Abs(Price revision)	1.04	1.04
Log(Shares offered)	1.73	1.74
Log(Age + 1)	1.05	1.05
High-tech dummy	1.60	1.61
VC-backed dummy	1.59	1.59
NASDAQ dummy	1.38	1.39
Reputable bookrunner dummy	1.36	1.37
IPO Activity	1.03	1.07
Log(Firm assets)	2.27	2.33
Log(Firm revenue + 1)	1.69	1.71
Positive EPS dummy	1.45	1.45
Log(Realized volatility$_{[15,1]}$)	1.03	1.03
Log(Realized volatility$_{[21,1]}$)	1.03	1.03
Log(Realized volatility$_{[42,22]}$)	1.01	1.01
Log(Realized volatility$_{[63,43]}$)	1.05	1.05
Log(Implied volatility$_{[15,1]}$)	1.03	1.03
Log(Implied volatility$_{[21,1]}$)	1.03	1.03
Log(Implied volatility$_{[42,22]}$)	1.02	1.02
Log(Implied volatility$_{[63,43]}$)	1.03	1.03

Appendix G

Table 12: Correlation matrix – Realized volatility across the time windows

The table presents the correlations for the realized volatility over the different time windows it is measured over. More specifically, the time windows are [15,1], [21,1], [42,22], and [63,43], referring to the periods from 15 to 1, 21 to 1, 42 to 22, and 63 to 43 trading days before the offer date, respectively, with the realized volatility measured using daily returns of the equally-weighted NASDAQ index. All variables are winsorized at the 1st and 99th percentiles. The sample includes 1774 observations.

	[15,1]	[21,1]	[42,22]	[63,43]
[15,1]	1.000	0.948	0.546	0.428
[21,1]	0.948	1.000	0.618	0.475
[42,22]	0.546	0.618	1.000	0.647
[63,43]	0.428	0.475	0.647	1.000

Table 13: Correlation matrix – Implied volatility across the time windows

The table presents the correlations for the implied volatility over the different time windows it is measured over. More specifically, the time windows are [15,1], [21,1], [42,22], and [63,43], referring to the periods from 15 to 1, 21 to 1, 42 to 22, and 63 to 43 trading days before the offer date, respectively, with the implied volatility measured as the average VIX during the respective time window. All variables are winsorized at the 1st and 99th percentiles. The sample includes 1774 observations.

	[15,1]	[21,1]	[42,22]	[63,43]
[15,1]	1.000	0.993	0.869	0.801
[21,1]	0.993	1.000	0.897	0.816
[42,22]	0.869	0.897	1.000	0.891
[63,43]	0.801	0.816	0.891	1.000

Appendix H

AI disclaimer

AI has been used in this paper to improve language and grammar, and to assist with R coding syntax and LaTeX formatting. The AI tools that have been used are Grammarly and OpenAI's ChatGPT.